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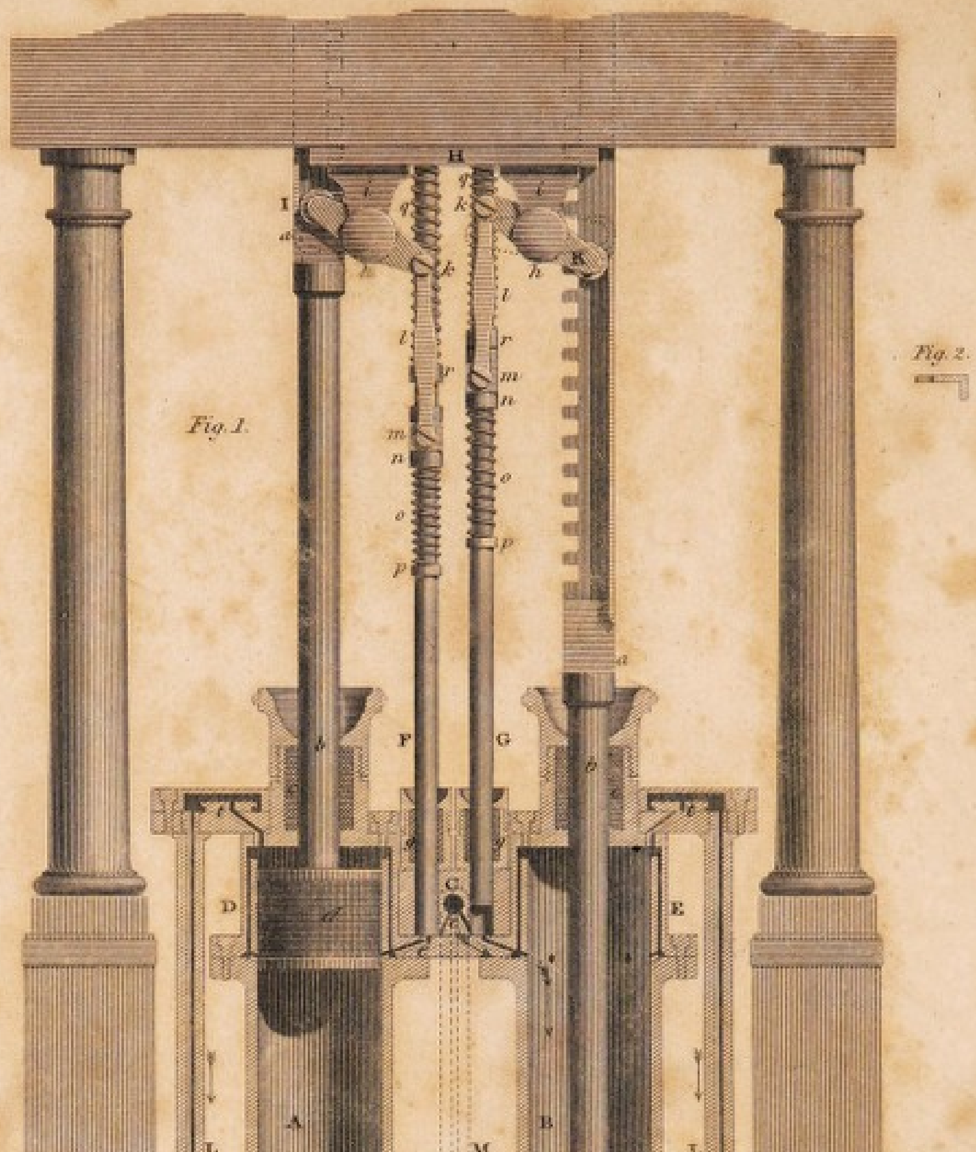

MR. STYLES' IMPROVED AIR PUMP.

G. Gladwin sculp.

London, Published Jan. 1828, by J. Taylor, High Holborn.

A

MANUAL

OF

NATURAL AND EXPERIMENTAL PHILOSOPHY,

BEING THE SUBSTANCE OF

A SERIES OF LECTURES

DELIVERED IN THE

LONDON, RUSSELL, SURREY, AND METROPOLITAN INSTITUTIONS.

BY CHARLES F. PARTINGTON,

AUTHOR OF AN "HISTORICAL AND DESCRIPTIVE ACCOUNT OF THE STEAM-ENGINE," "GALLERY OF SCIENCE," &c. &c.

ILLUSTRATED BY
FOUR COPPER PLATES, AND TWO HUNDRED AND
SEVENTY ENGRAVINGS ON WOOD.

IN TWO VOLUMES.

VOL. I.

LONDON:
PRINTED FOR J. TAYLOR,
ARCHITECTURAL LIBRARY, 59, HIGH HOLBORN.
1828.

LONDON,
PRINTED BY S. AND R. BENTLEY, DORSET-STREET.

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THE ACCOMPANYING COURSE OF LECTURES,

ORIGINATING IN AN ARDENT LOVE OF THOSE SCIENTIFIC PURSUITS WHICH HAVE HITHERTO FORMED SO PROMINENT A FEATURE IN THEIR ESTABLISHMENT,

IS DEDICATED,

WITH THE MOST SINCERE RESPECT AND GRATITUDE,
BY THEIR VERY FAITHFUL AND OBEDIENT SERVANT,

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INTRODUCTION.

THE value of science is best shown by its practical effects on the happiness and well-being of mankind. This important axiom appears, however, to have been much neglected, if not entirely lost sight of, in the olden time; for practical science was more generally employed by its early professors, as an instrument to darken and enslave the human mind, than to produce any useful result. That such, however, was the fact, will at once appear by the slightest reference to the writings of those early illuminati, Roger Bacon, Paracelsus, Albertus Magnus, Baptista Porta, and the various disciples of the "Angelic school." About the commencement of the seventeenth century, however, philosophy began to assume a new form, and the patronage of the Grand-duke of Tuscany gave birth to an Institution which

soon spread the fame of this *Mæcenas* in science, throughout civilized Europe. Galileo and Otto Guericke may be placed amongst the earliest fruits of the Florentine seminary; and the construction of the telescope, and a knowledge of the mechanical properties of the atmosphere may be considered as the first practical result of their labours.

From Italy, the pursuit of experimental science passed to our own shores, and found most active supporters in Evelyn, Boyle, and Wren; who were in the habit of meeting privately for the discussion of philosophical subjects; first in London, and afterwards at Oxford. These ingenious persons were speedily joined by Viscount Brouncker, Sir Robert Moray, Sir Paul Neale, and Dr. Hooke; who, by their united influence, succeeded in procuring a Charter, and establishing themselves as a permanent body, under the title of the "ROYAL SOCIETY OF LONDON."

Of this learned body, the King condescended to become the patron, and the members held their earliest meetings at Gresham College and Arundel House, although they occasionally adjourned their discussions to the Royal Palace itself.*

Professor Brande observes, with his accustomed acuteness, that "the foundation of this Society was

* If the Bishop of Rochester may be considered as an accurate reporter of his royal patron's labours in the cause of science, they far outstripped those of the other members of this learned

peculiarly favourable to its interests and objects; the country, long distracted by that worst of all evils, a civil war, and afterwards oppressed by the military usurpation of Cromwell, was threatened, upon the death of the Protector, with the horrors of anarchy, when the restoration of Charles II. healed all divisions, and checked the tide of revolutionary violence. Then was a propitious time to lead the rich and well-informed into the avenues of scientific inquiry, and to substitute the advancement of knowledge for political speculation."*

But, however propitious the circumstances under which it was founded, it is curious to observe how

body, and placed Charles in a very different point of view to what we are in the habit of considering him. We must, however, let Dr. Spratt speak for himself. "There is scarce any one sort of work whose advancement they regard, but from his Majesty's own labours they have received a pattern for their endeavours about it. They design the multiplying and beautifying of mechanic arts; and the noise of mechanic instruments is heard in Whitehall itself. They intend the perfection of graving, statuary, limning, coining, and all the works of smiths, in iron, or steel, or silver; and the most excellent artists of these kinds have provision made for their practice, even in the chambers and galleries of his court They purpose the trial of all manner of operations by fire; and the king has under his own roof found a place for chemical operators. They have begun an exact survey of the heavens; and St. James's Park may witness that Ptolemy and Alphonso were not the only monarchs who observed the motions and appearances of the stars." *History of the Royal Society*, p. 149.

* Vide "*History of Chemistry*," *prefixed to Professor Brande's Manual*.

slow was the progress of the Society in almost every thing really connected with the diffusion of useful knowledge.

At the meetings, which were generally attended by the very *élite* of its members, we find discussions on "grafting teeth, and making the teeth of one man grow in the mouth of another," occupying the place of rational investigation; and when we look for "an account of the present undertakings, studies, and labours of the ingenious in many considerable parts of the world," we find in place of so useful a report, some ridiculous disquisition on the probability of "horns taking root" in the earth, and vegetating like a tree.

Fortunately, however, for the cause of science, several of the members turned their attention, in an especial degree, to the practical illustration of subjects connected with mechanical philosophy; and the construction of a timepiece for ascertaining the longitude, and the formation of a standard measure of length, became the subjects of a promised reward.*

* The author of Hudibras, who most vehemently satirized the Royal Society, and especially its active member Sir Paul Neale, little imagined what would be the result of their labours in this respect, when he ridiculed the Society's early attempt to form a standard measure, and accused them of "vapouring that,—

" ——— The vibration of this Pendulum
Should make all Taylors' yards of one unanimous opinion."

The splendour of Sir Isaac Newton's discoveries, to which we must here briefly advert, as intimately connected with the history of the Royal Society, obscures, in some degree, the merit of both earlier and subsequent philosophers; and, indeed, it must be admitted, that the impulse furnished by the mathematical as well as mechanical researches of this extraordinary man, tended very materially towards the subsequent spread of scientific knowledge over civilized Europe.

Dissatisfied with the hypothetical grounds on which former philosophers, particularly Des Cartes, had raised the structure of natural philosophy, Newton adopted the plan of examination introduced by Lord Bacon, and determined to found a better system on the broader basis of actual experiment. He accordingly laid it down as a fundamental rule, that nothing is to be assumed as a principle, which is not established by observation and experience; and that no hypothesis is to be admitted into physics, except as a question, the truth of which is to be examined by its agreement with appearances. "Whatever," says he, "is not deduced from phænomena, is to be called an hypothesis: and hypothesis, whether physical or metaphysical, whether of occult qualities or mechanical, have no place in experimental philosophy."

In 1676, Newton first demonstrated the necessary connexion of the planetary revolutions in elliptical

orbits, with an attractive force varying inversely as the square of the distance. But he had collected the laws of that force from the discoveries of Kepler, respecting the periods of the different planets some time previous, as he stated to Dr. Halley. It may be proper to add, also, that he admitted in his "Principia," that Wren, Hooke, and Halley, had the merit of having made the same discovery, without any connexion with each other's investigations, or with his own. The manner in which Newton was led to attend particularly to the subject, is thus related by Pemberton, in the preface to his View of Sir Isaac Newton's Philosophy.

"The first thoughts," says his ingenious editor, "which gave rise to his great philosophical work the 'Principia,' he had when he retired from Cambridge in 1666, on account of the plague. As he sat alone in a garden, he fell into a speculation on the power of gravity: that as this power is not found sensibly diminished at the remotest distance from the centre of the earth, to which we can rise, neither at the tops of the loftiest buildings, nor even on the summits of the highest mountains, it appeared to him reasonable to conclude that this power must extend much farther than was usually thought:—why not to the moon? said he to himself; and if so, her motion must be influenced by it: perhaps she is retained in her orbit thereby. However, though the power of gravity is not sensibly weakened in the

little change of distance, at which we can place ourselves from the centre of the earth; yet it is very possible, that so high as the moon this power may differ very much in strength from what it is here. To make an estimate, what might be the degree of this diminution, he considered with himself, that if the moon be retained in her orbit by the force of gravity, no doubt the primary planets are carried round the sun by the like power. And by comparing the periods of the several planets with their distances from the sun, he found, that if any power like gravity held them in their courses, its strength must decrease in the duplicate proportion of the increase of distance."*

The Royal Society has occasionally had its proceedings interrupted by the effects of intestine cabal, and its walls have resounded with clamorous sounds

* It is gratifying to observe how cordially foreigners of all ranks have vied with each other in their attempts to do justice to our illustrious countryman. The secretary to the French Royal Academy thus characterizes him; "He had the singular happiness," says Fontenelle, "of obtaining, during his life, all the credit and consideration to which his sublime researches and his fortunate discoveries entitled him. All men of science, in a country which produces so many, placed Newton, by a kind of acclamation, at their head; they acknowledged him for their chief and their master: no opponent, nor even a cool admirer, dared to appear. His philosophy was adopted throughout England, and it is supported in the Royal Society, and in all the excellent productions of the members of that society, with as much confidence, as if it had been consecrated by the respect of a long course of ages."

of conflict, very foreign to the quiet dignity of scientific discussion. These feuds originated in the very infancy of the society, and were almost invariably renewed with additional heat, on the election of each new president. To such a height, indeed, had this risen, at the time that Dr. Horsley was actively engaged in the council, as almost to threaten its dissolution; and we find that distinguished prelate addressing Sir Joseph Banks in language not unlike that of Cromwell to the Speaker of the House of Commons, at the close of the Long Parliament.*

The LONDON and ROYAL INSTITUTIONS have similar objects in view, with this celebrated association, and pursue nearly similar means for the advancement of literature, and the diffusion of useful knowledge. The former of these establishments, although second in point of date, will, for obvious reasons, first claim our attention.

The design of forming a public library in the City of London appears to have been first suggested by Carte, the historian, who, early in 1743, published a prospectus for the establishment of a library, upon a

* The language is so strong and emphatic, as to require little apology for presenting the peroration to the reader. "Sir," observed Dr. Horsley, "we shall have one remedy in our power when all others fail. If other remedies should fail, we can at least *Secede*. Sir, when the hour of secession comes, the President will be left, with his train of feeble amateurs, and that toy upon the table, the ghost of a society in which philosophy once reigned, and Newton presided as her minister."

large scale, at the Mansion-House; and in the detail of his plan it was proposed, that the twelve principal companies of the city should each subscribe two thousand pounds, for the purchase of books, and other incidental expenses. This scheme, however, did not meet with the desired encouragement; and it was reserved for the active patriotism of the nineteenth century to carry into effect so laudable an undertaking.

The first general meeting of the proprietors of the London Institution was held on the 18th of October, 1805; and on the 18th of January, in the following year, extensive premises, in the Old Jewry, were rented for temporary purposes, and completely prepared for the use of the proprietors.*

In consequence of the expiration of the lease of the above house, and the difficulty experienced in procuring a situation sufficiently central and commodious for the establishment, the Board of Management decided on the purchase of some extensive premises in King's Arms Yard, which were entered

* This spacious edifice was erected, in 1677, by Sir Robert Clayton; and, during the time it was appropriated to the use of the Institution, the library was arranged on the first-floor, and the newspapers and pamphlets in three small apartments on the ground-floor. The staircase was finely painted by Sir James Thornhill for the original proprietor, and it exhibits several allegorical designs from the mythology of Hercules, among which was the rape of Dejanira, copied from a celebrated painting by Guido.

upon in the beginning of the year 1815. One of the principal objects of the Institution, however, still remained unprovided for; namely, the diffusion of general knowledge, by the delivery of literary and scientific lectures. Anxious to fulfil the original intention of the Institution in one of its most important features, the Board of Management entered into arrangements with the Committee of City Lands for the purchase of a suitable site in Moorfields. This being accomplished, Mr. Brooks was appointed architect, and the first stone of the new building was laid by the Lord Mayor, May 4th, 1815. The edifice was completed, and opened for the use of the proprietors, on the 21st of April, 1819.

The great architectural beauties and classical taste displayed in the erection, require a more particular description. The front is rather more than 100 feet in width, and is formed of massive blocks of Portland-stone. A magnificent portico, which, with its pediment, reaches to the upper balustrade, is supported by double rows of columns, and ornamented with wreaths of flowers, &c. The front is likewise decorated with pilasters of the Corinthian order; and a balustrade of masonry, occasionally relieved by sculptured blocks, runs along its whole extent.

On entering the great hall, the eye rests with pleasure on a perspective, at once chaste and elegant; the effect being in no small degree heightened by a

small octangular vestibule, which forms the extremity of the background. The ceiling of the hall is supported by eight fluted columns of Bath-stone, and is separated from the staircase by glazed doors. The two lower reading-rooms are appropriated to the use of newspapers and periodical works, beyond which are the committee-room, and apartments of the sub-librarian.

The Saloon, which is of sufficient magnitude to contain the whole library, may justly be considered one of the first of the kind in England. It is 97 feet in length, by 42 in width, and 28 in height; the whole of its proportions being admirably arranged and harmonised.

The area of this apartment is of an irregular octangular form; four reading-rooms, provided with tables, &c. at the angles, having been detached from the body of the room; thus uniting the advantage of study and privacy with a facility of access to the library. The sides are divided into thirteen recesses, formed by double book-cases, each recess being faced by an appropriate pilaster. A light, but substantial gallery extends completely round the room, and is supported at its eastern and western extremities, by richly ornamented Corinthian columns. The unbroken rays of a direct southern sun cast a cheering influence over the whole room; whilst a series of central chandeliers, supplied with gas,

made on the premises, diffuse a strong and clear light in the evening for the purpose of reading.*

The Library is open from ten o'clock in the morning till ten at night, with the exception of Saturdays and Sundays; on the former of which days it is closed at three o'clock.

The Theatre, or Lecture-room, which forms the frontispiece to the second volume, is connected with the principal staircase by a vestibule, and is built on a plan nearly similar to that of the Royal Institution. The audience part is capable of accommodating about 600 persons; and the seats are so admirably arranged, as to afford an uninterrupted view of the experiments performed on the lecture-table, from all parts of the theatre. The light is admitted by a circular lantern, placed immediately over the centre of the room, which may be darkened, when necessary, by an apparatus no less simple than efficient: a false ceiling sliding down the lantern, which, passing the windows, darkens the room.

* Of the literary treasures deposited in the library of this Institution, it may be enough to state that the classical department was formed under the direction of the late Professor Porson, its first librarian, and his erudite successor, Mr. William Maltby. The class of British topography and antiquities is also full and interesting, containing some of the best works in that department of English literature. A general catalogue of the library was published in 1813; and Mr. Upcott has since completed a particular account of the curious, historical and miscellaneous tracts, &c. including those collected by the Marquis of Lansdowne, comprising upwards of 700 volumes.

Behind the Lecture-room are placed the *Laboratory* and *Apparatus-room*, both of which are admirably constructed for the use of this department. The Laboratory is furnished with furnaces, sand-baths, a still, worm-tub, and a complete collection of chemical apparatus.

The Apparatus-room forms the opposite wing of the Laboratory. It is lighted by an oblong lantern; and the models and philosophical instruments, constructed and purchased under the direction of Mr. Pepys, form a very distinguished feature of the establishment.

The ROYAL INSTITUTION was founded at the commencement of the present century, and this establishment has certainly formed a chemical school, and given birth to teachers unequalled by those in any other part of civilized Europe. In support of this assertion, we need only enumerate the names of Davy, Brande, and Faraday, which form a splendid galaxy of talent, all nurtured by the same congenial soil.

The "SOCIETY FOR THE ENCOURAGEMENT OF ARTS, MANUFACTURES, AND COMMERCE," was founded, as its name implies, more for the benefit of trade and the improvement of commerce in Great Britain, than for the diffusion of abstract learning. It has, however, most materially benefited every branch of practical science, and the well-

filled Museum attached to the establishment, furnishes a sufficient proof of the appropriate application of their honorary and pecuniary rewards.

From this brief view of the progress of the Royal Society, and its sister establishments, we must now turn to another and more universal agent for facilitating the march of science :—to allude to the formation of a popular Institution, furnished with a theatre for the delivery of public lectures in the heart of the metropolis ; an establishment which, although originally intended exclusively for the use of mechanics and those persons who, from their limited means, were unable to belong to its more aristocratic parent, now boasts amongst its members some of the most learned and ingenious philosophers of the present day.

It is generally admitted that the honour of first suggesting establishments of this kind originated with Dr. Birkbeck; and their subsequent support, and immense extension, are, in a great measure, owing to the same beneficent individual.*

* The following eloquent oration, delivered by the President on laying the foundation stone of the great lecture-room in Southampton Buildings, fully illustrates the end and object of the philanthropic founder. "We are about to erect," observed the learned President, "a temple to the increase of knowledge, to the diffusion of the riches of the mind, to the amelioration of the human intellect; we are proceeding to found an institution for the improvement of the noblest faculties of man ; we are about to prepare a feast of reason, to which the invitations shall be as

The impetus that has been given to scientific pursuits, by the diffusion of periodical literature, that originated about the same period as the formation of Mechanics' Institutions, must not pass unnoticed. Scientific books were formerly rare, or of a costly character, and publishers paused, ere they undertook works that were so little likely to furnish a remunerating sale.* At the present time, however,

universal as the dominion of knowledge—to the highest and humblest alike and equal. After the long lapse of partial experiments on the intellect of man, it remains for us to ascertain, by the result of our present Institution, whether the limits of practical knowledge can be effectively and successfully extended; whether the barren mind, which has hitherto marred the anticipations of the friends of intellectual advancement, is to be attributed to the imperfection of the culture, or the sterility of the soil. If we succeed in the effort we have undertaken—if we can enlarge the practical powers of the human judgment—if we throw a light over the gloom of mental listlessness—if we shall be so happy as to rouse to life the dormant energies of the mechanical capabilities of man, we shall have achieved the most glorious and useful work that a partial body of men can confer on the general community of their fellow-men. When laying the stone, let me remind you of a sentence uttered by Lord Bacon: 'knowledge is power.' Yes, gentlemen, and it is more; it is wealth, it is comfort, security, happiness; it gives a charm to social life; it makes morals more upright; it supports religion, and purifies politics; it is, to speak mechanically, an avenue and a road-way to the temple that is made without hands, to eternity in Heaven."

* The Jesuits' edition of the Works of Sir Isaac Newton, though confessedly a most laborious and learned production, had so slow a sale, that the whole impression was not disposed of in half a century.

such is the immense extension of scientific inquiry, that we find a single periodical work producing from twenty to thirty pounds per week; whilst standard works on similar subjects are furnished by means of stereotype editions, in so accurate a form, and at so economical a rate, as to admit of an almost unlimited diffusion.

While speaking of the diffusion of useful knowledge by means of public institutions and public lectures, we must not omit to enumerate the names of three female professors who have distinguished themselves in this branch of instruction. The earliest on the list (Maria Cajetana Agnesi) actually held the Professor's chair at Bologna.*

Mrs. Bryan published her "Lectures on Natural Philosophy," in one volume quarto, though her labours were almost exclusively confined to the pupils in her own academy.

Mrs. Gent, who is the last female lecturer in order of date, was the friend and pupil of the author; and, at the time of her death, was rapidly rising to eminence in the scientific world. Her lectures are

* Her father, who had previously been professor, obtained a dispensation from Pope Benedict XIV. for his daughter to occupy his place in the University. Before this, at the early age of nineteen, she had supported one hundred and ninety-one theses, which were published in 1738, under the title, "Propositiones Philosophicæ." She also published a discourse, tending to prove that the "study of the liberal arts" was not incompatible with the understandings of women.

now in course of publication, and will best speak how varied, as well as profound, were her researches.

Having thus briefly examined the progress of mechanical science in this country, it may now be advisable to notice more in detail some of the more important branches of natural philosophy, commencing with astronomy, which was placed by the ancient schoolmen amongst "the most sublime of all pursuits."

The study of the heavenly bodies must evidently be as old as the creation; though, in all probability, the astronomer of that period confined his observations to the more obvious motions of the sun and moon, the rising and setting of the principal stars, and the apparent motions of the planets. The progress of the sun being thus followed, the regular transitions from day to night would at once be understood.

The level and extensive plains of Chaldea peculiarly fitted that favoured portion of the globe to the study of astronomy; and the clear nights which the inhabitants were wont to pass in the open air, united to a pure and serene sky and an unbroken horizon,—all conspired to engage that people to contemplate the motions of the stars, and to lead them to conjecture on the laws by which they were governed.

From Chaldea, astronomy passed into Egypt, and was soon afterwards carried into Phœnicia, where the people began to apply the observations which had been made to the uses of navigation, and thus rendered themselves the masters both of the sea and of commerce. Their guide, in steering their ships when far from land, was one of the stars in the constellation called the Little Bear, which, unlike other stars, appeared always to retain the same situation. Other nations, less skilful in astronomy, observed only the Great Bear in their voyages,—a guide too imperfect to enable them to lose sight of land with safety.

But the most ancient observations of which we are in possession, that are sufficiently accurate to be employed in astronomical calculations, were made at Babylon, about seven centuries prior to the Christian era: they relate to three eclipses of the moon: and Ptolemy, who has transmitted them to us, employed them for determining the period of the moon's mean motion, and therefore had probably none more ancient on which he could depend.

To Anaximander, one of the disciples of Thales, is ascribed the invention of the terrestrial globe, and of a gnomon which he erected at Sparta; by means of which he observed the equinoxes and solstices, and determined the obliquity of the ecliptic, more exactly than had ever been done before. The Greeks, assisted by the instructions they had received from

Thales and Anaximander, ventured to make considerable voyages, and planted several colonies in remote countries; yet the latter philosopher and his children were proscribed by the Athenians; and their lives would have been sacrificed but for Pericles, through whose influence the sentence was commuted for banishment. The charge against him was the discovery of truth; for it was thought impious to suppose "that the works of the Gods could be subject to immutable laws."

Pythagoras, another of the disciples of Thales, taught many sublime astronomical truths. To him is attributed the discovery of the true system of the world, which, after the lapse of many centuries, was revived by Copernicus, and which is now settled on the basis of so many truths, that it can never be overthrown. It was thought, even in his school, that the planets were inhabited like the earth; and that the stars, which are disseminated through infinite space, are suns, and the centre of other planetary systems. He is also said to have considered the comets as permanent bodies, moving round the sun; and not as perishing meteors, formed in the atmosphere, as they were thought to be in aftertimes.

The Arabian school of astronomy commenced with Almamoun, the son of the Caliph Haroun al Raschid. This celebrated warrior and philosopher, having conquered the Emperor Michael the Third, made it a condition of peace, that a copy of the

works of each of the best Greek authors should be delivered to him; and among them were the works of Ptolemy, of which he procured an Arabic translation. This occurred in the ninth century; and about four hundred years later, the work of Ptolemy was translated into the Latin language.

The fifteenth century was rendered memorable by the revival of the Pythagorean system. This was effected by Nicholas Copernicus, a native of Thorn, in Prussia. The Ptolemaic system, which supposes the Earth to be fixed in the centre of the universe, and the Sun and Moon, with Mercury, Venus, and the other planets, revolving round it in concentric circles, he perceived to be inconsistent with the celestial phenomena, and incumbered with many absurdities, which did not affect the hypothesis which considered the Sun to be in the centre, and the Earth a planet revolving about it annually with the rest, and daily turning upon its own axis.

The only opposition of any consequence which the theory of Copernicus ever met with from science and argument, proceeded from Tycho Brahe, a celebrated Danish astronomer, who attempted to set up against it a theory of his own. His system is not very different from the Ptolemaic, but is generally called by his name. He supposed the Earth to be immovable in the centre of the universe, and the Sun to revolve about it every twenty-four hours: the planets, he thought, went round the Sun in their periodical times,

Mercury being nearest to that luminary, then Venus, Mars, Jupiter, and Saturn; and of course to revolve also about the Earth. But some of Brahe's disciples supposed the Earth to have a diurnal motion round its axis, and the Sun, with all the planets, to move round the Earth in one year.

Kepler was one of the pupils of Tycho Brahe, and a man of a truly original and admirable genius. Hipparchus, Ptolemy, Tycho Brahe, and even Copernicus himself, were indebted for a great part of their knowledge to the Egyptians, Chaldeans, and Indians: pursuing paths already pointed out, they did little more than separate fancy from fact, with more or less success; but Kepler, by his own talent and industry, has made discoveries of which no traces are to be found in the annals of antiquity. Galileo was contemporary with Kepler; and whilst the latter was tracing the orbits of the planets, and settling the laws of their motions, he was investigating the doctrine of motion in general, which had been neglected for 2000 years; and from the result of their united labours, Newton and Constantine Huygens were afterwards enabled to establish the most complete theories of all the planetary motions.

The discoveries of Newton, with reference to the laws of planetary motion, have already been adverted to; and we may add, that from the time of our illustrious countryman, who carried the theoretical part of the science to its present state of perfection, as-

tronomy has never been without an illustrious phalanx of supporters, whose particular merits and discoveries are fully illustrated in the section devoted to the motions of the planetary bodies.

The first systematic treatise on light is ascribed to Empedocles; and a work on optics, attributed to Euclid, who flourished about 400 years before the Christian era, shows the state of knowledge on the subject generally about that period. The latter work adverts to the effect of bringing into view, by refraction, an object at the bottom of a vessel, by pouring water upon it; but chiefly treats of reflected rays, explaining the effects of different kinds of mirrors, and demonstrating the equality of the angles of incidence and reflection.

Ptolemy, in the second century, prepared a treatise on the science of optics generally, though it is now lost. From this period but little occurs worthy of notice, till Alhazen, an Arabian author, in the eleventh century, gave an account of the magnifying power of lenses; and in 1270, Vitellio, a Polander, published a treatise on optics, containing all that was valuable in Alhazen, digested in a better manner, and with clearer explanations of various phenomena. He observes, that light is always lost by refraction, which makes objects appear less luminous. He gave a table of the results of his experiments on the refractive powers of air, water, and glass, corresponding to different angles of incidence.

He ascribes the twinkling of the stars to the motion of the air in which the light is refracted; and illustrates this hypothesis by observing, that they twinkle still more when viewed in water put in motion. He also asserted, that refraction is necessary as well as reflection, to form the rainbow; because the body which the rays fall upon is a transparent substance,—at the surface of which, one part of the light is always reflected, and another refracted. He makes some ingenious attempts to explain refraction, or to ascertain the law of it; and considers the foci of glass spheres, and the apparent size of objects seen through them, though with but little accuracy.*

John Baptista Porta, of Naples, was a very ingenious experimentalist; and is supposed, on good authority, to have invented the camera obscura. His experiments with that instrument induced him to believe that light must certainly be a substance, by the reception of which into the eye, vision was accomplished. The importance of this suggestion will be evident, when it is observed, that previous to his time vision was supposed to be dependent upon what were termed visual rays proceeding from the eye.

* The celebrated Roger Bacon was contemporary with Vitellio, with whose writings, if not also with those of Alhazen, he was probably acquainted. He seems to have acquired the knowledge of some facts which were unknown to them, yet, with several important truths, he blended on this subject much that was wild and fanciful.

He justly considered the eye itself a camera obscura, the pupil performing the office of the hole in the window-shutter; he remarked also, that a defect of light is remedied by the dilatation of the pupil, which contracts involuntarily when exposed to a strong light, and expands when the light is too faint for distinct vision.

Baptista Porta, by publishing an account of the magic-lantern, tended very materially to diffuse a taste for scientific pursuits; as he was enabled with that ingenious instrument to amuse as well as instruct his pupils.*

In 1625, Scheiner very materially illustrated and improved on the discoveries of Porta with regard to the optical structure of the eye. For, taking the eye of an animal, and cutting away the coats of the back part, and presenting different objects before it, he viewed the picture distinctly painted on the expanded optic nerve, or retina, forming its posterior surface.

* It is said that Porta did not confine himself to optical magic alone, for when he drank with his friends from the convivial goblet, the same vessel that supplied him with wine, furnished them only with water. Another feat may be added: on a summer's day, when all complained of the sirocco, he would freeze his guests with cold air in the room; or, on a sudden, let off a flying dragon to sail along, with a cracker in its tail, and a cat tied on its back: shrill was the sound and awful was the concussion. So that it required strong nerves, in an age of apparitions and devils, to meet this great philosopher when in his best humour.

The commencement of the seventeenth century is justly celebrated for the application of the telescope to astronomical purposes; and for this instrument we are most especially indebted to Galileo.

Other accounts transfer the merit of the first discovery from Jansen himself to his children, who, while amusing themselves with a series of spectacle glasses in his shop, perceived, that when they held two of these lenses between their fingers at a certain distance from each other, the dial of the clock appeared greatly magnified, but in an inverted position. This incident suggested to their father the idea of adjusting two glasses on a board, so as to move them at pleasure to any required distance.

To the Jansens we are also indebted for the discovery of the microscope; an instrument depending upon exactly the same principles as the telescopic tube. In fact, it is not improbable that the double lens was first applied to the observation of near but minute objects; and afterwards, on the same principles, to objects which appeared minute on account of their distance.

The discovery of the different refrangibility of the component rays of light, suggested defects in the construction of telescopes, which were before unthought of; and, in the creative hands of a Newton and a Dollond, led to some no less extraordinary improvements in them. Those to which we now particularly allude, consist in using three glasses of dif-

ferent refractive powers, and thus producing an *achromatic* or colourless image. The discoveries of Brewster and Herschel are also examined under that division of our work which relates to the natural properties of light, and its application to the construction of optical instruments.

Some of the most curious properties of *atmospheric air* were known at a very early period, and it is a circumstance worthy of record, that Lucretius was well acquainted with the mechanical resistance offered by the air to the motion of falling bodies. This distinguished philosopher thus accurately accounts for the apparent difference in the velocity with which different bodies pass through the air.

> " In water or in air when weights descend,
> The heavier weights more swiftly downwards tend ;
> The limpid waves, the gales that gently play,
> Yield to the weightier mass a readier way :
> But if the weights in empty space should fall,
> One common swiftness we should find in all."

Now the modern illustration of the vacuous receiver furnished with a " guinea and feather apparatus," could not more accurately illustrate the phenomenon.

Hero, who published a treatise on Pneumatics, describes a number of very ingenious inventions, a few of which are calculated for utility, but the greater part for amusement only; they are prin-

cipally syphons variously concealed and combined, fountains, and water-organs, besides the syringe and the fire-engine. The description of this engine agrees precisely with the construction which is at this day the most usual; it consists of two barrels, discharging the water alternately into an air vessel; and it appears from Vitruvius, that this was the original form in which Ctesibus invented the pump.

About the year 1600, Galileo made the important discovery of the effects of the weight and pressure of the atmosphere, in the operation of suction-pumps: and fifty years later, Otto von Guericke, of Magdeburg, constructed a machine similar to the air-pump, by inserting the barrel of a fire-engine into a cask of water; so that when the water was drawn out by the operation of the piston, the cavity of the cask remained nearly void of all material substance. But finding that the air rushed in between or through the staves of the cask, he inclosed a smaller cask in a larger one, and made the vacuum in the internal one more complete, while the intervening space remained filled with water; yet still he found that the water was forced into the inner cask through the pores of the wood. He then procured a sphere of copper, about two feet in diameter; and was exhausting it in the same way, when the pressure of the air crushed it with a loud noise.

In the year 1658, Hooke finished an air-pump for Boyle, in whose laboratory he was an assistant;

it was more convenient than Guericke's, but the vacuum was not so perfect.

The air-pump made by Mr. Stiles, of which a graphic illustration is given in the frontispiece to this work, is the most perfect that has yet been constructed.

The first recorded account of the employment of steam in a highly expansive state, is furnished by Agathius.* He states, that the philosopher Anthemius, having received some offence from Zeno the rhetorician, resolved to avenge the affront by a display of his wonderful mechanical powers. In pursuance of this plan, the man of words was invited to the residence of the Trallian philosopher, but was scarcely seated ere the house began to shake, and nearly all the symptoms of a violent earthquake became apparent. Agathius adds, that the effect was produced by the passage of steam through pipes, from a cauldron at the bottom of the building.

The progressive labours of the Marquis of Worcester, Savery, Newcomen, and Watt, are fully detailed and exemplified in the section dedicated to the steam-engine.

The beginning of the modern experimental im-

* This distinguished scholar was one of the Byzantine historians, and composed his work in the sixth century. It was edited by Vulcanius, at Leyden, in 1594, and elegantly reprinted, in folio, at Paris, in 1660. A copy is preserved in the London Institution.

provements in hydraulics, may perhaps be dated from the investigations of Smeaton, respecting the effects of wind and water, which were published in the Philosophical Transactions for 1759. His observations are of material importance, as far as they are capable of immediate application to practice, but he has done little to illustrate their connexion with the general principles of mechanics. Mr. Borda first derived from a just theory the same results respecting the effects of undershot water-wheels, as Smeaton obtained from his experiments about ten years after. Before this time, the best essay on the subject of water-wheels was that of Helvius, published in 1742: his calculations are accurate and extensive; but they are founded, in a great measure, on the imperfect suppositions respecting the impulse of a stream of water, which were then generally adopted.

It was in the middle ages that navigable canals began to be considerably multiplied; first in China, and afterwards in other parts of the world. The canal from the Trent to the Witham, which is the oldest in England, is said to have been dug in 1134. Now, however, almost every principal town in Great Britain is furnished with one or more of these fluid roads.

The invention of the organ, by Ctesibus of Alexandria, about two thousand years ago, forms a remarkable epoch in acoustical science. The larger

instruments of this kind were furnished with hydraulic bellows, the smaller with bellows of leather only; and they had keys which were depressed, like those of the modern organs, by the fingers of the performer, and which opened valves communicating with the pipes.

The mechanical contrivances resorted to in the infancy of science were of a rude and simple character; though their very simplicity, by tending to diminish friction, gave them many advantages over our more perfect, but at the same time more complicated machines.*

We are informed by Pliny, that Ctesiphon lower-

* Much of mechanical ingenuity was shown in the construction of the military weapons employed both by the Greeks and Romans. With civil and domestic engineering, their acquaintance was of a very limited character, but their weapons of war were both numerous and effective. A slight enumeration of their names and uses, will at once show the bent of human nature when unenlightened by Christian principles.

These instruments were divided into three classes. The first being employed for throwing destructive weapons: amongst which we may especially enumerate the *scorpion*, for casting arrows; the *catapulta*, for stones and javelins; the *pyrobole*, for flaming darts; and the *balista*, for bullets.

The second species of war instruments were for razing the walls of fortified places, and partook in their general character of the properties of the Aries, or battering ram.

The third class was exceedingly numerous, and comprised the various movable towers and other large engines, which were used to approach the walls of a besieged town, or attack an otherwise inaccessible enemy.

ed his large blocks of stone, by placing them on heaps of sand-bags, and letting out the sand by degrees; and it is most probable that he elevated them by means of the inclined plane, which seems to be the simplest and most obvious method. Indeed, this mechanical power appears to have been a very favourite instrument with the architects of ancient times, as it was almost invariably employed in the erection of their public works. There appears little doubt but that our Druidical ancestors had recourse to a similar contrivance for the elevation of the immense horizontal stones that are still existing in Wiltshire.

The earliest attempt at dividing the hours of the day by mechanical means, consisted in the employment of a water-clock or clepsydra. This inconvenient instrument gave place in the middle ages to the wheel-work of the Arabians and Saracens.*

* There are many documents to prove the existence of clocks with wheels and weights in the middle of the fourteenth century; but the invention cannot be traced to an earlier date with any certainty. The sphere of Archimedes, indeed, has been considered as the first attempt towards the formation of a clock; it had a maintaining power, but, being without any kind of regulator, could only measure time as a planetarium exhibits the motion of the stars, with relative but not positive precision. The opinion of Berthoud, who has investigated the subject with attention, is evidently just, when he asserts that the clock is not the invention of any one man, but an assemblage of successive inventions, each of which is worthy a separate contriver.

The first English clock, of which we know the construction, is that which was made by Wallingford in 1326, and which was regulated by a fly; and the second that of Defondeur, with a simple balance, made about 1400. But it appears that some portable watches had been constructed in the beginning of the fourteenth century; and about the year 1460, several clock-makers are said to have come to England from Flanders.*

The labours of Tompion, Harrison, and Vulliamy in this branch of the mechanical arts, are too well known to need any eulogy; and the latter of these ingenious artizans possesses the peculiar merit of manufacturing large or turret clocks, with the same accuracy and precision as the most minute pocket chronometers. †

* Shakspeare, who is seldom guilty of scientific anachronisms, makes Malvolio the ideal possessor of a watch, and in the following passage alludes to the existence of striking clocks in the time of Richard the Third:

> "What is't o'clock?——
> ——Upon the stroke of four."

† It may be right to add, that we are indebted for much of the beauty and perfection exhibited in modern machinery, to the existence of a Society now but little known, though one of great antiquity; we allude to the Mathematical Society, which numbers amongst its members some of the most distinguished names that have illumined the horizon of practical science.

ON THE MECHANICAL POWERS,

AND THEIR APPLICATION TO THE CONSTRUCTION OF SIMPLE MACHINES.

Lever.—Art of Weighing.—Balance.—Steel-yard.—Bent lever balance.—Profile machine.—Pulley.—Combination of blocks.—Wheel and axis.—Capstan.—Rachet.—Tread-wheel.—Jack.—Inclined plane.—Probable mode of raising heavy weights by the Ancients. — Wedge. — Screw. — Compound screw. — Improved Wrench.—Orfyrean wheel.

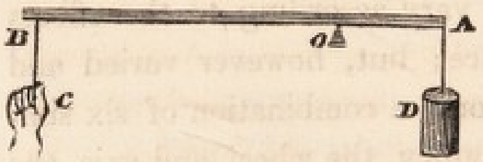
In examining the various simple mechanical agents, by the use of which we are enabled to adapt animal labour to the useful arts of life, and especially to the motion of heavy bodies, we must consider, first, the weight to be raised; and, secondly, the instrument or engine by which it is to be effected. The number of parts, and the arrangement of them, in mechanical engines, vary according to the effects they are designed to produce; but, however varied and multiplied, we find they are only a combination of six simple powers:—the lever, the pulley, the wheel and axis, the inclined plane, the wedge, and the screw; which are constructed to communicate motion to bodies, and to sustain a pressure which the ordinary strength of men and horses could not effect: but by dividing it among a certain number of these powers, the weight sustained individually is diminished, and the resistance overcome.

The first and most simple of the mechanical powers is the *Lever*. It is probable that this simple and easily accessible instrument in the hands of a rude people, was invented at a very early period; as soon indeed, as the wants of man rendered it necessary for him to raise the beams for his log-built hut, and long ere the more complex mechanical arrangements were suggested by a higher degree of civilization, or more artificial wants.*

The lever in its most simple form consists of a bar of wood or metal, one part of which is supported by a steady prop, called the fulcrum, or axis, about which it is moveable.

This mechanical power is usually distinguished into three sorts, according to the different situations of the axis, or prop, and the force employed, with respect to each other.

A sufficient illustration of the *first* form of the lever may be found by reference to an ordinary poker. This, when employed to stir the fire, will have for its axis the bar upon which it rests; the coals are the weight to be overcome, whilst the hand may be considered as the power employed, and it is also with reference to this mechanical power, that we construct the steel-yard.

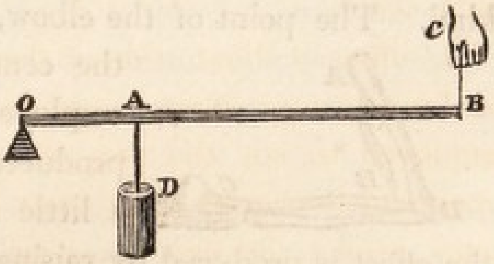


B A is a lever of the *first* kind, supported by an inflexible point O, and as the distance from O to B is twice as great as it is from O to A, the hand C, by exerting a force

* It is a circumstance worthy of record, that the celebrated Ferguson, who commenced his valuable career in very humble life, dated his subsequent advancement to the impression made upon his mind, on first seeing this simple engine used in the reparation of his father's cottage.

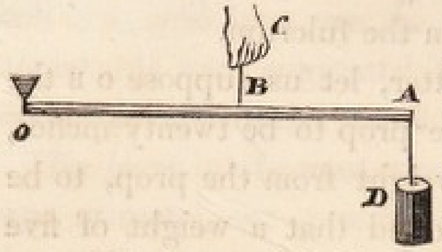
of one pound, may be placed in equilibrio with a weight of two pounds, or twice the amount. From this it will be seen that the length of the arm O B, multiplied into the power C, equals O A multiplied into the weight D and as such, that the power and the weight must be to each other inversely, as their distances from the fulcrum.

To further illustrate the matter, let us suppose O B the distance of the power from the prop to be twenty inches, and O A, the distance of the weight from the prop, to be eight inches, it will then be found that a weight of five pounds may be supported by a power of only two pounds, because the distance of the weight from the fulcrum *eight*, multiplied into the weight *five*, makes *forty*, and as such the longer arm will only require a power of *two*, which multiplied by *twenty*, will produce the same amount.



To illustrate the *second* form of the lever we have only to place the point of support at one extremity, employ the power at the other, and attach the weight at an intermediate point. In this case the hand C is placed at a point equal to three times the distance from the fulcrum O, than the weight D, so that one pound will exactly balance three pounds. A reference to this form of the lever will serve to shew, why two men carrying a weight between them, share the burthen to be supported, in proportion to the distance at which they are placed; thus, if one man be at O, and the other at B, with an inflexible pole resting upon their shoulders, the latter person will have a mechanical advantage over the former. This is an expedient occasionally resorted to in the *yoking* of cattle, so that if two horses of unequal strength are intended

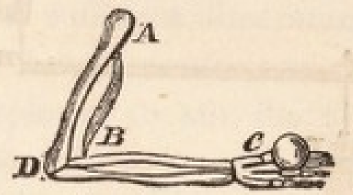
to pull the same vehicle, their forces may be equalised, by such a division of the bar to which they are attached, that the point of traction may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter.



The third form of the lever is when the fulcrum O is at one end, the weight D at the other end, and the power C between them.

In this form of the lever no mechanical advantage is obtained; but, on the contrary, a considerable loss of power is the result.

The bones of the human arm, and indeed, the greatest number of the moveable bones of animals, are levers of this kind. The point of the elbow, D, may then be considered



the centre of action. The power employed by the muscle (which is produced by contraction) is exerted a little nearer the wrist, at B, and the effect is produced by raising the weight C.

In this natural, though apparently unmechanical form of the lever, it will be evident that the power is not advantageously situated; for as it lies very near the centre of motion, it must be much greater than the weight which is lifted by the hand. This loss of power is, however, abundantly compensated for by other advantages, the principal of which is the compactness and smallness of the limb.*

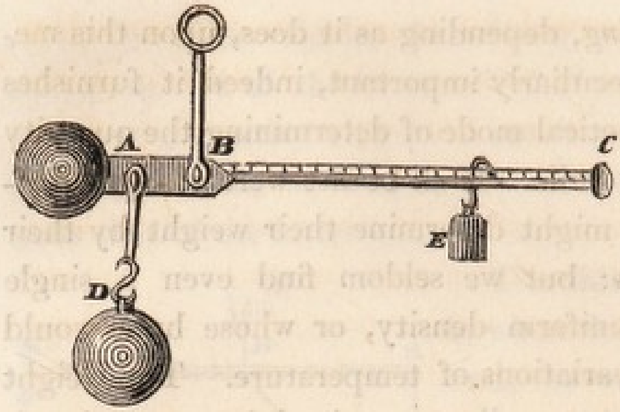
* Borelli has calculated that the immediate force of the *biceps*, or double-headed muscle, which bends the arm in an ordinary man, is equivalent to about three hundred pounds, while that of the muscles which raise the lower jaw is much greater.

Topham, a carpenter, mentioned by Desaguliers, could readily lift

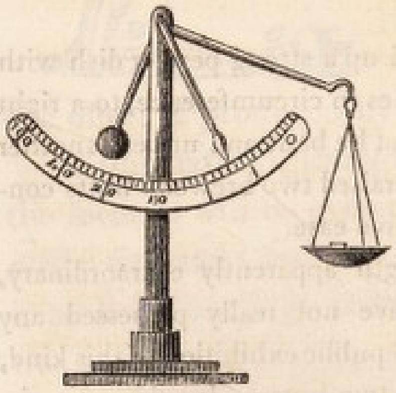
The art of *weighing*, depending as it does, upon this mechanical power, is peculiarly important, indeed it furnishes us with the only practical mode of determining the quantity of matter in a given bulk. If all bodies were of equal density throughout, we might determine their weight by their external dimensions: but we seldom find even a single body which is of uniform density, or whose bulk would not be affected by variations of temperature. The weight then of a body is most easily ascertained by comparing it with any other bodies whose weight is previously known; and this may be effected by attaching them to the extreme ends of a lever whose arms are equal. The arms of a balance are, however, frequently made unequal for fraudulent purposes, the axis being placed nearer to the scale containing the weight, than to the substance to be weighed, which will thus obtain a decided mechanical advantage. When this occurs, the fraud may readily be detected, by changing the contents of the two scales.

about eight hundred pounds. He rolled up a strong pewter dish with his fingers, and bent a poker, three inches in circumference, to a right angle, by striking it upon his arm; whilst he bent and unbent another about his neck. He also supported and raised two brewer's butts containing beer, and this too with comparative ease.

Sometimes, however, feats of strength apparently extraordinary, have been exhibited by men who have not really possessed any very remarkable strength of muscle. At a public exhibition of this kind, a person used to withstand the force of two horses, drawing at a girdle passed round his waist, while his feet were placed against a firm support. He also supported one or two men by forming his body into an arch; and by an harness fitted to his hips, he sustained a cannon weighing between two and three thousand pounds. The latter of these feats would at first view appear impossible, did we not bear in mind that in this, as well as in the preceding cases, the passive strength of the bones is more concerned than the active force of the muscles.



When the effective length of the arm, B C, is made variable, by means of the moveable weight E, the balance then becomes what is called a *steel-yard*. So that if E be one pound, and when placed at the *first* division B, is equal to a similar weight in the scale pan attached to the opposite end of the lever; on being removed to the *second* division, it will then balance two pounds; if to the *third*, three pounds; and so on to the end of the arm C. If any of these integral divisions be subdivided into as many equal parts as a pound contains ounces, and the weight E be made to counterpoise what is in the scale, the pounds and ounces may readily be ascertained.



In the annexed *bent-lever balance*, an immoveable weight is made to produce precisely the same result. For the arms of a balance, though constant in length, may vary in effect without limit, if the inclination with the horizon be altered in an equal ratio. The rapid diminution in the space passed over by the index hand, as the weight descends in the scale, is sufficiently observable. This arises from the arm to which the ball is attached, continuing to increase in its effective force, as the centre of gravity becomes more and more removed from a line perpendicular to the point of support.*

* Having seen that the longer arm of an unequal lever describes a

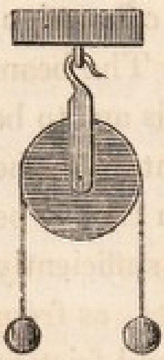
Common balances are subject to many imperfections, the principal of which are as follows:—1st. A balance is frequently in equilibrio, when the opposite weights in its scales are not equal. This arises from the points of suspension being not equidistant from the centre of motion; in which case the empty scales may be made to balance each other; yet when equal weights are put in them, those weights will not balance each other; for as they are suspended at unequal distances from the centre of motion, their momentums are actually unequal. 2dly. The beam is frequently made too slight; in which case it is apt to be bent more or less by the weights that are put into the scales; and, of course, the apparent equilibrium cannot be depended upon. 3dly. Balances seldom are sufficiently sensible. This defect arises from various causes, as from the great weight of the beam, from roughness and friction at the point of suspension, from the centre of gravity of the beam being considerably below the centre of motion, &c.

But it may be proper to observe, that balances have been made, in this country, of so delicate a construction, that

circle as much greater than the opposite extremity as its radius exceeds that of the shorter arm, it may be advisable to notice an application of this mechanical power, to the construction of a *profile-machine*. A patent has been obtained for this instrument by Mr. Schmalcalder, and it consists of a single lever of about twelve feet in length, which is made to revolve in a ball and socket, or universal joint; one end being furnished with a pencil, and the other employed as a tracer. If the joint (which is moveable) be fixed at three feet from the pencil, and the tracer passed over the object to be described, a profile likeness of the person may be delineated upon a piece of paper, by the action of the shorter arm, which is furnished with a pencil for that purpose. If, on the contrary, the profile is to be enlarged, it is merely necessary to remove the joint, and thus give the mechanical advantage to the opposite end of the lever.

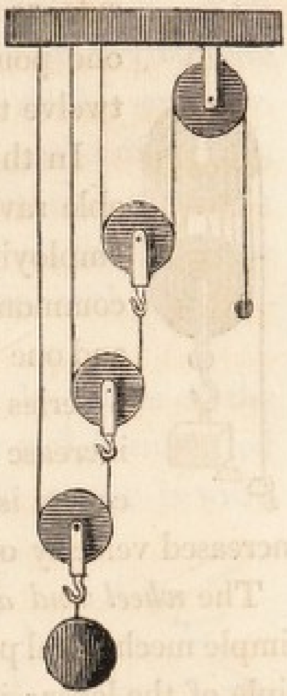
their equilibrium is readily disturbed by so small a quantity as $\frac{1}{1000000}$ part of the weight in each scale.

The *pulley* is a single wheel moveable upon an axis, and enclosed in a kind of case, called the block. This mechanical power is usually divided into two classes—the single pulley being fixed; while those which are compound, usually have one or more wheels attached to the weight with which they rise and fall.

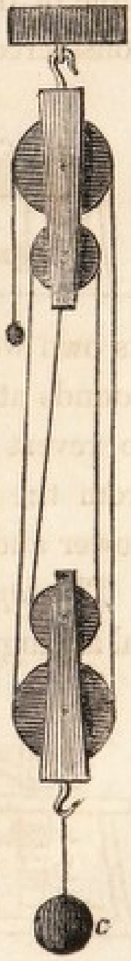


The first diagram represents a fixed pulley, which, it will be seen, is merely employed to change the direction of motion, as the two weights are equal, and it is placed under the same circumstance as a balance with equal arms.

In the second arrangement, a moveable pulley is combined with one that is fixed, and in this case a mechanical advantage of one in two is obtained; for the weight o is supported by the cords c and R, each of which bear half the amount. If it is intended to raise the weight o, it will be found that the two cords are placed in the relative situations of that form of the lever in which the weight is suspended midway between the axis and point of support, as R will be the fulcrum, and c the power, the pulley continuing to roll upon the point R, which rises with the weight. The same loss of power also, which has already been pointed out in the lever, arises from the use of a pulley; for the small weight must pass through four inches to raise the larger weight two inches.

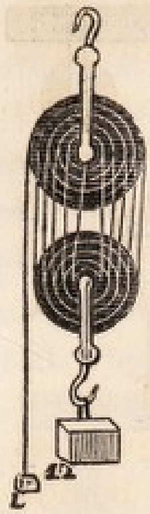


By employing a series of moveable pulleys, a still greater mechanical advantage may readily be obtained; so that if four pulleys be connected by means of as many different cords, and a force of one pound exerted, the *first* will give two pounds, the *second* four pounds, and the *third* eight pounds. The inconvenient space which this arrangement of pulleys is found to occupy, has suggested the use of a moveable frame, capable of containing the whole series, and, in that case, it is called a block.



When the upper and fixed block contains two pulleys, which only turn upon their axis, and the lower moveable block contains a similar number, the advantage gained is as four to one. For each lower pulley will be acted upon by an equal part of the weight; and as they tend to double the power, the force by which C may be sustained, will be equal to half the weight divided by the number of lower pulleys; that is, as twice the number of pulleys is to one, so is the weight suspended to the power.

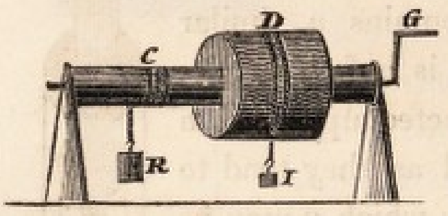
When pulleys are placed perpendicularly under each other, on separate pins, they occupy a considerable degree of space, and on that account are what is technically called *block* and *block* with each other, long ere the weight arrives at the point of support. To remedy this inconvenience, they are usually placed side by



side, as is seen in the annexed diagram, in which one pound is made to support a weight equal to twelve times that amount.

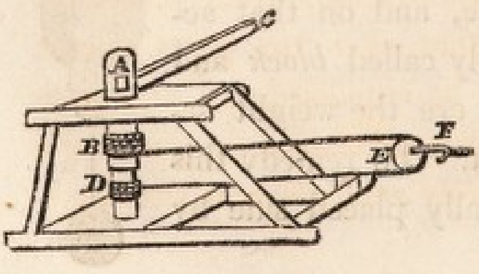
In this arrangement of the blocks, a considerable saving in friction is effected; for instead of employing a series of moveable pulleys, as is commonly resorted to, there is but one *moveable* and one *fixed* pulley, and these are furnished with a series of grooves, so proportioned, that their increase in diameter as they recede from the centre is so contrived as exactly to equalize the increased velocity of the rope.

The *wheel and axle* is usually placed next in the list of simple mechanical powers; though it acts entirely on the principle of the lever; indeed it has, with some propriety, been considered as a perpetual lever. That this is the case may



very readily be shewn: for the wheel or roller, D, being twice as large as the roller C, will operate upon the axle with a force equal to exactly twice its own weight. So that one pound at I will balance two pounds at R. To illustrate this more fully, we have only to revert to the handle G, which is at the same distance from the centre, and the analogy between this mechanical power and the lever, will then become apparent.

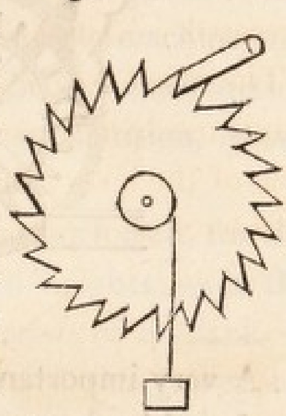
The *capstan*, *crane*, and a variety of other simple mechanical arrangements, also derive their power from the wheel and



axis. Thus if a lever, C, be connected with the axis A, a considerable force may be exerted by means of a cord coiled round the cylinder B, and if two cylinders are em-

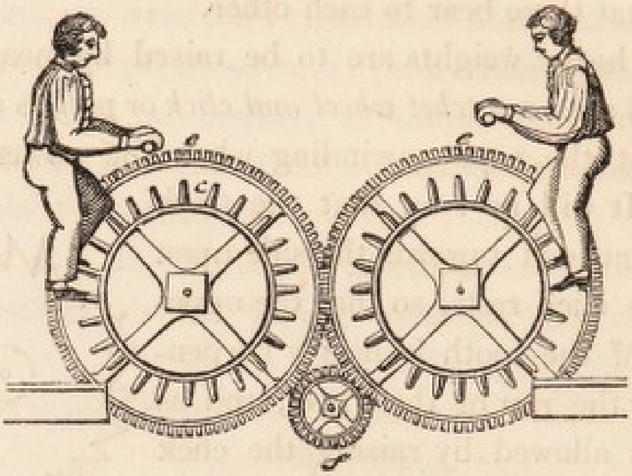
ployed as D, B, a vast increase of power is the result. F represents the point at which the power is to be exerted, and E the flexible cord which passes to the double cylinder. The two ends of the cord are coiled in opposite directions, so that when the one is wound up, the other is uncoiled; and as the cylinder D is smaller than that above it, the mechanical advantage is in an inverse ratio, with the proportion that these bear to each other.

When heavy weights are to be raised by means of the wheel and axis, a *ratchet wheel and click* or *pall*, is employed to prevent the rope unwinding when the power is withdrawn. It will be seen that the teeth are only inclined towards the side upon which the click rests, so that the opposite face of the tooth is nearly perpendicular to the rim of the wheel, and as such it is allowed by raising the click to turn in one direction, but its return is prevented by the end of the tooth against which it stops.



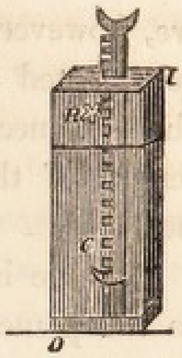
A wheel furnished with a series of handles, or rather of pegs, is sometimes resorted to, by means of which very minute portions of a circle, may readily be described, and a series of short impulses accomplish that which could not be effected by the lever; for experiment will shew that the effect is continually varying, although the power exerted remains the same, as it is continually operating in a new direction with reference to the axis. On this account it is that two handles are sometimes employed, placed at right angles to each other, so that when the effect is least at one handle, the power may be equalised, by a greater effect at the other. The boards represented in the periphery of the annexed wheel, are exactly analogous to the hand-

spikes used for hauling a ship into harbour, or raising the anchor of a vessel, with this difference, that the hand-spike is a lever which must continually change its situation with reference to the axis, while the wheel, on the contrary, may be considered as a perpetual lever.



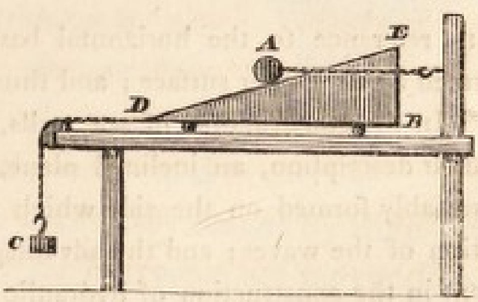
A very important application of the wheel and axle will be found in the construction of the *tread-wheel*, which consists of a wheel and axis, furnished with walking-boards, similar to those which are attached to the periphery of a water-wheel. The above sketch illustrates a double apparatus of this description, as the wheels *e e* are furnished with teeth which work into each other, and in a similar way communicate motion to the small wheel *f*. The use of the tread-wheel may be traced to a very early period. Vitruvius furnishes several instances of its use, and the Chinese have employed machines of this description from the earliest period. It may, however, be proper to state, that its most useful application has been as an instrument of prison discipline, for which purpose, under proper modifications, it appears admirably adapted.

The *Jack*, which is a portable as well as a very powerful prime mover, consists of a wheel and axis, or rather of a lever and nut R, working in a rack *c*. Motion is given to the wheel R by means of a lever, or handle, and as the base of the apparatus D rests against the earth or any other firm support, the power will be obtained at the upper extremity of the rack, a sharp prong being provided to ensure the necessary adhesion.



The *inclined plane* is the fourth mechanical power; and it is more than probable that this very simple machine was employed by our Druidical ancestors, in the construction of that stupendous monument of early superstition, *Stonehenge.*

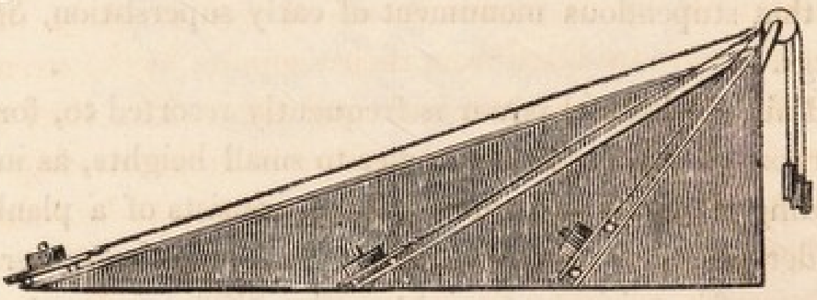
This mechanical power is frequently resorted to, for the purpose of raising heavy bodies to small heights, as in the loading of a cart; in which case it consists of a plank or ladder placed in an oblique direction; and the power necessary for raising a weight under these circumstances, will depend on the proportion that the length of the plane bears to the perpendicular lift. Thus, if we suppose the perpendicular height, B E, one third of the length from B to D, it will be found that a force equal to one pound will raise a weight of three times that amount, though it must of necessity pass through three times the distance that the body is raised.* Should



* It is a curious fact, that nearly all the elementary works which treat on this mechanical power, speak of its perpendicular height,

we, however, place the inclined plane on rollers, as it is represented above, and connect the weight A by a thread, the force necessary to retain it in equilibrio, will be as the length of the horizontal plane is to the perpendicular height.

If three inclined planes be formed at different angles to the plane of the horizon, and as many carriages connected by threads with weights passing over a similar number of pulleys at top, it will be found that the carriage supported by the central plane will arrive first at top; though, to produce this effect, the middle plane must (as is represented beneath) be twice as long as it is high.*



A reference to this circumstance will serve to explain upon what principle the late Mr. Rennie was enabled to

with reference to the horizontal base, instead of the oblique line formed by the upper surface; and thus mistake its proportions.

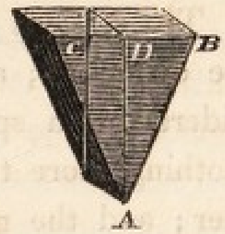
* In the construction of sea walls, and other embankments of a similar description, an inclined plane, more or less acute, is almost invariably formed on the side which is intended to resist the direct action of the waves; and the advantage of attending to this arrangement in the construction of hydraulic edifices will be apparent, when we recollect, that a perpendicular wall would have to resist a shock equal to the momentum of the entire mass. But if, on the contrary, we employ an inclined plane, the power of the advancing column of water is nearly destroyed ere it attains the summit.

construct an edifice, which, like the Lighthouse of Smeaton, appears formed to resist every attack of the warring elements.

This great national work consists of a mass of sunken stone thrown promiscuously into the water, leaving them to find their own base, which must, of course, be considerably extended, in most cases gradually narrowing from about 200 feet to an apex of 30 feet.

The *wedge* is usually reckoned the fifth mechanical power, though it is in reality but a species of inclined plane, consisting of two inclined planes, joined base to base.

The wedge is a mechanical power of considerable importance in mining, felling of trees, and raising large weights; for by its means vessels of war weighing many thousand tons are lifted from their supports by the strength of a few men applied to a battering ram. The chief use, however, of this mechanical power, is in penetrating and dividing bodies, as all cutting instruments may be reduced to the wedge, or inclined plane.* It is also used, as well as the screw, to unite the parts of machines; pins, bolts, and nails being wedges retained in their places by friction. The obvious analogy between an inclined plane and wedge will be apparent by separating A D B from A D C; the result is two inclined planes.

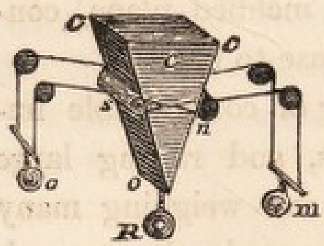


The proportion between power and effect in the wedge has been differently stated by different authors. If the pressure to be overcome act perpendicu-

* The edge of a tool employed for cutting wood is usually more acute than one for metal; the former having its planes at an angle of about 30°, while that for iron should be 50° or 60°, and that for brass little less than 90°.

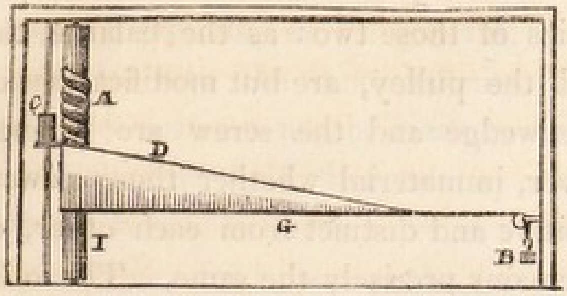
larly on the sides of the wedge, and the power be a pressure perpendicular to the back, the first must be to the latter, as the back of the wedge to its side; for it is kept in equilibrio by the pressures on its three sides. When the wood cleaves at any distance before the wedge, the impelling power will be as the length of the back to the depth of the cleft, measuring from the acting part of the instrument.

An apparatus for showing the power of the wedge may be thus constructed:—the two rollers N S are attached by cords to the weights M and O, each weighing ten pounds. The base C C is represented as equal to half the height, and it will require a weight of five pounds to preserve the apparatus in equilibrio. A reference to the arrangement of the weights will shew, that the power will be to the resistance, as half the base is to the height of the wedge. The thinner the wedge, therefore, the less will be the power necessary to overcome any required resistance.

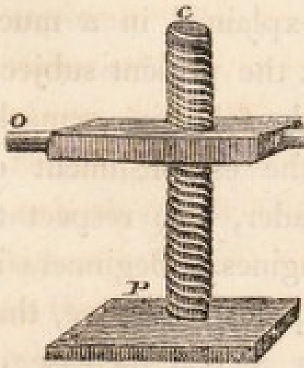


The *screw* is the last mechanical power that remains to be described; and this, like the wedge, may also be considered as a species of inclined plane—it being in fact nothing more than an inclined plane coiled round a cylinder; and the nut, or perforated body which moves up or down a screw, rests upon an inclined plane coiled in a circular, instead of being placed in a rectilinear direction.

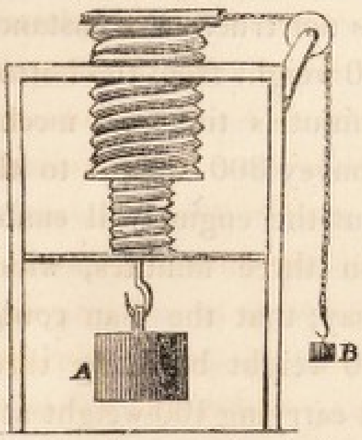
The striking analogy between this mechanical power and the inclined plane, has been beautifully exemplified by Dr. Young, who, in his Lectures at the Royal Institution, employed an apparatus admirably adapted for its illustra-



tion. In this the coil of parchment D B, of which the height is one fifth of the length, being rolled round the cylinder A, forms a screw or spiral, by means of which the weight B is capable of supporting a hollow cylinder C, five times as great at C.



C P represents a common screw, furnished with a nut and handles O G, producing a mechanical advantage equal to about sixty times the power employed. But even this effective force may be considerably augmented by combining two screws, the outer of which forms a nut for the screw to which the weight is suspended. The distance of the threads of the interior screw is four-fifths of that of the exterior or perforated screw, and this distance is one-thirtieth of the circumference. Hence the weight B is capable of sustaining a weight, A, 150 times as great as itself,—the mechanical advantage mainly depending on the difference between the height or angle formed by the two coils. This screw was invented by the late Mr. Hunter.



The least reflection on the preceding illustrations of the nature and properties of the mechanical powers, will sufficiently shew that, strictly speaking, the real and original mechanical powers are not more than two in number: namely, the lever and the inclined plane; so that all the

others are only species of those two: as the balance, the wheel and axle, and the pulley, are but modifications of the lever; while the wedge and the screw are inclined planes. It is, however, immaterial whether those powers be reckoned all primitive and distinct from each other, or not, for the theory remains precisely the same. The only advantage which might be derived from the idea of the original mechanical powers being only two is, that their properties might, in that case, be explained in a much more concise manner. Before we quit the present subject, it will be proper, however, to make the following remark, the object of which is to prevent the establishment of wrong notions in the mind of the reader, with respect to the powers of the above-mentioned engines. Beginners in this branch of natural philosophy frequently imagine, that by means of the mechanical powers, a real increase of power is obtained; whereas, this is not true. For instance, if a man be just able to convey 100 weight from the bottom to the top of his house in one minute's time, no mechanical engine will enable him to convey 300 weight to the same height in the same time; but the engine will enable him to convey the 300 weight in three minutes, which amounts to the same thing as to say, that the man could, without the engine, carry the 300 weight by going three times to the top of the house, and carrying 100 weight at a time, provided the load admitted of its being so divided. Therefore the engine increases the effect of a given force, by lengthening the time of the operation, or (since uniform velocity is proportional to the time) by increasing the velocity of that force or power. Thus again, if any active force is able to raise a weight of ten pounds with a given velocity, it will be found impossible, by the use of any instrument, to make the same force raise a weight of

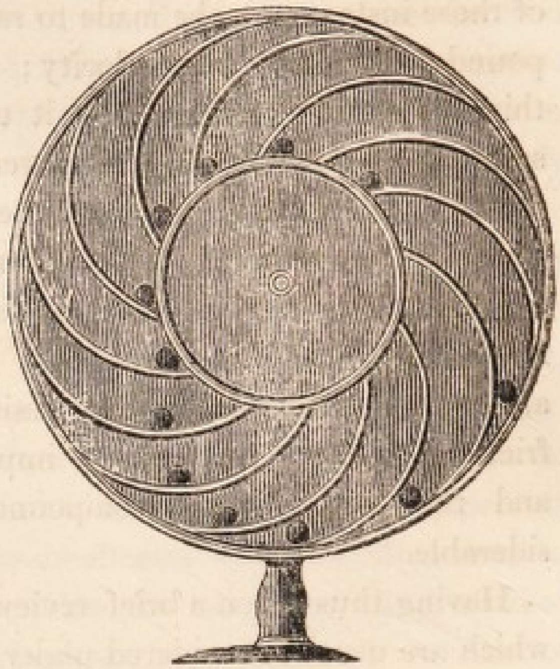
twenty pounds, or, in general, a weight more than ten pounds, with the same velocity; but it may, by the aid of those instruments, be made to raise the weight of twenty pounds with half that velocity; or, which is the same thing, it may be made to raise it to half the height in the same time; for it is not the power or force, but the momentum (viz. the product of the force by the velocity) that may be increased or diminished by the use of those engines. The power, or acting force, is so far from being increased by any machine, that a certain part of it is always lost in overcoming the resistance of mediums, the friction, or other unavoidable imperfections of machines: and this loss in some compound engines is very considerable.

Having thus taken a brief review of the simple machines which are usually considered under the general character of mechanical powers, it may now be advisable to examine how far a combination of these powers can tend towards producing a *perpetual motion.* There are few subjects, indeed, that have more engaged the attention of the mechanical world in every age, than the solution of this apparently difficult problem; and their repeated failure has been no bar to renewed attempts.

It may, indeed, be demonstrated that a perpetual motion is *impossible*, at least by the ordinary laws of nature; for to be possible, it is necessary that the *effect* should become alternately the *cause*, and the *cause* the *effect*. It would be necessary, for example, that a weight raised to a certain height by another weight, should in its turn raise the second weight to the height from which it descended—*now this we know to be impossible.*

Amongst the various attempts at a perpetual motion, that of a circular wheel, described by the Marquis of Wor-

cester and Orfyreus, offered at first view the greatest chance of success.*



In this cylindrical wheel, or drum, are formed channels, containing balls of lead which alternately approach and recede from the centre; and it would seem, upon the principle of the lever, that as the weights are always further from the centre on one side than on the other, a continuous rotatory motion must be produced.

But notwithstanding the specious appearance of this reasoning, experience has proved that the machine will

* The Marquis of Worcester's account of a perpetual motion occurs in the fifty-sixth Art. of his "Century of Inventions," and the following extract is copied from the original MS. preserved in the British Museum:—

"To provide and make that all the weights of the descending side of a wheel shall be perpetually further from the centre, than those of the mounting side, and yet equal in number and heft of the one side as the other. A most incredible thing, if not seen, but tried before the late king of happy and glorious memory [Charles I.] in the Tower, by my directions; two extraordinary ambassadors accompanying his Majesty, and the Duke of Richmond, and Duke Hamilton, with most of the court attending him. The wheel was fourteen feet over, and forty weights of fifty pounds a-piece. Sir W. Belford, then lieutenant of the Tower, can justify it, with several others. They all saw that no sooner these great weights passed the diameter

not turn perpetually; and it will be seen, on inspection, that though some of the weights are more distant from the centre than others, yet there is always a proportionably smaller number of them on the side at which they have the greatest power, so that these two circumstances precisely counterbalance each other.

line of the upper side, but they hung a foot further from the centre; nor no sooner passed the diameter line of the lower side, but they hung a foot nearer. Be pleased to judge the consequence." *Harleian MSS.* No. 2428.

STEAM ENGINE.*

Introduction of the Steam Engine.—Hero.—Brancas.—Marquis of Worcester.—Morland.—Captain Savery.—Papin.—Newcomen's atmospheric engine. — Improvements by Watt. — Condenser. — Governor.—Improved piston.—High pressure engine.—Perkins' generator. — Double cylinder apparatus. — Safety-valve.— Locomotive engine.—Steam navigation.—Rotatory engine.—Smoke-consuming furnaces.

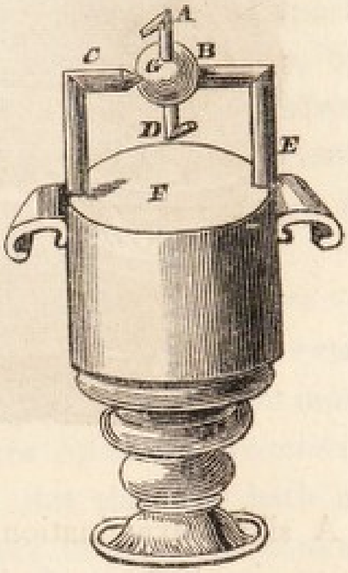
THE merit of first applying steam as a moving power in mechanics is generally attributed to the Marquis of Worcester, who published a curious collection of scientific enigmas in the reign of Charles I.; this, however, is not the fact, as steam was certainly employed as a prime mover more than two thousand years prior to that period.

The first *high pressure steam engine* upon record, appears to have been suggested by *Hero* of *Alexandria*, a

* It may appear at the first view, that the subject we are about to examine had better have found a place in that division of our work exclusively devoted to hydrostatical machines; but the great importance of the steam engine in the arts of life, certainly requires for "*that* potent commander of the elements, *that* abridger of time and space," a more prominent feature, and, indeed, a distinct section confined exclusively to itself. Another reason for adopting this arrangement will be found in the intimate connexion which subsists between the simple mechanical powers, and their combination in this stupendous machine.

disciple of Ctesibius, who flourished about one hundred and twenty years before the Christian era.

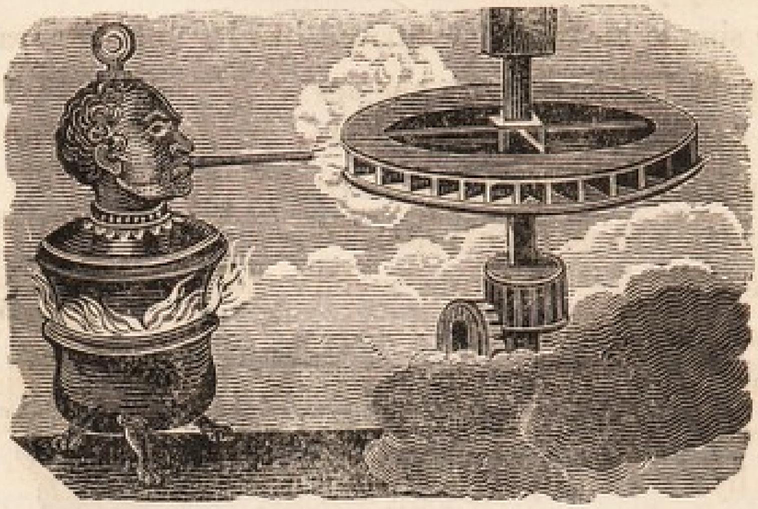
The simple apparatus contrived by Hero may be readily understood by reference to the annexed figure: F represents a cauldron in which steam is generated by the application of a concealed furnace beneath. The tube E and bent arm B is intended to convey the elastic vapour, thus produced, to a revolving ball G, which is connected by a steam-tight joint at B. Two tubes bent to a right angle at A and D, are the only parts open to the air; and as the steam rushes out from these minute apertures, the re-action produces a rotatory motion.*



We come now to the labours of an Italian philosopher, of the name of Brancas, who published a work entitled "Le Machine" in 1629; and this ingenious mechanic appears to have applied steam to useful purposes early in the 17th century.

The apparatus of Brancas consisted of little more than a hollow copper vessel, containing water for the production of steam. This was furnished with a small tube, similar to the spout of a tea-kettle, through which the steam was propelled with a considerable degree of force, and striking against the vanes of a float-wheel produced a rotatory motion. The principal axis being connected with a pounding-mill by a train of wheels and pinions.

* An account of this curious philosophical toy is preserved in *Hero's Spiritalia*, published by the Jesuits in 1693.



A slight examination of the principle upon which the above simple apparatus is constructed, will shew that no very considerable force could have been obtained; as the steam, passing through the atmosphere in its passage to the wheel, must, to a certain extent at least, be converted into water.

After the publication of this scheme, which it is probable was never put in practice with any very useful effect, nearly thirty years elapsed ere the further consideration of this important subject was resumed by the Marquis of Worcester.

The mode of employing steam recommended by the Marquis, and which he describes in his "Century of Inventions" to have been completely carried into effect, was entirely different from that of his predecessors; and it is evident that the noble author had received no previous hint of Brancas's invention, as he expressly states, in another part of the above work, that he "desired not to set down any other men's inventions," and if he

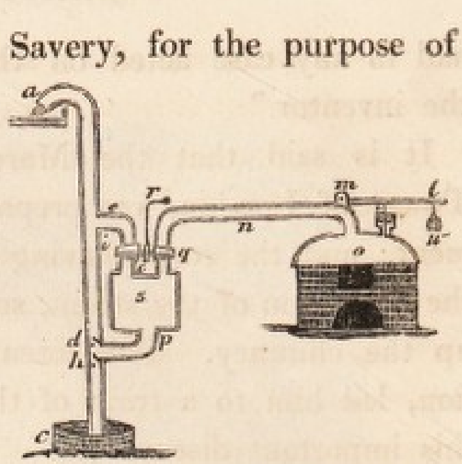
had in any case acted on them, "to nominate likewise the inventor."

It is said that the Marquis, while confined in the Tower of London, was preparing some food in his apartment; and the cover having been closely fitted, was, by the expansion of the steam, suddenly forced off, and driven up the chimney. This circumstance attracting his attention, led him to a train of thought, which terminated in this important discovery.*

The Marquis s account of his invention is as follows:—"An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards, for that must be as the philosopher calleth it, *Infra Sphæram activitatis*, which is but at such a distance. But this way hath no bounder; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken end, as also the touch-hole, and, making a constant fire under it, within twenty-four hours it burst and made a great crack; so that, having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain-stream forty feet high; one vessel of water rarefied by fire driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and re-fill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

* Vide Historical and Descriptive Account of the Steam Engine, by C. F. Partington, p. 6.

The engine suggested by Savery, for the purpose of raising water, consisted of a boiler *o*, furnished with a safety-valve *m*. The steam vessel *s* was connected with the well *c* by a suction-pipe *h*; and when water was to be raised, the vessel *s* was filled with steam, which,

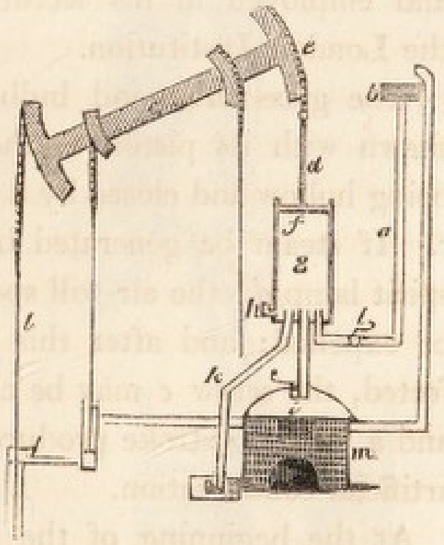


rushing in, soon expelled the air. When that was completely effected, the communication with the boiler was closed, and the steam condensed, which, diminishing its bulk, formed a vacuous space within the vessel; the pressure of the atmosphere then operating upon the surface of the water at *c*, drove it up the pipe. In this form of the apparatus, the inventor was seldom able to raise water more than thirty feet; and when a greater altitude was required, it was effected by the impellent force of the steam. This was accomplished by the ascending pipe *a d*, which was sometimes carried sixty feet higher than the steam vessel *s*; and a reference to the principle by which it was effected will shew that this operation must be sometimes attended with considerable danger. After condensing the steam, and filling the vessel *s* with water, a new supply of steam was then introduced, which, pressing on the surface of the water, drove it up the pipe *d*; and it will be evident that the pressure on the internal surface of the boiler must be proportioned to the height of the column of water thus raised by the steam.

The principal objection to this form of the engine arises from the great consumption of fuel,—a considerable portion of the caloric employed in the generation of the steam being absorbed in heating the new surface of cold water

last raised from the well; and where great heights are required, there appears no mode of completely obviating this objection. Should it, however, be required merely to raise water about thirty feet, there are few contrivances more economical, or better adapted for general use. While speaking of Savery's apparatus, it may be advisable to notice the very ingenious adoption of the same principle to the construction of a *gas engine* by Mr. Brown. In the latter case a vacuum is formed by the introduction of an inflamed jet of carburetted hydrogen gas, which consumes the oxygen, and rarefies the nitrogen by the increase of temperature which ensues. The vacuum thus produced is much more perfect than would at first view have been supposed, from the nature of the process resorted to by the patentee; but the economy of employing hydrogen gas, as a substitute for condensable vapour, is still somewhat problematic.

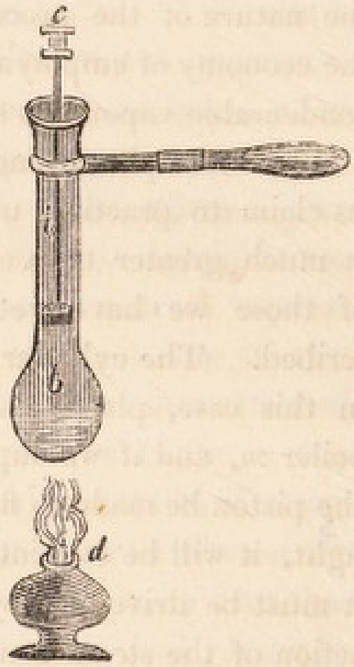
The atmospheric engine will come next in order, and its claim to practical utility is much greater than either of those we have yet described. The cylinder *g* is, in this case, placed over a boiler *m*, and if we suppose the piston be made to fit airtight, it will be evident that it must be driven up by the action of the steam beneath, should a sufficient supply of heat be applied: when this



is effected, the condensable vapour may be reduced to its original bulk by the introduction of water from the cistern *b*. In the working engine, however, the ascent of the piston is effected by the action of the lever *c e* acting on the ful-

crum *c;* while to the end *e* of the same lever or working-beam is attached the pump rod *l,* and it will be apparent that whenever that preponderates over the piston *f*, the latter must be drawn up. On the readmission of the steam, a new supply of condensing water is introduced by turning the cock *l,* and the pressure of the atmosphere above the piston being unbalanced by any resistance beneath, the end *e* is again depressed, and the pump rod again elevated. The pipe *k* is employed to carry off the condensing water which would otherwise accumulate within the cylinder; and the small forcing-pump, with its rod, supplies the condensing cistern *b* by a bent pipe.

A very simple and, at the same time, ingenious mode of illustrating the operations of an atmospheric steam engine, will be found in the annexed apparatus, suggested by Professor Brande, and employed in his lectures at the London Institution.



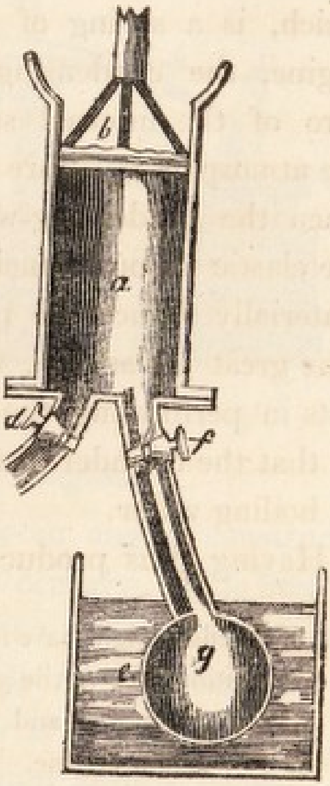
The glass tube and bulb *b* is shewn with its piston *i*; the rod being hollow and closed by a screw *c*. If steam be generated by the spirit lamp *d,* the air will speedily be expelled; and after this is effected, the screw *c* may be closed, and a working stroke produced by artificial condensation.

At the beginning of the last century, the atmospheric engine had made considerable progress in the mining districts; and in 1718, the patentees agreed to erect an engine for the owners of a colliery in the county of Durham, where several hundred horses had previously been employed. Mr. Henry Beighton, who was engaged as an agent in this

concern, materially improved the engine by making it self-acting, and divesting it of nearly all the complicated machinery which had been previously employed for that purpose.

We come now to a new and distinct era in the history of this important invention; and in noticing the labours of Mr. Watt,* we may almost speak of his engine as the gigantic offspring of a hand giving birth to an automaton no less powerful than that of the fabled enchanters of the "olden time."

Mr. Watt's first great improvement in the engine of Newcomen may be best understood by reference to the annexed diagram, in which *a* represents the cylinder, and *b* its plug or piston, made to fit air-tight. The pipe *d* is furnished with a stop-cock, by means of which the elastic vapour is occasionally admitted; a similar pipe, furnished with a stop-cock at *f*, passes from the other side of the cylinder, and enters the vessel *g*; *e* is a reservoir to contain water. If we now suppose the piston at the bottom of the cylinder, and steam admitted by the pipe *d*, its expansive force will elevate the piston, and the whole internal cavity of the tube will be filled with condensable vapour. On closing the steam-



* Dr. Ure, speaking of Mr. Watt, furnishes the following just and eloquent tribute to his memory.

"To the theory of latent heat, which, ike the hydrostatic paradox

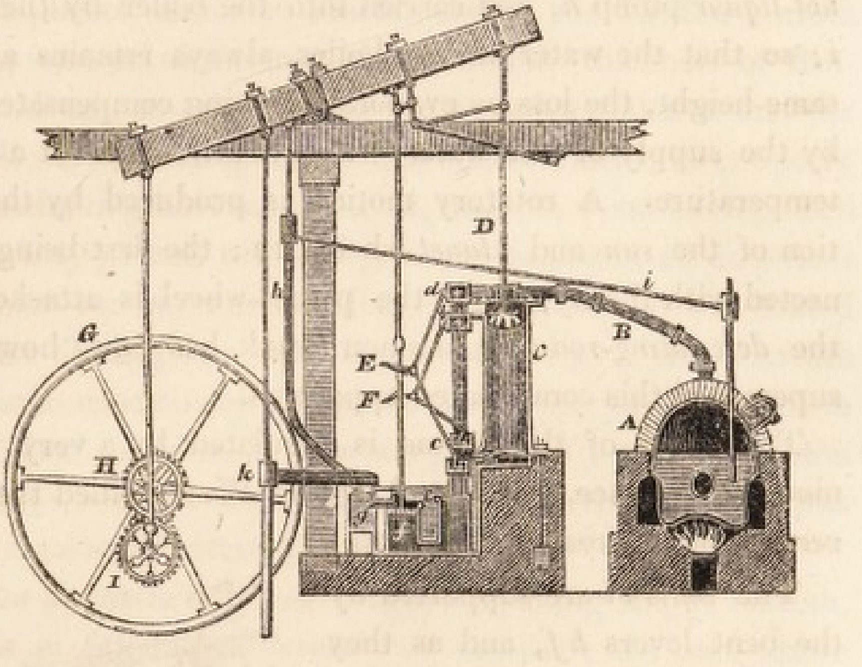
cock, and opening that connected with the vessel *g*, a portion of the vapour will immediately expand itself, and coming in contact with the cold sides of the vessel, a portion of its heat must be absorbed by the water at *e*. A new supply of steam then descends, and is also condensed; and, indeed, the same process continues till the whole of the steam is drawn from the tube. A vacuum being thus formed, the pressure of the atmosphere will preponderate, and the piston-rod be depressed to the bottom of the tube. On closing the stop-cock *f*, a new portion of steam may be admitted by the other pipe, and after raising the piston, the process of condensation may be readily repeated.

The advantages that arise from this mode of forming a vacuum are very considerable, not the least important of which, is a saving of nearly half the fuel. In the old engine, the condensing-water must reduce the temperature of the internal surface of the cylinder to that of the atmosphere, before a vacuum could be produced; and when the condensing-water was applied more sparingly, the elastic vapour remaining in the cylinder was found to materially reduce the pressure of the air operating above. The great advantage, then, of Mr. Watt's apparatus consists in performing the condensation in a separate vessel, so that the cylinder is always preserved at the temperature of boiling water.

Having thus produced a vacuum without the interven-

of Archimedes, might have remained for ages a barren, though a beautiful proposition, the fertile genius of that philosopher gave all at once its noblest application and most beneficial influence on human life, by his new steam engine. After him, many minds of the first order for science and ingenuity have offered schemes for further improvement, but all are either frivolous or abortive; with such prophetic judgment had Mr. Watt anticipated the happiest form and structure of which it was susceptible."

tion of condensing-water beneath the piston, Mr. Watt's next improvement consisted in closing the top of the cylinder, so that the piston-rod worked through an air-tight hole in the centre of the cap; and to ensure the necessary pressure within the cylinder, steam with an elastic force greater than that of the atmosphere was admitted above the piston. The atmospheric engine of Newcomen was thus converted into a steam engine, and its power was easily regulated.

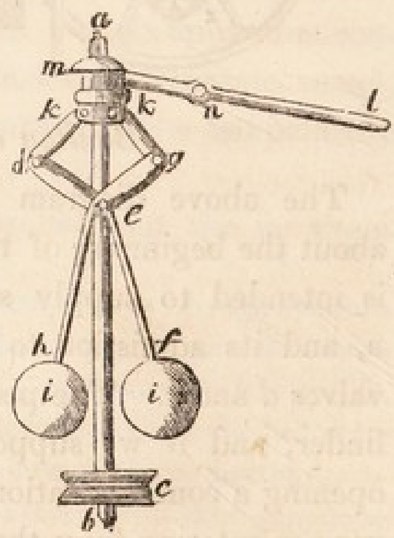


Boulton and Watt's Engine.

The above diagram represents an engine constructed about the beginning of the present century. The boiler A is intended to supply steam by the communicating-pipe B, and its admission to the cylinder is regulated by the valves *d* and *c*. The piston is now at the top of the cylinder, and if we suppose a vacuum formed beneath by opening a communication with the condenser *f*, the elastic vapour entering from the boiler will drive it to the bottom. An alteration in the situation of the valves then takes

place by the descent of a rod attached to the beam which operates on the levers E and F, so that a communication is opened between the condenser and upper side of the piston, while the steam enters beneath. Thus it will be seen, that the reciprocrating motion is regularly produced. The pump *k* supplies the condenser with a sufficient supply of cold water to ensure its being preserved at the temperature of the atmosphere. The condensed steam, after it has attained the form of water, is drawn off by the *hot-liquor* pump *h*, and carried into the boiler by the pipe *i;* so that the water in the boiler always remains at the same height, the loss by evaporation being compensated for by the supply of hot water, which is introduced at a high temperature. A rotatory motion is produced by the action of the *sun* and *planet*-wheel, H I; the first being connected with the fly, while the planet-wheel is attached to the *descending-rod:* a common crank has now, however, superseded this complicated apparatus.

The speed of the engine is regulated by a very ingenious contrivance, introduced by Mr. Watt, called the *governor*, and represented beneath.



The balls *i i* are supported by the bent levers *h f*, and as they are made to revolve with the fly-wheel axis, by means of a band passing round the pulley *c*, any increase in the speed of the engine will cause the balls to diverge. The moment this takes place, the shorter arm of the lever *n* is depressed, and as the extremity *l* is connected with the steam-pipe by the throttle-valve,

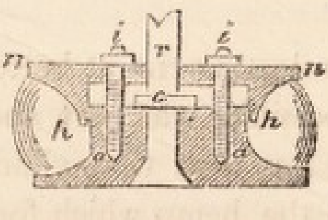
which regulates the supply of steam, the quantity is increased or diminished, as the speed of the engine may require.

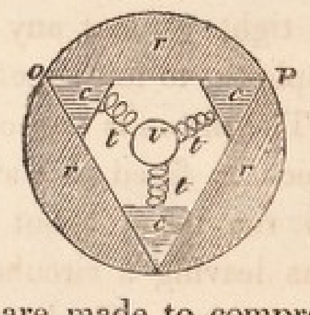
As the working power of the engine depends very materially on the accurate fitting of the piston, it may be advisable to examine some of the principal modes of effecting this important object.

Mr. Smeaton, who greatly improved the atmospheric engine, coated the under side of the piston with elm or beech planks, about two inches thick; the wooden bottom being screwed to the iron with a double thickness of flannel and tar, to exclude the air between the iron and the wood. By the adoption of this improvement, its property of conducting heat was reduced, and the wood having been previously jointed with the grain, radiating in all directions from the centre, was not liable to expand by the heated steam. This piston was kept air-tight by a small stream of water continually falling on its upper surface; but in Mr. Watt's engine, he was compelled to make the piston fit tight without any other *media* than the oil that was employed to lubricate it.

The piston is now cast with a projecting rim at bottom, which is fitted as accurately as possible; the part above the rim being about four inches less than the cylinder, thus leaving a circular groove for the hemp which forms the packing. To keep this in its place, a lid or cover is put over the top of the piston, with a projection which enters into the circular groove for the packing, and pressing upon it; the plate is forced down by screws, which work into the body of the piston. By this means the packing is made to fill the internal part of the cylinder with tolerable accuracy, and thus prevent for a time any steam passing between the piston and the cylinder. When,

however, by continued working, the packing ceases to fit, it occasions a waste of steam, to remedy which, the cylinder-cap must be removed; and as this is accompanied with a considerable degree of trouble to the engine-man, it is seldom attended to, till a considerable loss of power has arisen. There are two improvements on the piston, by which this inconvenience is to a certain extent obviated. In the first, by Mr. Woolf, each of the screws is furnished with a wheel or nut, and these are all connected together by means of a central wheel working loose upon the piston-rod, in such a manner, that if any one of the screws be turned, a similar motion is given to the remainder. In a piston thus constructed, there is little difficulty in drawing down the packing, by applying a key to the square head of the projecting screw employed to communicate with the rest: the key-hole being afterwards closed by a cap. The second contrivance is by Mr. Barton, a diagram of which, accompanied by a piston as it is usually constructed, is shewn beneath.





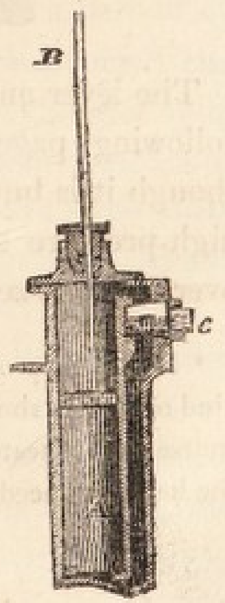
In the first piston the screws *i i*, are made to compress the packing *h h*, by acting on the plate *n n*, the rod *r* being firmly attached by the nut *c*. In one of the modifications of Barton's piston, on the contrary, the packing is dispensed with, as the flexible springs *t t t* press upon the wedges *c c c*, and expand the intermediate plates. A *break-joint* is readily formed, by making the series of plates double; the second set of plates falling upon the spaces which occur between the first row.

The action of the *high-pressure engine*, which may now be examined, depends upon the property of steam to expand itself, and thus acquire a very considerable elastic force by the addition of a given quantity of heat. It may, indeed, be considered as a return to the principle of Brancas and the Marquis of Worcester, as in this engine no condensation is necessary, and it acts merely by the elastic or repellant force of steam.

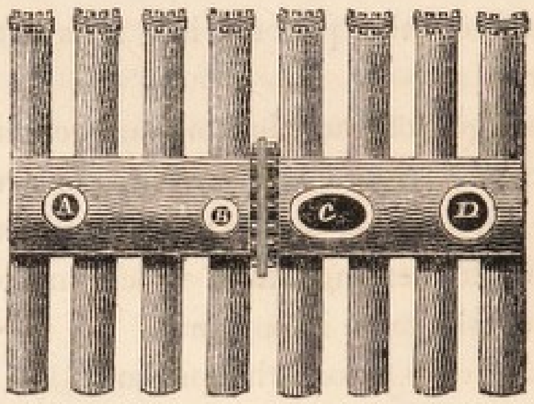
The high-pressure engines, constructed by Messrs. Trevithick, differ but in a very small degree from the engine invented by Mr. Watt. In the high-pressure engine the condenser is taken away, and the steam, instead of being converted into water by artificial cold, in a close vessel, is allowed to escape into the atmosphere from one side of the piston while it is acting forcibly on the other.

The advantages of the high-pressure engine over that used with a condenser are, cheapness in construction, and a saving of the whole expense attendant on procuring a sufficient supply of condensing water, which, in some cases, is an object of considerable importance.

In the annexed section, the piston *B* passes through an air-tight stuffing box; and the steam is entering beneath it by the four-way cock *c*. If we now suppose the piston at the top of the cylinder, a new arrangement of the communicating pipe then takes place; as the steam which was beneath escapes, while a fresh supply enters above, and an alternate upward and downward motion of the piston is thus produced.

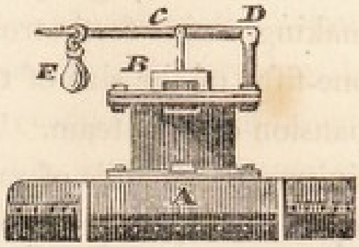


Having thus briefly examined the nature of Mr. Woolf's simplest high-pressure engine, it may now be advisable to revert to the boiler, by which he has proposed to generate steam of sufficient elasticity for the use of the cylinder, which requires elastic vapour of great expansive force. The boiler represented by the diagram beneath, consists of a series of tubes of cast iron, connected by screw-bolts with the under side of a larger vessel A D, communicating with the engine. The upper boiler is furnished with four, and in some cases with five apertures; the first of which is intended for the admission of water, to supply the waste which continually arises from evaporation. The safety-valves, man-hole, and water pipe are also shewn.*

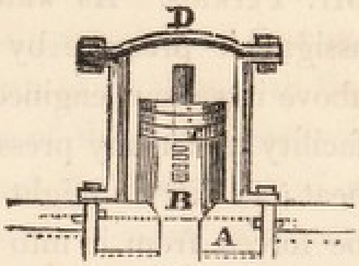


The lever and balance-ball safety valve, B C D E, in the following page, was employed in all the early boilers, though it is but little calculated for those engines in which high-pressure steam is employed, as the engine-man, in an over anxious zeal for the full performance of the machinery

* It may be proper to observe, that a furnace for this, or any other kind of boiler, should always be built so as to give a long and waving course to the heated air, by which means the water absorbs nearly all the heat produced by the fuel.



confided to his care, has been frequently known to increase the internal pressure of the steam in a large boiler, represented at A, many thousand pounds beyond the resistance to which it was originally proved. To prevent a recurrence of those accidents, which first drew the attention of the legislature to this important part of the engine, it appears advisable to inclose the safety-valve in an iron case, of which a section is annexed.



The valve *B* in this case rests upon a conical seat in the boiler beneath, and is furnished with a series of small moveable plates lettered *c*, which are employed to increase or diminish the entire weight of the safety-valve, the whole being covered by the box *D*; and as this is pierced with a number of small holes, the steam readily escapes when the expansive force exceeds the resistance offered by the loaded valve.

In Mr. Woolf's improved engine, high-pressure steam is also employed; but in a cylinder, or rather a pair of cylinders of unequal size. These are so constructed that the steam, after it has performed its office in the first cylinder, is allowed to expand into one of larger dimensions, where it produces a vacuum by condensation;—the steam entering above the small piston, while a vacuum is formed beneath the large one, and *vice versâ*.

The value of this engine may, however, be best understood by an examination of its effective force, when applied to the raising of water. A double cylinder expansion engine was constructed for Wheal Vor mine in 1815, fur-

nished with a large cylinder of 53 inches in diameter, and making a nine-feet stroke; the small cylinder being about one-fifth of the size of that which was employed for the expansion of the steam. The engine was constructed to work six pumps, capable of raising at each stroke a load of water, equal to 37,982 pounds, seven feet and a half high; and so perfect was its action, that a bushel of coals raised 46 millions of pounds one foot high.

It may now be advisable to notice, though of course but briefly, the experimental high-pressure engine contrived by Mr. Perkins. As water can be subjected to almost any assignable pressure by a forcing-pump, it occurred to the above ingenious engineer, that it might also be heated with facility under any pressure produced by the application of heat; so that it might be heated in one vessel, and then be forced from it into another, in which it might expand into vapour, and thus be made available to every purpose for which steam is applied at present. His contrivance for doing this was exceedingly ingenious; and, in 1823, after he had obtained a patent, he exhibited to the public a large working model of his invention.

This experimental apparatus had a boiler made of copper, about three inches thick, and of a capacity to hold about eight gallons of water. It was closed at the lower end, and at the upper end it had five small perforations, in which were inserted as many pipes. This cylinder was placed vertically in a furnace, in which the fuel was kept in vivid combustion, by forcing a stream of air through it by bellows. Two of the small pipes had valves placed in them, loaded with a weight equal to thirty-five times that of the atmosphere, and the other loaded to thirty-seven atmospheres; the boiler was quite filled with water, and was heated to between 300 and 400 degrees of Fahrenheit.

When it had acquired this temperature, which was ascertained by means of a common gauge placed on the boiler, a small quantity of water was forced through the pipe, in which was the valve loaded to thirty-seven atmospheres: and as water is nearly incompressible, an equal quantity was forced (by the difference of the pressures) through the small pipe, in which was placed the valve loaded with a weight equal to thirty-five atmospheres. This valve being raised, the water, heated to between 300 and 400 degrees, was admitted into a horizontal chamber, and expanded into steam of great elasticity. In this horizontal chamber, or cylinder, Mr. Perkins placed a piston, and having opened a communication between both of its sides with the boiler and condenser, the expansion of the hot water into steam on one side of the piston, and the formation of a vacuum on the other, alternately gave a reciprocating motion. The steam was condensed under a pressure of five atmospheres, and Mr. Perkins estimated the power of his apparatus at the difference between five and thirty-five atmospheres, or 430 pounds on each square-inch of the piston.

Part of the water which was condensed at a temperature of 350 degrees, was pumped back into the boiler, as in common engines, and thus saved so much of the heat which would otherwise have been wasted.

The safety of this apparatus is insured by the usual contrivances of a steel-yard valve, loaded with that weight which the boiler has been proved to be able to sustain without danger of bursting. The experimental boiler, Mr. Perkins considered to be equal to resist an internal pressure of four thousand pounds on the inch, being eight times greater than any strain the safety-valves would admit its being subjected to. As an additional security, he also revived the mode of making a safety-valve, by connecting

with the boiler a pipe of metal, of that strength which would resist a pressure of a certain intensity, and burst when that force exceeded its proper limit; and he tried the efficacy of this scheme, by increasing the pressure of the water, until the pipe really gave way.

We have stated that Mr. Perkins's boiler contained eight gallons, and that it was three inches thick; his cylinder was two inches in diameter and eighteen inches long, and the piston made a stroke of twelve inches: this was estimated as equal in effect to a Watt engine of ten-horse power, with an expense of only two bushels of coals per diem. The machine and appendages stood in an area of forty-eight feet; and, with the exception of the cylinder and its piston, the apparatus was considered in strength and dimension as sufficient for an engine of three times the power.

We have now to notice the application of steam engines to the *propelling* of *carriages* on the public road, which has hitherto been considered as a refinement in mechanics, rather to be wished for, than a matter of reasonable expectation. The *locomotive* engine was first employed for this purpose by Messrs. Trevithick and Vivian, in 1802; and it found a ready introduction to the mining districts where rail roads are general. In some cases, five, six, and even ten waggons, laden with coal, are dragged up an inclined plane by means of these vehicles; and of course impelled by a high-pressure engine, from the utter impossibility of carrying condensing water in a moveable vehicle.

An engine of four horses' power, employed by Mr. Blenkinsop, impelled a carriage lightly loaded on a rail road at the rate of ten miles an hour, and when connected with thirty coal waggons, each weighing more than three tons, its average rate was about one third of that pace.

When the locomotive engine was first tried, it was found difficult to produce a sufficient degree of re-action between the wheels and the rail road: so that the wheels turned round without propelling the vehicle. This inconvenience was, however, obviated by Mr. Blenkinsop, who, when he adopted the locomotive engine, took up the common rails on one side of the whole length of the road, and replaced them by a series of racks, or rails, furnished with large teeth. The impelling wheel of the engine was made to act in these teeth, so that it continued to work in a rack which insured a sufficient degree of re-action.

From the great weight of an ordinary *locomotive engine*, as well as the construction of its wheels, it must be evident that the employment of this species of prime mover on the public roads would be in the highest degree destructive; and as such, that its use will still be partially confined to the mining districts, in which the greatest facilities are already offered for its general adoption. Indeed, we find in one neighbourhood alone, and within a space of less than thirty square miles, more than eight miles of road admirably adapted for this species of conveyance; and it is a well-known fact that there are many situations in which iron rail-roads might be advantageously employed, in which it would be quite impossible to open a navigable canal. In illustration of the above fact, it may be proper to state, that a company, with a large capital, is now forming for the express purpose of facilitating the conveyance of goods by locomotive engines.

The great mass of inert matter contained in the working beam of the reciprocating engine, must of necessity produce a proportionate waste of power; each elevation of the piston causing a change from a state of rest to motion, or *vice versâ*. This inconvenience is also much enhanced

by the necessity of employing a fly-wheel of considerable weight to equalize its motion. To prevent this loss of power, a variety of contrivances have been suggested, for the purpose of producing a continuous action without the intervention of a cylinder and piston, thus dispensing with the beam and fly-wheel.

To produce a continuous rotatory motion is, however, little more than a return to the simple principles on which the earliest engines were constructed, as it has already been seen, that the Italian philosopher Brancas directed steam of considerable repellent force against the vanes of a wheel, which he applied to the working of a stamping mill.

Somewhat of the same species of machine was also attempted by Kempel, who is said to have constructed a working model to illustrate its operation.

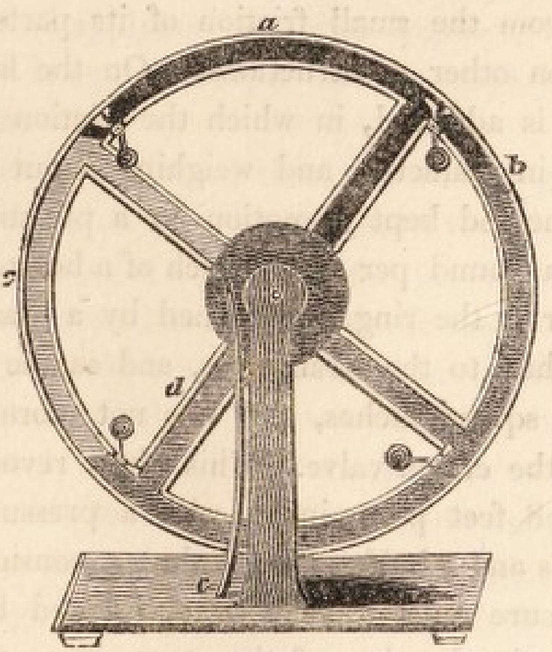
Kempel's machine consisted of a hollow cylinder, or tube, furnished with two arms, at the end of which were transverse apertures. This was connected with the boiler by means of a moveable socket, and the steam rushing from the apertures produced a rotatory motion, exactly in the same way as a rotatory motion is produced in the common rocket wheel.

The same thing was also attempted by Mr. Sadler, who, several years after the period of Kempel's invention, took out a patent for a similar machine.

The patent *revolving wheel*, invented by Mr. Masterman, appears at first view to promise the best results of any rotatory engine yet invented, the friction being much less than in any other apparatus in which steam is employed as a prime mover. In this engine Mr. Masterman proposes to employ water, or the fluid metal mercury, as the immediate agent, which he effects by enclosing it in the tubular rim of a large wheel, furnished with valves open-

ing in one direction. This wheel is made to revolve on a hollow axis connected with the steam boiler. The arms or spokes which radiate from the axis are also hollow; and on the admission of steam from the boiler, it is conducted through the arm immediately opposite, and entering the rim of the wheel, comes in contact with, and presses against the column of water beneath and the closed valve above the arm. The water being previously heated to the boiling point, no condensation ensues; but the whole weight of water, which was previously balanced in two columns of equal height, is driven by the pressure of the steam to the side opposite to that at which the elastic vapour entered, and that side of the wheel will necessarily preponderate. If this process be repeated, the steam being allowed to blow through each radiating arm in succession, a continuous rotatory motion will be produced. Should it be advisable to employ steam of less elasticity, a condenser may be added, and that, too, without materially increasing the expense.

MASTERMAN'S ENGINE.



From the above diagram it will be seen that the moving power is derived from the gravity of the water; but although the column of fluid (when the condenser is used) cannot exceed in height a column equal to the atmospheric pressure, its horizontal section may be made of any dimensions. In practice, however, it is recommended by the inventor not to work it with a less pressure than about twenty-eight feet. It is obvious that this wheel may be worked by high-pressure steam, by merely allowing the pipe which leads from the fixed perforation to open into the atmosphere, instead of opening into the condenser, and the wheel may then be made of any diameter; and it is estimated that it might be worked in this manner, with about half the pressure of steam required for a reciprocating engine.

Mr. Masterman states (from experiment), that his wheel is a great deal cheaper than a common condensing lever engine, will cost less to work and keep in repair, occupies a smaller space, possesses a greater facility and certainty of being put in motion, besides realising a great saving of power from the small friction of its parts, compared with that on other constructions. On the last point an experiment is adduced, in which the friction of a wheel, fifteen feet in diameter, and weighing about three tuns, was overcome and kept in motion by a pressure of three-eighths of a pound per square inch of a horizontal section of the water in the ring, ascertained by a glass mercury-gauge attached to the steam-pipe, and as the valves were about 78 6 square inches, this was not more than thirty pounds on the closed valve. This wheel revolved with a speed of 688 feet per minute, with a pressure of about three pounds and a half per inch; but a considerable part of this pressure must have been occasioned by the confinement or wire-drawing of the steam in passing through

the radii: the most economical speed, however, is about 400 feet per minute.

If we suppose the diameter of the wheel to be about twenty-eight feet, the depth of the rim twelve inches, with the radiating-pipe, or arms, three and one-eighth inches, the whole turning on an axis of six inches in diameter, with a column of water equal to ten pounds on the inch, and using a condenser, this will be a twelve-horse power engine; and with a column of water equal to ten pounds acting against the atmosphere, it will be equal to a power of thirteen horses; but the expenditure of fuel will be greater in proportion to the effect, in the ratio of about 150 to 94. In comparing the effect of a reciprocating engine, working with a pressure of seventeen pounds per square inch, or leaving only an available power of seven pounds, Mr. Masterman obtains an available power of eight and one-sixth pounds weight of a pressure of thirteen and a half pounds; so that the effect from the same quantity of coal will be about 150 for the rotatory engine, and 95 for the common condensing engine.

The mode of applying the steam engine to the purposes of navigation is equally simple with its employment in our manufactures.

It is generally supposed that the *steam boat* is of very recent invention; on the contrary, however, the possibility of employing steam as a prime mover in the propelling of vessels, was suggested as far back as the reign of Charles I.

In one of the old tracts preserved in the library of the London Institution, there is a very curious representation of a steam boat, constructed by an engineer of the name of Hulls; and this individual, now so little known, was undoubtedly the first who applied a steam engine to the purposes of navigation.

To impel a vessel by this means, two paddle-wheels

like those used in an undershot water-wheel, are connected by means of a long axis and crank, with the working beam of the steam engine, and if this motion is not found sufficiently rapid, a wheel and pinion is added, which, although it decreases the effective power of the engine, yet increases the velocity of the paddle wheels.*

The vast vomitories of smoke which take their rise from the various steam engines in the metropolis, and which disfigure our walls, while they destroy the health of its inhabitants, is a subject of too great importance to be passed entirely unnoticed.

The first attempt at consuming smoke appears to have been made by a French engineer of the name of Dalesme, who exhibited a contrivance of this description at the fair of St. Germain's, in 1685, and an engraving has been preserved in the Transactions of the Royal Society.†

In 1785, Mr. Watt obtained a patent for the construction of an economical furnace, which not only consumed the smoke, but is said to have effected a considerable

* The first appearance of a steam boat on the great river Hudson, appears to have excited the most lively emotions of fear and dismay, and has been thus described by the biographer of Fulton:—

"The first steam boats (he observes) used dry pine wood for fuel, which invariably sends forth a column of ignited vapour and sparks, many feet above the flue. This uncommon light first attracted the attention of the crews of other vessels. Notwithstanding the wind and tide were adverse to its approach, they saw with astonishment that the vessel was rapidly coming towards them ; and when it came so near that the noise of the machinery and paddles was heard, the crews shrunk beneath their decks from the terrific sight, and left their vessels to go on shore ; while others prostrated themselves, and besought Providence to protect them from the approaches of the horrible monster, which was marching on the tides, and lighting its path by the fires which it vomited.

† Vide Vol. XVI. page 78.

saving in the consumption of fuel. Mr. Watt proposed to accomplish these very desirable objects by stopping up every avenue to the chimney, except such as might be left in the interstices of the ignited fuel, and the smoke from the fresh coal was consumed by passing through the burning mass or coke.

The principle, however, upon which nearly all the smoke-consuming furnaces have been constructed may very readily be explained by reference to the nature of a common furnace.

Oxygen gas, which forms one of the constituents of atmospheric air, is essential to combustion, and the smoke may fairly be considered as so much good fuel which escapes from the want of a sufficient supply of air to consume it; and as such, any contrivance that will tend to increase the current of air without cooling the boiler must tend to improve the furnace. A grate, whose area is large, and so fed with fuel as to produce a thin brisk fire, appears best adapted for the purpose; and there is little doubt but that a more positive legislative enactment would completely free the public from the nuisance now so justly complained of.

The best mode of calculating the force of the steam engine has not yet been accurately established, though that of a given number of horse-power, adopted by Messieurs Boulton and Watt, appears the most eligible. Prior to the use of steam as an impelling power in our manufacturing districts, this work was performed by the agency of water, wind, or horses; and to render the amount of this new force intelligible, it was found advisable to make the least variable of these powers a general standard of comparison for the rest.

An engine whose cylinder is thirty-one inches in diameter, and which makes seventeen double strokes per minute,

is equivalent to forty horses, working day and night, and burns eleven thousand pounds of Staffordshire coal per day, while it takes a cylinder of twenty-four inches to do half that quantity of work, or the labour of twenty horses.

To illustrate the great advantages possessed by the steam engine, even in its rudest state, over every other species of prime mover yet enumerated, it may now be advisable to examine its effective force when employed in the working of pumps. It has been found that one hundred weight of coals, burned in an engine on the old construction, would raise at least *twenty thousand cubic feet* of water twenty-four feet high; an engine with a twenty-four inch cylinder doing the work of *seventy-four horses.* An engine upon Captain Savery's plan, constructed by Mr. Keir, has been found to raise nearly *three millions* of pounds of water, and Mr. Watt's engine upwards of *thirty millions* of pounds the same height.

To the mining interests this valuable present of science to the arts has been peculiarly acceptable; as a large portion of our now most productive mineral districts must have long ere this been abandoned, had not the steam engine been employed as an active auxiliary in those stupendous works. In draining of fens and marsh lands, this machine is in the highest degree valuable; and, in England particularly, it might be rendered still more generally useful. In practice it has been ascertained that an engine of six-horse power will drain more than eight thousand acres, raising the water six feet in height; whilst the cost of an engine for this species of work, including the pumps, will not exceed seven hundred pounds. This is more than ten windmills could perform, at an annual expenditure of several hundred pounds; while in the former case, the

outgoings will not exceed one hundred and fifty pounds per annum. To the *mariner*, also, the steam engine offers advantages of a no less important and novel nature than those which have already been described. By its use he is enabled to traverse the waters both against wind and tide, with nearly as much certainty, and, as the machinery is now constructed, the traveller may effect this with much less danger, than by the most eligible road conveyance. It too frequently, however, happens that the faults of any new invention are unjustly magnified, while its real advantages are seldom duly appreciated; and this axiom has been fully verified in the clamour so unjustly raised against the application of the steam engine to nautical purposes. Accidents are now, however, but of rare occurrence; and it is more than probable, that the great improvements which have been made in the boiler and safety-valve, will effectually secure those parts of the engine from a recurrence of such tremendous explosions as characterized the first introduction of steam navigation. And, lastly, the political economist must hail with the most heartfelt gratification, the introduction of so able and efficient a substitute for animal labour as the steam engine; for it has been calculated that there are at least ten thousand of these machines at the present time at work in Great Britain; performing a labour more than equal to that of two hundred thousand horses, which, if fed in the ordinary way, would require above one million acres of land for subsistence; and this is capable of supplying the necessaries of life to more than fifteen hundred thousand human beings.*

* An ingenious foreigner, who lately visited England, has published an estimate of the mechanical force set in action by the steam engines of this country.

He supposes that the *great pyramid* of Egypt required for its erec-

tion the labour of more than one hundred thousand men for twenty years: —but if it were required again to raise the stones from the quarries, and place them at their present height, the action of the steam engines of England, which are managed at most by thirty-six thousand men, would be sufficient to produce the same effect in eighteen hours.

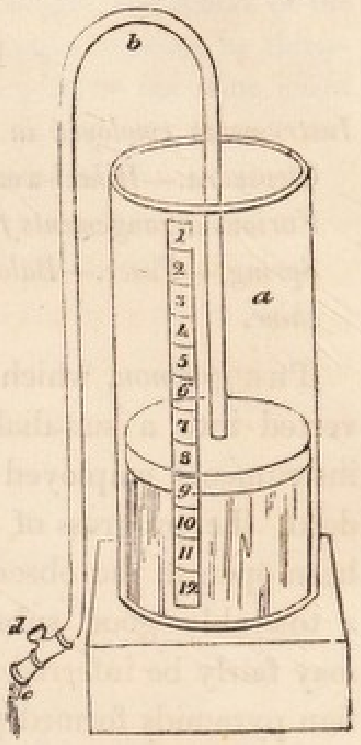
HOROLOGY.

Instruments employed in the Measurement of Time.—Gnomon.—Clepsydra.—Wheel-work.—Clock.—Escapement.—Pendulum.—Various arrangements for Compensation.—Pocket Watch.—Main Spring.—Fusee.—Balance.—Repeating Watch.—Musical Machine.

THE *gnomon*, which subsequent improvements have converted into a sun-dial, was probably one of the earliest instruments employed in the measurement of time. Indeed, the progress of a tree's shadow, which must have been open to the observation of all, might have served as a tolerably good substitute for that instrument; and it may fairly be inferred that the vast altitude of the Egyptian pyramids formed part of a design for representing the wide dominion of the living monarch, by the shadow thrown from his mausoleum when dead. However useful the ancient gnomon might have been as a coarse measure of time, it could have been of but little use in those climates whose atmosphere did not admit of frequent observation. Accordingly, we find that the *clepsydra*, or water-clock, was employed at a very early period: the principle on which it was constructed will be fully examined under that branch of our subject which relates to hydrostatic pressure; and we shall in the present case merely advert to one form of the clepsydra, which unites, in a very eminent degree, simplicity of construction with accuracy in performance.

If a hole be pierced in a tall vessel, the water will flow through the aperture, at a rate varying with the altitude of the column then in operation, so that as the fluid sinks the stream will diminish in an equal ratio. This circum-

stance renders it very difficult to graduate the common clepsydra; but the above inconvenience may readily be obviated by placing a floating syphon *b*, in the vessel *a*, and as the water flows from the aperture *c*, the float continues to descend, so that the twelve figures may in this case be equidistant from each other. The flow of the water is regulated by a stopcock at *d*.



The French annals mention a curious water-clock, sent by Aaron, King of Persia, to Charlemagne, about the year 807, which, it would seem, bore some resemblance to the clocks now in use: it was of brass, and shewed the hours by twelve little balls of the same metal, which at the end of each hour produced sounds from a bell. There were also figures of twelve cavaliers, which at the end of each hour came out through certain apertures, or windows, in the side of the clock, and shut them again.

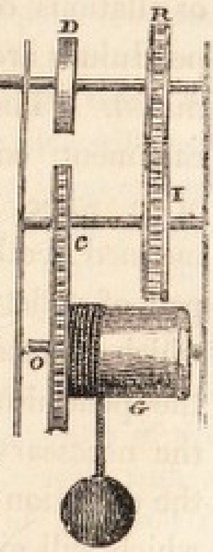
The invention of clocks with wheels is ascribed to Pacificus, archdeacon of Verona, in the ninth century, on the credit of an epitaph, quoted by Ughelli, and borrowed by him from Panvinious. Others attribute the invention to Boethious, about the year 510.

Mr. Derham, however, makes clockwork of a much older date,—placing the sphere of Archimedes, mentioned by Claudian, and that of Posidonius, mentioned by Cicero, among machines of this kind; not that either their form or use was the same with those of the present day, but that they derived their motion from concealed weights or springs, furnished with wheels.

The first clock known in England, was furnished by a fine imposed on Radulphus de Hengham, Chief Justice of the King's Bench, in 1288; and this clock remained in its original situation (New Palace-Yard) as late as the reign of Queen Elizabeth.

In the reign of Richard II. a large astronomical clock was made by Richard of Walingford, Abbot of St. Alban's, and continued to shew the motions of the heavenly bodies in the reign of Henry VII. Large sums appear to have been paid for the horological machines of this period, and few besides kings could afford to purchase them; but they must have been exceedingly well executed, as we find that a watch belonging to Henry VIII. was seen in action by Sir Isaac Newton.

At the latter end of the reign of Elizabeth, *watches* had come into general use, and Shakspeare describes them as worn by the servants of that period; they were also much reduced in size, and might truly be called "pocket watches." *



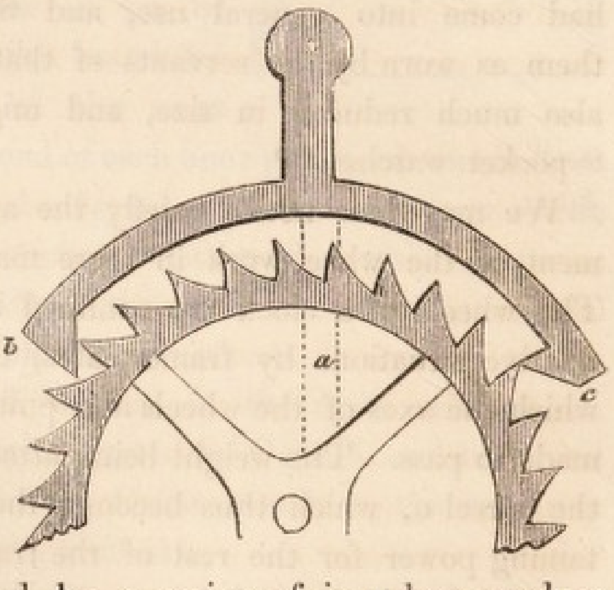
We may now notice briefly the arrangement of the wheel-work in these machines. The wheels of a clock are confined in their relative situations by frame-plates, through which the axes of the wheels and pinions are made to pass. The weight being attached to the barrel G, which thus becomes the maintaining power for the rest of the train. If the time-piece is intended to go for one week, the barrel is cut into a worm of sixteen turns, which allows two revolutions per day, with an overplus of a similar number of turns, in the event of any irregularity in the winding. The

* "I frown the while, and perchance *wind up my watch*, or play with some rich jewel."—*Malvolio*, in "Twelfth Night."

necessity for employing a train of wheels and pinions will now become apparent, as the last wheel in the series must make at least one revolution per minute, to allow of the division into seconds; and as such, the wheels and pinions are essential to prevent the too rapid descent of the weight, which would otherwise unwind the whole of the chord in a few minutes.

In some cases, clocks are made to go for a much longer period of time. One at Hampton Court, constructed under the direction of his late Majesty, was so contrived that the operation of winding was only performed once in each succeeding year. To effect this desideratum, it is merely necessary to encrease the number of wheels and pinions, taking care that the maintaining power is encreased in an equal ratio.

It may now be advisable to examine the mechanism by which the oscillations of the pendulum are produced. The escapement consists of a wheel with inclined teeth, and pair of pallets, *b c*, which operate upon



the pendulum A, and by a series of impulses produce the necessary number of vibrations. The wheel turns in the direction *c b*, and a tooth has just fallen on the pallet *b*, which will give an impetus to the pendulum in that direction. When the tooth is liberated, the opposite pallet *c* receives a similar impulse, and the pendulum is driven to-

wards the other side. The axis which supports the pallets, is called the pallets' arbor.*

Plate 1, fig. 1, represents the interior of a striking clock: *a a* being the pillar plate, in which is rivetted the five connecting pillars, *b b b b*. There are two barrels with main-springs, *c* and *d*, of which *c* is for the going part, and is closed with its cap; but *d*, which is the barrel for the striking part, is left open, to shew the coils of the main-spring contained in it. There are also two fusees, *e* and *f*, attached to their respective great wheels,—*e*, the fusee of the going part, and *f*, that of the striking part: *g* is the centre, or hour-wheel, of 64 teeth, placed partly behind the great wheel of 96, by which its pinion 8 is actuated; hence the fusee revolves in $\frac{96}{8}$ of an hour, or once in twelve hours, so that the 16 spiral grooves, filled by the gut, give motion to the whole machine for just eight days. The second wheel *h*, of 60 teeth, has its pinion

* *The setting a clock into beat* is usually effected by bending the crutch, till the vibrations on each side are equal. To know when this is the case, it is merely necessary to mark the exact point occupied by the lower extremity of the pendulum, when the ball is at rest. If it be then moved till the tooth escape, or, in plainer terms, till the clock is heard to *tick*, its extreme distance at that side will then be known. This must also be marked correctly; and if, on moving it in the opposite direction, it be found to describe a similar portion of a circle, it may then be considered as accurately in beat. If this should not be the case, the crutch must then be bent, or, in more complete machines, an alteration made by screws. It is also an essential condition, that the centre of suspension of the pendulum shall be exactly in the same vertical plane with the centre of the verge; for if the pendulum-spring happen not to coincide with a perpendicular line passing through the pivot-hole of the pallets' arbor, one-half the arc of vibration will be greater than the other, even after the crutch is properly adjusted. An error of this kind must, however, be very obvious, and may be remedied by the eye.

of 8 impelled by the centre-wheel; and in its turn impels the pinion of 8 on the arbor of the third wheel of the train *i*, which is here also the escapement-wheel; the revolutions, therefore, of the arbor of the wheel *i*, are $\frac{64}{8}$ $\frac{60}{8}$ 60, while the hour-wheel revolves once; consequently, this arbor, which revolves in $\frac{1}{60}$ of an hour, is proper for carrying the seconds-hand round in a minute. The escapement-wheel has 60 teeth, and the pendulum vibrates twice in every second; but one tooth does not escape the pallets of the anchor *k*, until two vibrations have been completed; consequently, 60 teeth escape, *i. e.* the escapement-wheel makes one revolution in 120 vibrations, or in the space of one minute: hence the clock before us indicates half-seconds. The square ends of the two fusees are opposite two holes in the clock-face, at each side of the centre of the circles of indication (which are too well known to need description) but a little below it, and the same handle fits both squares. *l* is a jointed lever fixed to the inside of the front plate, called the guard-gut, or simply the guard; the use of which is to prevent the chain, or gut, from doing more than just fill the sixteen grooves of the fusee in winding: *m* is a spring, also attached to the inside of the front plate, which presses the lever *l* towards the middle of the fusee, and keeps it there till the chain, or gut, meeting with it, drives it back again, in the act of winding, so far till the claw *o* is presented to the beak or catch of the end-piece *n*, which then stops the further motion of the fusee, and limits the quantum of chain to be wound up. These pieces, *l* and *m*, constituting the guard, being attached to the front plate, are taken off within when the frame is dismantled; but we have put them into its places in a detached state in our figure, to shew more evidently the nature of their office. *o* is the

arbor of the warning piece, which will be described in its place presently. The wheels *p*, *q*, and *r*, with their respective pinions, constitute the movement of the striking part, and the fly *s* regulates the velocity with which they move. The wheel *p* has eight pins, which lift the cross-piece *t* of the arbor *i* eight times in each revolution of the wheel *p*. These elevations of the piece *t* occasion so many portions of a revolution of the arbor *i*, which arbor has its pivot projecting to *v*, behind the frame, and carrying on its squared projection the hammer *v*, fig. 2; the hammer is consequently raised every time a pin of the wheel *p* moves the piece *t*. *w* is a long and strong spring, called the hammer-tail-spring, attached to the back plate of the frame, and pressing with its upper extremity under the cross-pin, passing through a hole in the arbor *i*, near the face of the back plate; so that when the hammer is raised at any time, the spring *w* urges it back again with a smart blow, and makes it strike the blow behind the frame, which is concealed from view in our figure; but, lest the blow should be too strong, a counter-spring, *u*, is fixed to the contiguous pillar, which breaks the violence of the blow, and makes the hammer return smartly to its place when the blow is made: this spring, *u*, also serves as a guard, in case a stroke of the hammer should be made when the bell is taken off at any time. The fusee *f* is provided with a guard similar to that of the fusee *e*; and the vane of the fly or fanner *s* is kept to the arbor, on which it is placed, by the friction of a spring pressing upon it, so that it may go round either with or without the arbor; the latter of which is the case only after the striking is ceased, till the momentum of the fly has been annihilated by the resistance of the air.

We may now revert to the front of the frame, and begin

our description of the striking and repeating work, with the arbor of the centre-wheel *g*, the end of which is seen within the cannon pinion. The tube of this pinion is put tight on the arbor of the hour-wheel, which we have also named the centre-wheel, and has a spring placed on the hour-wheel arbor, pressing its posterior surface, so as to force it forwards against the cross-pin that keeps the hands on; this action of the spring occasions so much friction, that though the tube is carried round by the hour arbor, yet it is capable of being moved round by its hand, placed on the square end, independently of this arbor, for the purpose of setting the hand to the requisite minutes in the divided circle of 60 spaces, usually figured with the Arabic characters. The cannon pinion, as it is called, has 40 teeth, and impels a similar pinion, *g*, round also in an hour; this pinion, *g*, which is called the pinion of report, has a pinion of 6 on its arbor, and is pivoted in the cock *h*, so that the small pinion of 6 also revolves in an hour; this pinion of 6 again impels the wheel *i*, of 72 teeth, in $\frac{72}{6}$ of an hour, *i. e.* in 12 hours; this 12-hour-wheel has also a tube surrounding the tube of the cannon pinion, but in such a way, that a third tube, attached to the bridge *k*, and seen in a detached state in fig. 3, is interposed between the said two tubes of the cannon pinion and 12-hour-wheel; the use of which third fixed tube is to prevent the friction that would necessarily take place, if the two revolving tubes had been in contact, and had pressed on one another, while their velocities are to each other as 12 to 1. On the exterior tube of the 12-hour-wheel the hour-hand is inserted, which indicates the hour in the circle of Roman figures; and it is obvious that whenever the minute-hand carries the common pinion round, the pinion of report, *g*, also moves the same

quantity, and by means of the small pinion of 6, the wheel *i* at the same time must move $\frac{1}{12}$ of the same space; and consequently, the two hands are so connected, that one cannot move without the other, supposing them both to be fast to their respective tubes; but the hour-hand is put on the round part of the tube, and kept to it by mere friction, and therefore may be put to any hour, without carrying the minute-hand round many revolutions; and yet when once placed right, it preserves its relative velocity as well as though it were more firmly attached to its tube. *I* is the arbor of the seconds-hand, which, we have seen, revolves in a minute, and which measures the 120th part in its divided small circle, on the face of the clock, at so many vibrations of the pendulum, or at so many half seconds. To the 12-hour-wheel, *i*, is screwed fast an indented spiral piece of metal called the snail, the shell of which it resembles in some measure, which snail consequently revolves likewise in 12 hours; the indentations appear to the eye to be irregular as to their relative extents, but each subtends an angle of 30° ($\frac{360}{12}$); so that one indentation, whether near to the centre of motion, or remote from it, is exactly the measure of an hour's motion of the 12-hour-wheel. The steel piece, *m n*, is called a rack, from the teeth, on the cross-piece of which is the rack-tail; this rack is moveable on a pin, or stud, at the lower angular point, near which the horse-shoe-spring presses to keep a pin on the remote end of this tail, against that indentation of the snail which happens to be contiguous to it. This pin is hid from the sight; but the place may be seen, on the extremity of the tail, where it is inserted. Above the rack is a horizontal steel bar, *p q r*, moveable round a stud at *r*, which is called the hawk's bill, from the bill or angular piece

at *q*, that catches the teeth of the rack. The piece *s* is fixed to the protruding pivot of wheel 2, plate 1, near its lower extremity, and, revolving with it, gathers up a tooth of the rack at each revolution, on which account it is called the gathering pallet; the catch of the hawk's bill, having a contrary slope, gives way in the mean time, and comes back again by its gravity. The pinion of the pin-wheel, *p*, which has 64 teeth and eight pins, has eight leaves, and therefore revolves once every time that the hammer of the bell is lifted; but we have said that its gathering pallet takes up a tooth of the rack at each revolution of its arbor; consequently, a tooth of the rack is gathered up at every stroke of the hammer, when the striking part is in motion. The angular piece, *t u v*, moveable round an arbor, denoted by *o* in the same plate, is called the warning-piece; its lower end, *v*, falls in the way of a pin in the small hour-wheel, *y*, and its bent end, *t*, passes through an aperture, *w*, in the front frame, and is presented to the pin in one of the crosses of the wheel *r*, of the striking movement, when in its quiescent situation. The action of the different parts may be thus explained: whenever the hawk's bill, *q*, is lifted from the teeth of the rack, the spring *o*, pressing against a pin near its tail, makes it fall back till it meets with some obstacle to arrest its motion; that obstacle would be the pin, *x*, in the front plate, if there were no other interposed before it had fallen so far back; but if the snail is in any other position than that wherein its nearest indentation towards the centre is contiguous to the pin of the rack-tail, the tail-pin of the rack will fall upon the edge of the snail before the rack has fallen back to the pin *x*, and all the teeth of the rack will not pass the catch of the hawk's bill in this case, but just so many as there

are indentations or steps counted from the remote angular point of the snail, to the step on which the tail-pin rests; in the present position in the plate, the tail-pin is resting on the step 6 of the snail, which denotes that six strokes will be given by the hammer, or that six teeth of the rack are to be gathered up by as many revolutions of the hawk's bill: but we see that only five teeth remain to be gathered up of the rack; hence we know that the clock has struck one out of six, and is in the act of striking; accordingly, we see that the pin in the hour-wheel, *g*, has just raised the warning-piece, and permitted it to go again; the clock will therefore now continue to strike till the upper end of the gathering pallet, *s*, falls on the projecting pin, *m*, of the rack, which will be as soon as the last tooth of the rack is drawn up to the hawk's bill; in which situation the wheel 2 cannot revolve any farther till another hour has elapsed. After another hour is passed, the pin of the wheel, *g*, will elevate the warning-piece, *v*, the bent end, *t*, of which will first be raised out of the way of the pin of the wheel, *r*, and the fly will run on a revolution or two, with a whistling noise, *i. e.* the clock will give warning; but the end, *p*, of the hawk's bill has not yet been raised far enough by the pressure of the end, *t*, of the warning-piece to make the catch, *q*, clear the teeth of the rack; therefore the rack cannot yet fall back. Presently, however, the hawk's bill is lifted high enough by the pin of the pinion of report, *g*, which has a slow motion; the rack falls back till its tail-pin rests on step 7 nearer the centre, which has now arrived at the point of contact, and therefore seven teeth of the rack pass the catch, *q*, in the fall of the rack, and the hour of seven is now struck before the tail of the gathering pallet, *s*, falls again on the pin, *m*, of the rack,

and stops the striking; at the same time the bend of the warning-piece catches the pin of the wheel, *r*, and stops the fly; and in this way any number of hours will be struck by the hammer on the bell that the snail regulates, which, we have said, revolves once in every 12 hours; and if any other cause than the pin of the hour-wheel, *g*, should lift the warning-piece within the hour, counting from warning to warning, the same number of strokes will be repeated, though it should be a hundred times or more. To put in motion this striking mechanism, therefore, it is only necessary to place a lever, *y*, to revolve round a stud on the front plate of the frame at the point *y*, with a slender spring, *z*, over it, to bring it back to its original situation; when the end placed under the warning-piece is elevated, by depressing the exterior end, which may be done by pulling a string down, which is tied to a hole in the end, as represented in the figure; and as often as the string is pulled, so often will the clock repeat the strokes of the current hour. There is yet remaining the three-armed piece, 1 2 3, undescribed, called strike or silent, the use of which is explained by its name. This piece is differently made in different clocks: in the clock before us it is moveable on a socket, rivetted to the end, 3, of one of its arms, round a stud in the front plate of the frame; and as the socket has scarcely any shake, the other two ends, 1 and 2, move always in the same plane; and at the end marked 1, is a pin projecting above the upper circumference of the face or dial of the clock, so that it may be moved to the right or left at pleasure, when the glass-door is opened. The end marked 2 has a slope, like a wedge, on that side which is next to the plane of the frame-plate, and the end of the arbor, *o*, in fig. 1 of the warning-piece, projects so far as to touch

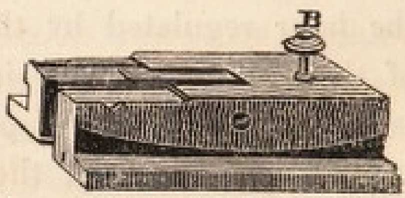
the inclined plane; this arbor of the warning-piece has some shake, in the direction of its length, within the frame, and its posterior pivot passes between the prongs of a forked spring, *x*, which, resting against the shoulder of the pivot, pushes it close to the interior side of the front plate of the frame, where a similar shoulder stops it. When the pin at *i* is pushed to the right, the wedge of the end 2 pushes the arbor back, notwithstanding the forked spring, *x*, just described, at the end, *v*, of the warning-piece, being carried with its arbor nearer to the frame than it otherwise would be, falls in the way of the pin of the hour-wheel, *g*, and the clock consequently strikes the hour regulated by the snail: but when the pin at *i* of the strike, or silent, is pushed to the left, the end 2 is withdrawn from the pivot of the arbor, on which the warning-piece is fast; the spring, *x*, in the frame pushes it forward so far that the end, *v*, of this warning-piece is clear of the pin of the hour-wheel, *g*, which therefore continues to revolve, from hour to hour, in a state completely detached from the mechanism of the striking part, which we have been describing.

Sometimes there is a hand immoveable in a small circle in the dial, which answers the same purpose as the pins *a i*; but this is generally the case when there is no circle for the seconds, or when there is some other circle to which it is intended to correspond, for the sake of uniformity, which is generally attended to in the dial-work of every clock.

The *Pendulum*, although the most simple, is unquestionably the most important part of the mechanism in a common clock. The vibrations of a ponderous body are performed in a shorter or longer time in proportion to the distance of the centre of oscillation from the point of sus-

pension. A pendulum of about 39⅛ inches in length makes 3600 vibrations in an hour, and on this account is called a *second's pendulum.** But a pendulum of a little more than 9 inches makes 7200 vibrations in an hour, or twice as many as the first. So that having thus seen the proportion which they bear with reference to their length and periods of vibration, the length of a pendulum to vibrate in any other given period of time is easily ascertained.

A short flexible spring is usually employed to support the pendulum, but this has been superseded in French clocks by a piece of fine silk. For more delicate purposes, however, and especially when the exact length of the pendulum is required to be known, the support employed by Captain Kater appears most desirable. The pendulum fur-



nished with a *knife-edge suspension* rests on agate planes. It is a fact generally known, that clocks go slower in warm weather than they do in cold. This effect is principally owing to the expansion of the pendulum, which, being lengthened by the effect of an encreased temperature in the summer season, makes a longer vibration, and consequently loses a proportionate quantity of time. While, on the contrary, the pendulum being contracted by cold, the vibrations will be reduced in an equal degree; and

* Captain Kater has ascertained that the length of the pendulum vibrating seconds in vacuo at the level of the sea, measured at the temperature of 62° of *Fahrenheit*, is by Sir G. Shuckburgh's standard 39.13860 inches; General Roy's scale, 39.13717 inches; and Bird's Parliamentary standard, 39.13842 inches: the latitude of the place of observation being 51° 31′ 8″ 4 N. For a full account of Capt. K.'s very ingenious experiments for determining the length of the pendulum vibrating seconds, vide *Phil. Trans.* Vol. 108, p. 33.

although a slight variation in the temperature will not produce much alteration in a single oscillation of the pendulum, yet as the vibrations are often repeated, the effect in a few days becomes considerable;—an alteration of one hundred thousandth part of the time of a single beat, amounting to nearly one second in twenty-four hours.

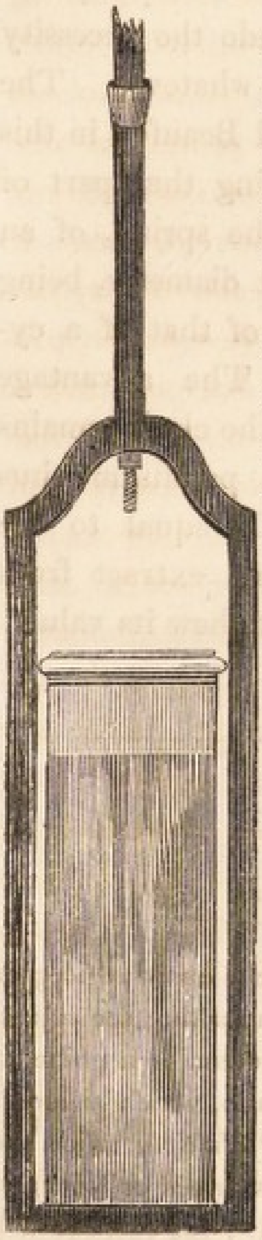
If any substance, sufficiently long for a pendulum, could be found in nature, that has not its dimensions enlarged or diminished by heat or cold, such substance would be the most suitable for a simple attached pendulum; but all attempts to discover such a substance have hitherto been ineffectual. Hence contrivances have been devised, by ingenious men, to counteract the effects of a variable temperature on the pendulum; and some of them have succeeded in effecting this desirable purpose. So long ago as the year 1648, the different expansibilities of various metals were known by Wandelin to exist; and in 1715 that ingenious artist, George Graham, made several experiments with the pyrometer, invented by Musschenbrock, to ascertain the relative rates of expansion in different metals, with the view of availing himself of the difference of the expansions of some two or more metals, when opposed to each other, in the construction of a compensating pendulum; but the difference which he detected, between iron and brass for instance, was so small, that he relinquished all hope of being able to accomplish his object in this way, and therefore gave up the project. (Phil. Trans. London, 1726.) However, it occurred to the same artist, that mercury was affected by changes of heat and cold, sufficiently to answer the purpose of keeping the centre of oscillation of a pendulum always equi-distant from the point of suspension, provided the mercury could be made to ascend, while the verge of the pendulum de-

scended, or was elongated, by any increase of heat, and *vice versâ*. In 1721 the trial was made with a pendulum, which we shall presently describe, and in which the compensation, after some adjustment, was found so complete, that its error in the extremes of temperature was reduced to one-eighth of the quantity observable in an ordinary pendulum.

Another excellent contrivance for the same purpose is described by M. Thiout, a French author on clock-making. It was used in the north of England by an ingenious artist, about fifty years ago. This invention is as follows:—a bar of the same metal with the rod of the pendulum, and of the same dimensions, is placed against the back part of the clock-case; from the top of this, a piece projects, to which the upper part of the pendulum is connected by two fine flexible chains, or silk strings, which, just below, pass between two plates of brass, whose lower edges will always terminate the length of the pendulum at the upper end. These plates are supported on a pedestal fixed to the back of the case. The bar rests upon an immoveable base at the lower part of the case, and is inserted into a groove, by which means it is always retained in the same position. From this construction, it is evident that the extension or contraction of this bar, and of the rod of the pendulum, will be equal, and in contrary directions. For, if we suppose the rod of the pendulum to be expanded any given quantity by heat; then, as the lower end of the bar rests upon a fixed point, the bar will be expanded upwards, and raise the upper end of the pendulum just as much as its length was increased; and hence its length below the plates will be the same as before.

As the space allotted to this part of the subject will not allow even an enumeration of all the contrivances that have been suggested for correcting the effects of heat and cold in

pendulums, it may be enough to state, that the compensation by a moveable column of mercury, introduced by Mr. Graham, appears to offer advantages infinitely superior to any that have succeeded it. That ingenious clockmaker, in the first instance, employed an iron tube, partly filled with the fluid metal mercury, which was raised, by the addition of heat, as much as the tube that contained it was elongated.



The annexed diagram will serve to illustrate the common form of this pendulum; in which an iron frame being connected with a pendulum-rod, by a nut and screw, forms a species of stirrup, in which the mercurial vessel is placed.

The amount of mercury necessary for compensating a bar of a given length, may readily be calculated; but the same end may be effected by attending to the rate of the clock to which it is attached;—for if we find the clock gain by an increase of temperature, the mercurial column must be reduced; but if, on the contrary, it is found to lose, the addition of more mercury will restore the equilibrium, and thus the effective length of the pendulum will be preserved.

The depth to which Hardy's vessel was proposed to be filled, was 6 $\frac{7}{10}$ inches; but on trial, at the Royal Observatory, it was found necessary to add $\frac{1}{10}$th more, and 6 $\frac{8}{10}$ inches are now found to compensate the steel-verge so admirably, that the greatest deviation in the rate, during winter and summer, has never yet ex-

ceeded four tenths of a second *per* day. The escapement that acts with Hardy's pendulum, is of the remontoire sort, acting almost constantly on the pendulum, and therefore requiring to be somewhat longer than an exact standard.

In dismissing the subject of pendulous bodies, employed for the regulation of time in horological machines, it may be proper to observe, that a pendulum of baked wood may be so constructed as almost to preclude the necessity of employing any compensating machinery whatever. The latest improvement introduced by Colonel Beaufoy in this simple apparatus, consists merely in making that part of the pendulum, between the crutch and the spring, of an eliptical form,—the transverse, or longest diameter, being parallel to the back of the clock, instead of that of a cylinder; the shape usually adopted. The advantage which arises from this alteration is, that the clock remains accurately in beat, at all seasons; and a pendulum thus constructed, may be considered as nearly equal to the most perfect compensation form. A short extract from Colonel Beaufoy's table will, however, best shew its value.

*Table containing the rate of a Clock kept at Bushey.**

Date.	Clock fast or slow.		Differences.	Daily rate.
Jan. 3	0′	49.11″	0.37″	0.12
5	0	48.45	0.66	— 0.33
8	0	49.16	0.71	0.24
15	0	48.84	0.32	— 0.05

* When a pendulum of a given length has been observed to gain or lose a certain quantity daily, it is convenient, in making the adjustment for exact time, to have some concise theorem as a guide to bring it to the point desired, at one trial in all cases, which theorem Professor Bridge has given in these words:—"*Multiply* twice the length of the pendulum by the number of seconds gained or lost, and *divide* the result by the number of seconds in a day; the *quotient* will

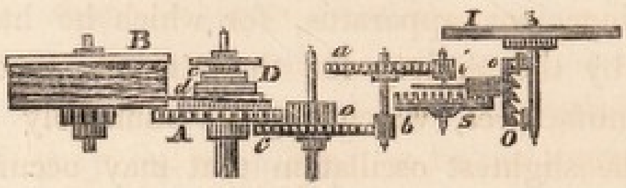
In all pendulum-clocks, but more especially those that are employed for astronomical purposes, the greatest attention should be paid to the stability of the case or frame to which they are attached. The necessity of employing care in this respect, may be best shown by reference to a curious fact furnished by the late Mr. Ellicott. It occurs in the Transactions of the Royal Society; * and he states that a very excellent regulator was repeatedly stopped by the motion of a pendulum attached to another clock in the same apartment. At other times its rate was materially affected, and yet no apparent motion of the clock-case was observable. On this account it is, that the best regulators are usually attached to a firm support, altogether independent of the walls of the building in which they may be placed. Mr. Hardy has suggested a very ingenious apparatus, for which he has been rewarded by the Society for the Encouragement of Arts and Manufactures, which appears admirably adapted to detect the slightest oscillation that may occur. It consists of an inverted pendulum, and may be readily constructed, by supporting a perpendicular wire by a slight steel-spring; a moveable weight being attached to a tube sliding on the wire. Should any vibration occur,

give the number of inches, or parts of an inch, by which the pendulum is to be lengthened or shortened." Suppose the gain of a second's pendulum to be three minutes, or 180″ in a solar day, then $\frac{39.2\ \ 2\ \ 180''}{86400''}=.163$ parts of an inch is the quantity, in this case, by which the pendulum must be *lengthened* to measure mean time; but if the three minutes had been *loss*, with a half-second's pendulum, then $\frac{9.8\ \ 2\ \ 180}{86400}=.041$ of an inch, or the fourth part of the former gain, will be the quantity by which the said pendulum will require to be *shortened*. This rule is not only short in its application, but easy to be remembered.

* Vol. xli. p. 126.

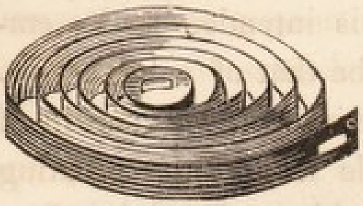
the pendulum is immediately put in motion, and a graduated arc is sometimes attached to the upper part of the frame, which serves to mark the amount of oscillation.

The mechanism of a *pocket watch* differs from the movement of a clock, in having its motions regulated by a revolving wheel or balance, instead of a pendulous body. This ingenious contrivance appears to have been employed at a very early period; but the *pendulum spring*, which renders the motion of the balance nearly isochronal, was not employed till the middle of the seventeenth century, when our countryman, Dr. Hooke, introduced it to the world. The arrangement of the train of wheels and pinions is nearly the same as that of a clock; it may, however, be best understood by reference to a diagram.



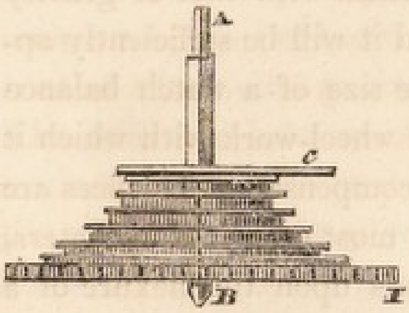
The spring barrel, B, is connected by a chain, *d*, with the fusee, D, the wheel of which works in the centre-pinion, *o*. The centre-wheel, *c*, drives the third wheel, which, in its turn, gives motion to the next pinion in succession. The contrite wheel, S, is furnished with teeth, acting at right angles to the plane of the wheel, the teeth of which acting in the last pinion of the balance-wheel, O, gives motion to the verge and balance, I; and it is the latter very important appendage which regulates the whole. The centre-pinion makes one revolution in an hour, and as this communicates with a second wheel and pinion, the velocity of the hour-hand is reduced to one-twelfth of that which marks the minutes. The frame plates, in which the pivots turn, are purposely omitted, to allow of an unobstructed view of the internal mechanism.

In examining the mechanism of a clock, it has been seen, that a weight is generally employed as the impelling power. But the relative situation of a watch, varying as it does continually by every change of position in the wearer, forbids the employment of this species of prime mover in portable horological machines.



A common watch spring is represented in the annexed diagram, and consists of a piece of flexible steel, which is afterwards coiled up in a cylindrical case, so that the spiral in its attempt to expand itself, gives motion to the train of wheels.*

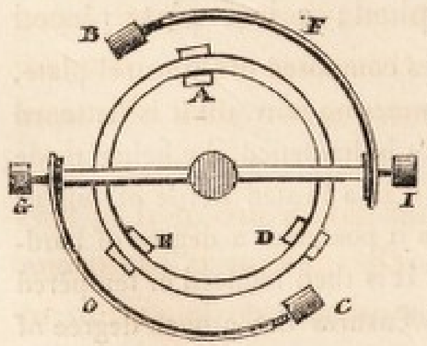
It has already been stated, the immediate agent of communication between the mainspring and wheels is called a *fusee*. This ingenious mechanical contrivance is employed to equalize the force of the spring, which would otherwise act with the greatest degree of energy, when completely coiled round its arbor; and it will be equally evident that the maintaining power would gradually diminish as it unwound, till the train ceased its motion altogether. In the annexed diagram, A B represents the fusee arbor, A being the end at which the watch-key is applied; C is a plate placed



* The spring of a watch is sometimes composed of thin steel plate, and at other times it is formed by hammering wire till it is flattened to the proper thickness. After which it is hardened, by being made red hot, and subsequently immersing it in a heated kettle of oil, or warm mutton suet. After this process it possesses a degree of hardness but little inferior to that of glass. It is then reduced or tempered to a fine violet or blue colour, which ensures the proper degree of elasticity.

above the top of the fusee-cap, and by stopping against a small steel bar, prevents the watch being over-wound. I is the fusee wheel. A ratchet wheel is also placed at the bottom of the fusee, which allows it to turn in one direction, but prevents its flying back when the key is removed. The best form of the fusee can only be ascertained by reference to the watch for which it is intended to be employed, but its general outline will be that of a hyperbola.

We now come to that part of the internal mechanism of a watch, differing most in principle from the regulating pendulum of a larger horological machine. In the earliest constructed watches, a circular wheel, called the *balance*, was pushed forward by the verge and pallets upon which it was made to revolve. This motion was allowed to continue till it was destroyed, partly by friction, and partly by a succeeding impulse in the opposite direction, so that these vibrations must have been irregular, and, as such, the time-piece very imperfect. To remedy this defect, Dr. Hooke employed a spiral spring, connected with the balance, which is in its effects nearly identical with that of gravity in the pendulum of a clock; and it will be sufficiently apparent, that any alteration in the size of a watch balance must affect the regulation of the wheel-work with which it is connected. On this acccount, compensation balances are generally employed in naval and most other chronometers, the most simple of which depends upon the flexure of a



compound metallic ring divided into two portions, F and D; the extremities B and C being furnished with small weights. The outside of the hoops is of brass, and the internal surface of steel. When the cross-bar

is elongated by an increase of temperature, and as such the rims enlarged, the watch would lose time; but the *compensation balance* now begins to operate, as brass expands more than steel, the weights B and C are driven inwards, so that the operative power of the balance remains the same.

Repeating-watches are such as, by pulling a string, &c. repeat the hour, quarter, or minute, at any time of the day or night. This mode of repetition was the invention of Mr. Barlow, and was first put in practice by him, in larger movements or clocks, about the year 1676. The contrivance immediately set the other artists to work, who soon contrived various modes of producing the same effect: but its application to pocket-watches was not known before King James the Second's reign; when the ingenious inventor, above mentioned, having directed Mr. Tompion to make a repeating-watch, was engaged in soliciting a patent for the contrivance. The report of a patent engaged Mr. Quare to resume his previous plans, which he had had in view some years before: he now effected his object; and being pressed to endeavour to prevent Mr. Barlow's patent, a watch of each kind was produced to the King in council; upon trial of which, the preference was given to Mr. Quare's. The difference between them was, that Mr. Barlow's was made to repeat by pushing in two pieces on each side the watch-case,—one of which repeated the hour, and the other the quarter; whereas Quare's was made to repeat by a pin that projected near the pendant; which being thrust in (as it is now done by thrusting in the pendant itself), repeated both the hour and quarter with the same thrust.

Mr. Elliot, of Clerkenwell, has lately invented a very simple repeating-watch, in which the motion is performed with much fewer parts than in the usual construction; by

which means he is enabled materially to reduce the price for a good repeater on this principle.

The method by which this repeater is so much simplified, is by the use of a single part, so contrived as to perform the operations of several; this consists of a flat ring, or centreless-wheel, of nearly the same diameter as the watch, supported in its place, so as to admit of a circular motion, by four grooved pulleys placed round its external circumference, in the same manner as the part in common clocks, which denotes the moon's age. This part is put in motion by turning the pendant, whose extremity is formed into a small vertical wheel, which works in teeth cut on the external part of the flat ring, for almost a third of its circumference. The lower part of the ring contains the pins, at right angles to its face, which lift the hammers for striking the hours and quarters; the internal part of the ring contains indentations of regularly increasing depths, which, receiving the tails of the lever, whose other extremities are pressed by their springs against the hour-snail and the quarter-snail, is by them prevented from moving beyond a certain degree proper for the time. After the pendant is turned, the ring is brought back to its position by a box-spring, round which a fine chain is coiled, whose extremity is connected with the inner part of the ring.

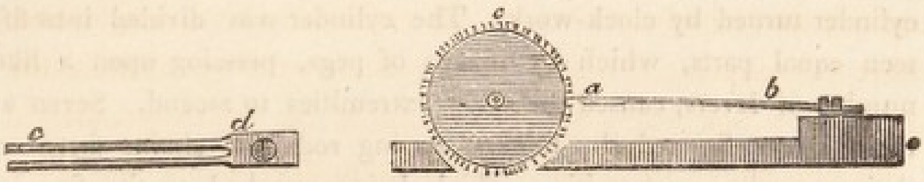
By turning the pendant to the left, the hour is struck, and by turning it to the right, the quarters are repeated; and the returning spring, just mentioned, is made to operate in both directions, by its chain passing between two little pulleys, which on either side convert the direction of the chain to the line of traction. Hence it is evident this single flat ring performs all the following operations.

1. It receives the motion for the striking the hour from

the pendant. 2. The same for striking the quarters. 3. It carries the pins, or teeth, which lift the hour-hammer. 4. The same for the quarter-hammer. 5. It contains the indentations, by which the hour-snail operates on it by its lever. 6. The same, by which the quarter-snail operates on it. 7. It carries the part that recoils the movement which tells the hour, to its first position. 8. It carries the part, for the same purpose, for the quarter movement. 9. It contains a cavity, which moves over a fixed pin, that prevents the pendant from turning it too far.

In this ring, the same parts, in three instances, are made to perform double operations, by which simplicity of construction is advanced apparently to its greatest extent.

A combination of wheel-work is sometimes employed to give motion to musical machines; a familiar instance of which occurs in the musical snuff-box.



a b represents an end-view of the spring, or fork, which produces the musical tone, by the action of the pins projecting from the barrel, E, a plan of the spring being shewn at c. d.

* Automata have been so constructed as to produce nearly all the motions of real life. The most ingenious, at least the most celebrated, of which were made by Vaucauson, at the beginning of the last century. One of them represented a flute-player, who, by the means of a combination of wheel-work, was enabled to execute music of the most difficult nature, the tone being produced by wind issuing from the mouth of the figure, and which entering a German flute, was brought to the proper pitch by the action of the fingers. The second was a standing figure, which in a similar way played on the Provençal Shepherd's pipe, held in its left hand, and with the right beat upon

a drum. The third was a duck of the usual size, which ate and drank, moved its wings, and, indeed, appeared to perform all the functions of animal life. The automaton chess-player, constructed by Maelzel, may also be cited as an instance of mechanical ingenuity which has but few equals.

"Of these automata, or rather *androides*, the flute-player of Vaucauson is the only one of which a correct description has been preserved; a particular account of its mechanism having been published in the Memoirs of the French Academy. The figure was about five feet six inches high, and was placed upon an elevated square pedestal. The air entered the body by three separate pipes, into which it was conveyed by nine pair of bellows, which expanded and contracted in regular succession, by means of an axis of steel turned by the machine. The three tubes, which conveyed the air from the bellows, after passing through the lower extremities of the figure, united at the chest; and ascending from thence to the mouth, passed through two artificial lips. Within the cavity of the mouth was a small moveable tongue, which, by its motion at proper intervals, admitted or intercepted the air in its passage to the flute. The fingers, lips, and tongue, derived their specific movements from a steel cylinder turned by clock-work. The cylinder was divided into fifteen equal parts, which by means of pegs, pressing upon a like number of levers, caused the other extremities to ascend. Seven of these levers directed the fingers, having rods and chains fixed to their ascending extremities; which, being attached to the fingers, made them to ascend in proportion as the other extremity was pressed down by the motion of the cylinders, and *vice versâ*. Three of the levers served to regulate the ingress of the air, being so contrived as to open and shut, by means of valves, the communication between the lips and reservoir, so that more or less strength might be given, and a higher or lower note produced as occasion required.

"The lips were directed by four similar levers; one of which opened them to give the air a freer passage; another contracted them; a third drew them backward, and the fourth pushed them forward. The remaining lever was employed in the direction of the tongue, which by its motion shut or opened the mouth of the flute. The varied and successive motions performed by this ingenious androides, were regulated by a contrivance no less simple than efficacious. The axis of the steel cylinder or barrel was terminated by an endless screw

composed of twelve threads, above which was placed a small arm of copper, with a steel stud made to fit the threads of the worm, which, by its vertical motion, was continually pushed forward. Hence, if a lever were moved, by a peg placed on the cylinder, in any one revolution, it could not be moved by the same peg in the succeeding revolution, in consequence of the lateral motion communicated by the worm. By this means the size of the barrel was considerably reduced; and the statue not only poured forth a varied selection of instrumental harmony, but exhibited all the evolutions of the most graceful performer."—*New edit. of Century of Inventions, by* Charles F. Partington.

WHEEL CARRIAGES.

Nature of Friction.—Rollers.—Sledge.—Carriage.—Point of Traction.—Centre of Gravity.—Roads.—System of Mac Adam.—Rail Roads.

Of the various machines of luxury or utility which are in use amongst civilised nations, none have been more generally adopted than *wheel carriages*, and an examination of the principles on which they may be most advantageously constructed, will serve as an additional illustration of the mechanical powers. In some of the colder parts of Europe and America, where ice is to be met with in considerable quantities, sledges are much in use, as they may be made to pass over the face of a lake or frozen snow, with nearly as much ease as a plate of smooth metal would upon one of glass.

To understand the advantages which a wheel carriage possesses over these primeval machines, it will only be necessary to bear in mind the different degrees of friction which arise from rubbing and rolling motions; and that in the former of these cases, the sliding of a sledge must of necessity generate a degree of friction, which will materially retard the motion of the body; but that when we apply a wheel beneath the rubbing motion is converted into a rolling operation, and the friction is materially reduced.*

* The amount of friction, though not very considerable in a piece of light wood, may yet be rendered sufficiently apparent if it be placed

If for example, we employ a wheel of six inches circumference turning upon an axis of one inch, it will be evident that the friction will be reduced to little more than one *sixth*, as the rolling motion which takes place at the circumference of the wheel will produce a comparatively small amount of friction, the friction being transferred to the axle, and as *this* is only one inch, it can only pass over one-sixth of the space.

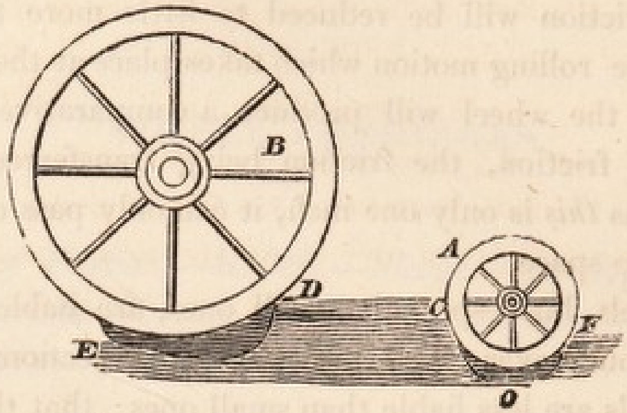
All wheels, but especially small ones, are liable to sink into the ground over which they pass,—an objection to which large wheels are less liable than small ones: that this is the case may be seen in the construction of most four-wheel carriages; the *hind* wheels are made larger than those in front, the fore wheels being smallest in order to enable them to turn in the least possible room. The idea, however, of the larger wheels helping to drive the smaller ones, is a vulgar error, and has not the least foundation in truth.

That the large wheels possess a very considerable me-

upon an inclined plane: at a small angle it will not slide down; should, however, a piece of metal of the same weight be substituted for the wood, it will immediately descend. This then shows, that the smoother the surface the less the friction.

It will thus be seen, that the loss of power from friction may differ very considerably in the same machine, by the employment of different materials, and Mr. Emerson has shewn, that when a cubic piece of soft wood of eight pounds weight moves upon a smooth plane of soft wood, at the rate of three feet per second, its friction is about *one-third* of the weight; but if it be rough, the friction is little less than *half* the weight: on the same supposition, when both the pieces of wood are very smooth, the friction is about *one-fourth* of the weight; the friction of soft wood on hard, or of hard wood upon soft, is *one fifth*; of hard wood upon hard wood, *one eighth*; and of polished steel moving on steel, *one fourth* of the weight. It is also found that dissimilar metals produce the least friction, and of these, brass and steel are the best adapted for practical purposes.

chanical advantage, may be readily illustrated by reference to a diagram.

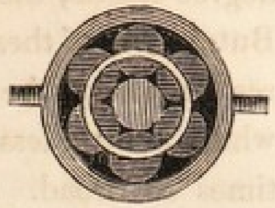


The two hollows E D and C F, are of nearly equal depth, and it is sufficiently evident that the large wheel will not go so far into the ground as the small one: and even if we suppose them to descend equally deep in both cases, the large wheel B, by the power acting so far above the impediment D, may be easily drawn out. This, however, could scarcely be effected in the present situation of the small one by an ordinary horizontal draught; unless, indeed, the ground gave way before it, which would not be the case in a hard road.*

A very ingenious mode of applying friction balls is sometimes resorted to in the wheels of a carriage. A box, as is

* From accurate observations made by Professor Anderson, of Glasgow, it appears that a single horse, on a level turnpike road, draws 25 *cwt.* in a cart which weighs about ten hundred weight, having wheels six feet high, and its axle passing through the centre of gravity of the load in the cart. This, however, and several other very essential particulars, are not usually attended to; and, as carts are usually constructed, they seldom draw more than half that load.

Six horses, in *three common* carts, with *two* horses in each, can draw upon an uneven road 90 *cwt.* that is, 10 cwt. more than they could do in a waggon; the weight, wear and tear, and mode of drawing, being the same in each. These facts will sufficiently demonstrate the advantages that a cart possesses over the four-wheeled carriage or waggon.



shown in the annexed diagram, is provided, and a sufficient number of rollers introduced to allow a free passage for the axis between them. The balls are confined in the box by a ring which retains them in their proper situation; and as the axis is made to revolve, the balls partake of a similar motion.

The greater part of the resistance to the motion of a carriage very frequently arises from the continual displacement of a portion of the materials of the road, which do not re-act on the wheels with perfect elasticity, but undergo a permanent change of form proportional to the loss of force. Hence, in a soft sand, although the axle of the wheels may move in a direction perfectly horizontal, the draught becomes exceedingly heavy. The more the wheel sinks, the greater is the resistance; and if we suppose the degree of elasticity of the materials, and their immediate resistance at different depths, to be known, we may calculate the effect of their re-action in retarding the motion of the carriage. Thus, if the materials were perfectly inelastic, acting only on the preceding half of the immersed portion of the wheel, and their immediate pressure or resistance were simply proportional to the depth, like that of fluids or of elastic substances, the horizontal resistance would be to the weight, nearly as the depth of the part immersed to two-thirds of its length; but if the pressure increased as the square of the depth, which is a more probable supposition, the resistance would be to the weight, as the depth to about four-fifths of the length: the pressure may even vary more rapidly, and we may consider the proportion of the resistance to the weight, as no greater than that of the depth of the part immersed to its length, or of half this length to the diameter of the wheel; and if the materials are in any

degree elastic, the resistance will be lessened accordingly. But on any of these suppositions it may be shown, that the resistance may be reduced to one-half, either by making a wheel a little less than three times as high, or about eight times as broad. This consideration is of peculiar consequence in soft and boggy soils, as well as in sandy countries: thus, in moving timber in a moist situation, it becomes extremely advantageous to employ very high wheels, and they have the additional convenience, that the timber may be suspended from the axles by chains, without the labour of lifting it so high as would be necessary for placing it upon a carriage of any kind.

Theoretically speaking, it is possible that the curvature of the obstacle to be overcome may be intermediate between two wheels of unequal size; and in that case the higher wheel will touch a remoter part of the obstacle, so that the path of the axis will form an abrupt angle, while the smaller wheel follows the curve, and produces a more equable motion. The two following diagrams will, however, best explain the effect of an obstacle on a wheel in both situations.

In the first figure the centre of the wheel A B, passing over the ridge C, describes the path D E; that of the larger wheel F G, the path H I, which is less steep. In the second diagram, the centre of the wheel A B describes the curved path C D, in passing over the obstacle E, while that of the larger wheel F G has an angle at H.

But the magnitude of a wheel must, in practice, be partly determined by the strength or the weight of the materials of which it is made, by the danger of overturning when the centre of gravity is raised too high; and in the case of a four-wheeled carriage, by the inconvenience that would arise in turning a corner, with a wheel that would interfere

with the body of the carriage. It is also of advantage that the draught of a horse should be in a direction somewhat ascending, partly on account of the horse's shoulder, and partly because the principal force that he exerts is in the direction of a line passing through the point of contact of his hind feet with the ground: but a reason equally strong for having the draught in this direction is, that a part of the force may always be advantageously employed in lessening the pressure on the ground; and to answer this purpose most effectually, the inclination of the traces or shafts ought to be the same with that of a road on which the carriage would begin or continue to descend by its own weight only. In order to apply the force in this manner to both pairs of the wheels, where there are four, the line of draught ought to be raised to a point half way between them, or rather to a point immediately under the centre of gravity of the carriage; and such a line would always pass above the axis of the fore-wheels. If the line of draught pass immediately through this axis, the pressure of the hind-wheels will ever be somewhat increased by the draught. It is evident, therefore, that this advantage cannot be obtained if the fore-wheels are very high; we may also understand, in some cases, the common opinion of the elegibility of placing a load over the fore-wheels, rather than the hind-wheels, may have some foundation in truth. When several horses are employed, the draught of all but the last must be nearly horizontal; in this case, the flexure of the chain brings it into a position somewhat more favourable for the action of the horses; but the same cause makes the direction of its attachment to the waggon unfavourable: farther than this there is no absolute loss of force, but it appears advisable to cause the shaft-horse to draw in a direction as much elevated as possible; and on

the whole it is probable, that horses drawing singly have a material advantage, when they do not require additional attendance from drivers.

The practice of making very broad wheels conical, has obviously the effect of producing a degree of friction at each edge of the wheel when the carriage is moving in a straight line; for such a wheel, if it moved alone, would always describe a circle round the vertex of the cone to which it belongs. When the wheels are narrow, a slight inclination of the spokes appears to be of use in keeping them more steady on the axles than if they were vertical; and when, by an inclination of the body of the carriage, a greater proportion of the load is thrown on the lower wheel, its spokes being then in a vertical position, are able to exert all their strength with advantage. The axles being a little conical, in order that they may not become loose, or may easily be tightened as they wear, it is necessary that they should be bent down, so that their lower surfaces may be horizontal, otherwise the wheels would press too much on the linch-pin. For this reason, the distance between the wheels should be a little greater above than below, and their surfaces of course slightly conical.

It has been proposed to fix the wheels to their respective axles, to continue the axles as far as the middle of the carriage only, and to cause them to turn on friction wheels or rollers, as we have already shown at p. 81. This plan may succeed if the apparatus be not too complicated for use; but in fact, the immediate friction on the axles is not great enough to render such a degree of refinement necessary. If both opposite wheels were fixed to a single axis, one of them would be dragged backwards and the other forwards, whenever the motion deviated from a straight line; and a similar effect actually takes place in those carriages which are supported on a single roller.

Mr. Cumming, in his "Essay on Wheel Carriages," states, that he can discover no good quality which the bent axle and conical rim possess; and he accounts for their introduction, by supposing that the first wheel-carriages were made narrow on account of their small burthen and of the narrow roads, and that a track being thus formed, the wheels of larger carriages were made to fit the old track, by throwing them out, or making them wider at the top only,—which inclination of the wheel was effected by bending down the arms of the axle; and that the rim was then made conical, to give it a bearing for its whole width.

Mr. Edgeworth, though a strenuous advocate against the present system, compared a model with conical wheels, of which the inside diameter of the wheels was to the outside as 33 to 27, with a pair of cylindrical wheels, of which the diameter was as 34, and found that when put upon smooth deal boards, the conical wheels required an addition of 50 per cent. to the moving power to make their velocity equal to that of the cylindrical; but that when the experiment was made upon a fine gravel road in summer, the 50 per cent. was reduced to 8; and that upon gravel stones, like a newly made coarse road, there was no perceptible difference between the cones and the cylinders, although the wheels were only eight inches high, and four inches broad; that is, the breadth of the sole or rim was one-half the height, whereas the breadth of the wheels of a six-inch waggon, is only one-tenth of the height of the hind, and one-seventh of the fore wheel. The tire of coaches and light carriages is under two inches in width, and the taper or coning of the rims is so very small, that Mr. E. doubts of the difference being perceptible under any circumstances. The tire of the mail-coaches is only one and a half inch wide, and even in that width it is formed rounding; so that not so much as an inch

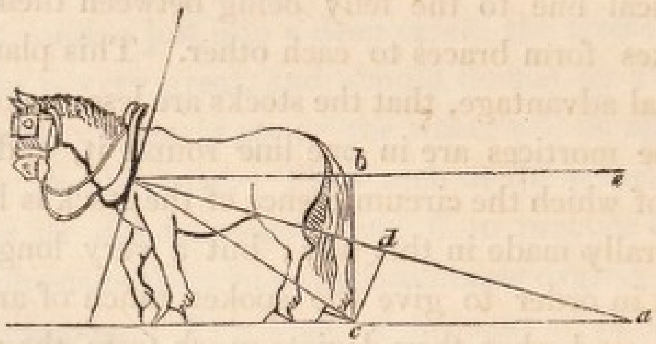
in width touches the road, and the bend down or set of the arms of the axle is just such as to compensate for the taper of the arm, and to bring its lower surface to be horizontal. This property of the tapering arm is, by the by, worthy of attention, and shows that that shape is not deserving of the censure which has been thrown upon it; for by it the upper surface of the arms, which has no weight to support, is so inclined as to give the proper angle to the upper part of the wheel, while the lower part, that bears the weight of the carriage, is in light carriages horizontal and perpendicular to the direction of the spokes which are under it.

The upright is the strongest position in which a post can be placed to carry a dead weight, and a large angle produces a great decrease in the strength; and this will apply to the present subject; for when one of the wheels of a heavily loaded waggon rises over an obstacle in the road, or sinks by a sudden jolt into a deep crack, the momentum it has to resist is very great, and should be met by a perpendicular spoke, or nearly so, or the wheel will be apt to be broken by its obliquity. Thus each of the recommended wheels has its disadvantages; and if in practice the carriage be subject to them in any considerable degree, it is unfit for its purpose. This want of bracing or of strength has probably never been felt in experiments with models, for the reasons that have already been stated; and even where the model moved upon a proportionably rough surface, its weakness would not probably appear, because the waggon and strength of its parts, when extended to the full size, increase in the ratio of the square, while its dead weight increases as the cube. Thus, a model made to a scale of three inches to the foot may be found perfectly secure; but when we extend it to full size, which is only four times the scale, we increase the strength of the tim-

bers 16 times—but we increase the weight of the machine at the same time 64 times; that is, we give the parts which have to support the weight four times the load to carry, in proportion to their strength, which they before had; and we might extend our scale until our heavy waggon had load enough in bearing up under its own weight. (This principle it is which sets a boundary to the strength of all animals; of man himself, as well as of his works; and renders a small animal or a small waggon stronger in proportion to its weight than a large one.) The desideratum, therefore, is to combine strength with stiffness, or to connect a vertical pressure upon the ground with a dished or braced wheel, in order to give strength and firmness to the carriage. This has been tried by making the spokes of the wheel a brace within themselves, by fixing them alternately into two different lines in the nave, the vertical line to the felly being between them, so that the spokes form braces to each other. This plan has the additional advantage, that the stocks are less weakened than when the mortices are in one line round it, and carriage wheels, of which the circumference of the stock is but small, are generally made in this way; but a very long stock is required in order to give the spokes much of an angular direction, and when they deviate much from the perpendicular, they become liable to the same objection as the vertical dished wheels.

In concluding our examination of this subject, we may quote the opinion of an experienced practical surveyor, who states it as his opinion generally, that any legislative measure which has for its object the improvement of wheel carriages should be confined chiefly to the width and flatness of the tire, and to the regulation of weights proportioned to the width of the wheels, as the only points in which the

interests of the roads and of the coach-owners can be much at variance; and we may extend this observation in many respects to heavy carriages, until better proof is given of the extent of the injury to the roads arising from the present shape of wheels, and of the other effects that may be consequent upon the remedying of that evil. The question is, whether, by expelling the use of cylindrical wheels, the reduction of the horse's labour, and of the wear of the roads will more than compensate for the reduction in the strength and wear of the wheels. To assist in solving this question, a waggon might be made with cylindrical wheels on the one side, and conical ones on the other. The tire of the wheel that is best for the horses and for the roads would last the longest, and the difference in the wear of the frame of the wheels would at the same time be seen.



With respect to the position of the line of traction or draught, errors of considerable importance are frequently committed, as a little attention will enable any one to perceive, who shall consider for a moment the form of the shoulders of a horse. It is evident, that at the place where the neck rises from the chest of the animal, the shoulder-blades forms the resting-place of his collar or harness into a slope. This slope or inclination forms an angle with a perpendicular to the horizon, of about fourteen or fifteen degrees, and there-

fore the line of traction or draught should form the same angle with the horizon, because he will then pull perpendicularly to the shape of the shoulder, and all parts of that shoulder will be equally pressed by the collar.

When the horse, as represented in the preceding page, is yoked to a post, or has any great obstacle to overcome, he converts himself into a lever, making his hind feet the fulcrum, and the centre of gravity of his body to lean over it, at as great a distance as possible, by thrusting out his hind feet; by this means, acting both by his weight and muscular strength, and lengthening the acting part of the lever *a b*, he overcomes the difficulty more by his weight than his muscular strength: for the muscles of the fore-legs act upon the bones to so great a mechanical disadvantage, that though he exerts them with all his might, they serve in great efforts for little more than props to the fore-part of the body. Hence we see the great use of heavy horses for draught. But the great mechanical use and advantage of the inclined line of draught may be more particularly seen, by calling the line *a b* the acting part of the lever, and the nearest approach from the fulcrum *b* to the inclined line of draught (that is, *b c*,) the resisting part of the lever, and compare this with the resisting part of a lever touching the horizontal line of draught, (that is, *b d*,) and it will be found nearly double; in consequence, agreeably to the known properties of the lever, a weight at *g* would require double the exertion in the horse to remove it, that the same weight would require were it placed at *e*. From the above data, several important practical conclusions may be drawn;—one is particularly important—that single horse-carts are preferable to teams, because in teams, all but the shaft-horse must draw horizontally, and consequently in a mannner inconsistent with their structure and the established laws of mechanics.

The small horses of the north of England draw more weight of actual goods than our largest waggon-horses, and go longer stages. The small horses of Ireland, as a common load, draw fifteen hundred weight of goods, and travel farther in a day than our waggons, and over worse roads than ours are in general; ten or twelve hundred weight of real goods is as much as falls to the share of one waggon-horse, whose superior strength is wasted upon a cumbrous vehicle, and by the mechanical disadvantages of his draught.

The effect of suspending a carriage on *springs*, is to equalize its motion, by causing every change to be more gradually communicated to it, by means of the flexibility of the *springs*, and by consuming a certain portion of every sudden impulse in generating a degree of rotatory motion. This rotatory motion depends on the oblique position of the strap attached to the carriage, which prevents its swinging in a parallel direction; such a vibration as would take place if the straps were parallel, would be too extensive, unless they were very short, and then the motion would be somewhat rougher. The obliquity of the straps tends also in some measure to retain the carriage in a horizontal position: for if they were parallel, both being vertical, the lower one would have to support the greater portion of the weight, at least according to the common mode of fastening to the bottom of the carriage; the spring, therefore, being flexible, it would be still farther depressed. But when the straps are oblique, the upper one assumes always the more vertical position, and consequently bears more of the load; for when a body of any kind is supported by two oblique forces, their horizontal thrusts must be equal, otherwise the body would move laterally; and in order that the horizontal portions of the forces may be equal, the inclination to the horizon must be the greater: the upper

spring will, therefore, be a little depressed, and the carriage will remain more nearly horizontal than if the springs were parallel. The reason for dividing the springs into separate plates has already been explained: the beam of the carriage, that unites the wheels, supplies the strength necessary for forming the communication between the axles: if the body of the carriage itself were to perform this office, the springs would require to be so strong that they could have little or no effect in equalizing the motion, and we should have a waggon instead of a coach. The ease with which a carriage moves, depends not only on the elasticity of the springs, but also on the small degree of stability of the equilibrium, of which we may judge in some measure by tracing the path which the centre of gravity must describe, when the carriage springs.

We may now notice, though of course but briefly, the mode of constructing *rail-ways*. This valuable medium of communication between the distant portions of a manufacturing district, has now become of considerable importance to a commercial country like Great Britain. In the infancy of their construction we find them formed of flat bars nailed on pieces of wood, technically called *sleepers*. But the wood which was employed in this case as a foundation, being found liable to rot, and as such requiring very frequent repairs, cast-iron was substituted for so perishable a material.

An improvement has now, however, been made in the construction of malleable iron rails, which promises to be of essential utility. It consists in the use of bars, not rectangular, but of wedge form, or swelling out on the upper edge. In the rectangular bar there is evidently a waste of metal under the surface, which, not requiring to be of the same thickness as where the waggon-wheel is to roll, may be evi-

dently reduced with advantage, if it can be done easily. The bar may then be made deeper and broader at the top than before, so as with the same quantity of metal to be equally strong, and present a much broader bearing surface for the wheel. This has been accomplished by Mr. Birkenshaw, of the Bedlington Iron-works, who has obtained a patent for these broad-topped rails. The peculiar shape is given them in the rolling of the metal by the means of grooves cut in the rollers, corresponding with the requisite breadth, and depth, and curvature of the proposed rail. Mr. B. recommends his rail to be of eighteen feet in length. One of these patent rails may be seen at Sir John Hope's colliery, and it certainly forms the most perfect iron rail which has hitherto been contrived ; combining very simply and ingeniously in its form, the qualities of lightness, strength, and durability. It is twelve feet long, two inches broad along the top, about half an inch along the bottom, and still thinner between. It rests on sleepers at every three feet, and at those places the rail is two inches deep, while in the middle point between the sleepers it is three inches deep. All the inequalities, as we have already stated, are produced on the metal by means of rollers ; and this circumstance is well deserving of attention, as it may obviously be applied not merely to the formation of rail-ways, but to a variety of other purposes in the arts. The moulding and shaping of the metal in this manner is quite a new attempt in the iron manufacture of this country, and it is not easy to say how far the invention may yet be carried by the skill of British artists.

The waggons used in rail-ways are of various sizes, but of nearly the same general shape, and all placed on four wheels, from two to three feet diameter. They are made to carry

from 20 to 50 cwt. exclusive of the waggon itself, which weighs from 12 to 15 cwt. The axles of the fore and hind wheels are fixed three feet asunder or more, so that the rail is never loaded with more than one-fourth of the waggon at once. According to Mr. Wilson, "The size of the coal waggons of Kilmarnock colliery are, on an average, mean length 80 inches, mean breadth 45 inches, and depth 30 inches. Each contains 40 bushels, equal to 32 cwt. of fire coal, and 35 cwt. of blind or malting coal. The weight of the waggon, exclusive of the coal, is 13 cwt. In particular situations these waggons are loaded by little carts, rolling in one direction down inclined planes, and emptying themselves; they are also provided with similar contrivances for being readily unloaded, when they arrive at the place of destination. The carriages used for drawing loaded boats over inclined planes, where they have to ascend and again to descend, are made to preserve their level, by having at one end four wheels instead of two, on the same transverse line, the outer ones as much higher than the pair at the other end, as the inner ones are lower; and the wheel-way being so laid, that either the largest or the smallest act upon it, accordingly, as the corresponding part of the plane is lower or higher than the opposite end. It is possible, that roads paved with iron may hereafter be employed for the purpose of expeditious travelling, since there is scarcely any resistance to be overcome except that of the air, and such roads would allow the velocity to be increased, almost without limit.*

* In regard to the expense of constructing a rail-way, this will depend greatly on the nature of the difficulties to be met with in forming the road, and making up the inequalities to the required slope. A rail-way

While treating on the construction of carriages and other vehicles for locomotive purposes, it may be advisable briefly to notice the improved system of *road-making* now so generally adopted under the direction of Mr. Mac Adam.

No additional materials, he observes, are to be brought upon a road, unless in any part of it there be not a quantity of clean stone equal to ten inches in thickness.

The stone already in the road, supposing it to have been made in the usual manner, is to be loosened and broken so that no piece may exceed six ounces in weight; the road is then to be laid as flat as possible, leaving only a fall of three inches from the middle to the sides, when the road is thirty feet wide. The stones thus loosened are to be dragged to the side by a strong heavy rake, with teeth two inches and a half in length, and there broken; but the stones are never to be broken on the road itself.

When the great stones have been removed, and none are left exceeding six ounces in weight, the surface is to be made smooth by a rake, which will also settle the other materials into a better consistence, bringing up the stone, and letting the dirt fall down to its place.

The road being so prepared, the stone that has been broken by the side is then to be carefully spread over it: this operation requires very particular attention, and the future quality of the road will greatly depend on the manner in which it is performed; the stone must not be laid

described by Mr. Neilson cost only £660 per mile; but where there are considerable embankments to form, bridges to build, and deep cuttings, the expense may rise to £4,000 and £5,000 per mile. The usual rate of tonnage on coals, &c. conveyed on rail-ways, is 2*d.* per ton, per mile.

on in shovels-full, but scattered over the surface, one shovel-full following another, and being spread over a considerable space.

Only a small part of the length of the road should be lifted up in this manner at once; that is, about two or three yards: five men in a gang should be employed to lift it all across, two continually digging up and raking off the large stones, and preparing the road for receiving them again, and the other three breaking them at the side of the road. It may however happen, that the surveyor may see cause to distribute the labour somewhat differently.

The only proper method of breaking stones, in general, both for effect and for economy, is in a sitting posture. The stones are to be placed in small heaps, and women, boys, and old men past hard labour, may sit down and break them with a small hammer into pieces not exceeding six ounces in weight. When the heavy work of a quarry can be performed by men, and the lighter by their wives and children, the stone can be obtained by contract for two-thirds of the former prices, although the stones were left four times as large. It has also been recommended by Mr. Mac Adam and others, that the largest stone employed should not exceed the measure of an inch in its greatest dimensions, or, in other words, that it should be capable of being contained in a sphere of about an inch in diameter, which would seldom weigh more than a single ounce.

The whole expense of lifting and forming a rough road to the depth of four inches has generally been from a penny to two-pence a square yard, being more or less according to the quantity of stone to be broken. With proper tools, and by proper arrangements, stone may be broken for ten-

pence or a shilling per ton, including, in some cases, the value of the stone itself. A very material advantage of Mr. Mac Adam's method is the introduction of a much greater proportion of human labour, instead of the work of horses: formerly one-fourth of the whole expense was paid, in the district of Bristol, for men's labour, and three-fourths for that of horses: now, on the contrary, one-fourth only is paid for horses' labour, and the other three to men, women, and children.

PNEUMATICS.

Nature of Atmospheric Air.—Component Parts.—Essential to Vitality and Combustion.—Experimental Illustrations of Materiality.—Weight of a given Portion of the Atmosphere.—Pressure.—Syphon.—Hydro-pneumatic Machines.—Air Pump.—Experiments of Otto Guericke.—Experiments to illustrate the Compressibility and Expansive Force of Atmospheric Air.—Fountains.—Air Gun.

THIS science derives its name from the Greek word *Πνεῦμα*, which signifies a breath or spirit, though, in reality, the air in which we live and breathe, is as decidedly material as the more dense and visible fluid, water : indeed, our globe is completely bathed and surrounded by this transparent and elastic fluid, which is essential to animal life, combustion, and a variety of other natural processes.

Until the latter part of the last century, air was generally considered as a simple fluid, and as such, was named one of the four elements.—It is now, however, satisfactorily ascertained that the component parts forming this universally diffused fluid, consist of two gaseous bodies, called oxygen and nitrogen, in the proportion of about twenty-one of the former to seventy-nine of the latter.*

* To show that atmospheric air, or rather that constituent of the atmosphere which we call oxygen-gas, is essential to combustion, we need only insert a taper in a bottle, and it will be seen that the light will be extinguished the moment that the oxygen is consumed. On this account it is, that an Argand lamp furnishes more light and less smoke than one with a solid wick—a larger surface being exposed to the action of the atmosphere, by which more oxygen is absorbed, and as such, the combustion rendered more perfect. In the economy of an ordinary fire-place a similar effect is produced. When the fire

Air being an elastic fluid, is consequently compressible; and this with the early philosophers was considered as a sufficient line of distinction between the atmosphere and liquids,—air and the various gasses being considered as compressible fluids, while water was said to be incompressible. This distinction, however, as we shall presently find, is totally without foundation; as water is compressible in a very considerable degree; and it is probable, that by a sufficient abstraction of the latent heat contained in air, it might be converted into a solid, in the same way as ice is formed by the congelation of water.*

The materiality of air may be shown in a variety of ways—the most simple of which consists in the mere immersion of an inverted glass in a basin of water: as it will invariably be found that the elastic fluid contained in the glass, will prevent the admission of the water beneath which it is immersed.

If we substitute a tube for the glass employed in the

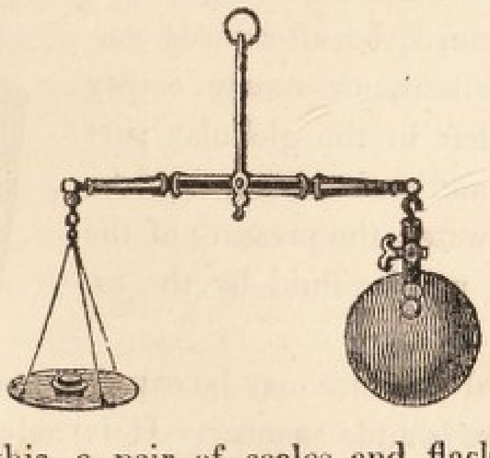
is said to want a *draft*, combustion proceeds but languidly, or ceases altogether; should we, however, apply the poker or bellows, an additional supply of oxygen is furnished, and the flame being provided with its proper food revives.

* The production of fire by the mere compression of atmospheric air, was a fact first observed by the ingenious Robert Boyle. This curious discovery has lately been applied to practical utility in this country, by means of an instrument which answers all the purposes of that well-known article in domestic economy, a tinder-box. It consists of a common syringe, about ten inches long, and not more than five-eights internal bore. At the lower extremity it is furnished with a cap, which serves as a chamber to receive the substance to be fired, and is attached to the instrument by a screw. Instead of this cap, a common stop-cock may be employed. To use the instrument, the cap is unscrewed, or the stop-cock turned, a small piece of amadou, or common tinder, is placed in the chamber, and the cap is screwed on again; if the piston of the instrument be then rapidly depressed, a portion of latent heat is squeezed out of the gaseous fluid, and the tinder ignited.

preceding experiment, and close the upper end with a cork, it will be found, on immersion, that the moment the cork is withdrawn, the water will rise to the same height within the tube as without.—Thus showing, that the entrance of the water was impeded by the air. A close bladder will also serve to illustrate this fact, for no force, short of breaking the animal membrane of which it is composed, will bring the two sides into perfect contact.

It may, however, be asked—If, as has been stated, air be material and so universally diffused, why is it not also visible? This arises from the transparency and minuteness of its particles; for we well know that glass and common water, when in a state of purity, produce similar results.—The rays of light pass through the air without being bent or reflected back to the eye; and it is to this transparent property that we owe the benefit we now derive from vision, which would otherwise be materially obstructed, if not destroyed altogether.

Having shown that air is material, it will of course follow that it must possess weight; the amount of which we may readily ascertain.

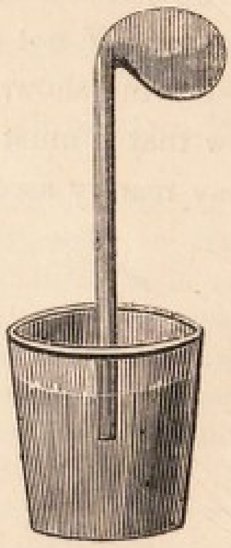


To effect this, a pair of scales and flask may be employed, similar in form to the apparatus above. On ex-

hausting the flask of its air, which is effected by a process which we may presently examine, it will be found that the equilibrium of the balance is destroyed, and if we re-admit the air, the weight which had previously been found to preponderate, will resume its original situation.

The above experiment proves that air possesses weight, and it will be quite evident that our atmosphere must press upon those bodies that are immersed in it, or beneath it, according to their distance from the earth's surface. The existence of this pressure was entirely unknown to the ancients, who imagined that air was possessed of perfect levity, and it is scarcely one hundred and fifty years since philosophers have been convinced of this now well-known and acknowledged fact.

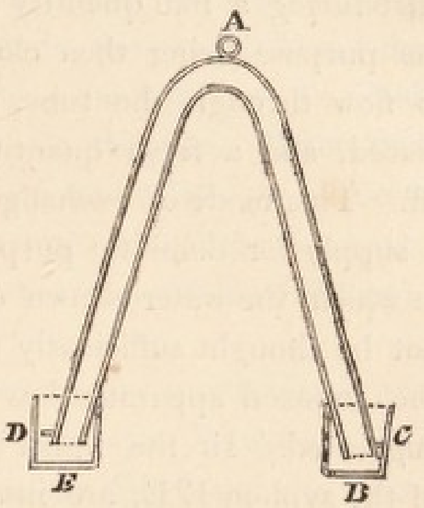
The downward pressure of the air may easily be shown by reference to a very simple experiment. A retort or flask, as is shown in the diagram beneath, may readily be emptied of its air, by boiling a few drops of water in it, over a spirit lamp, and as the steam is generated, it expels the atmospheric contents by the perpendicular tube. If the steam which has thus been formed, be afterwards condensed, a vacuous, or nearly empty space will be left in the globular part of the vessel, and on inverting the tube in a glass of water, the pressure of the air will drive up the fluid by the ascending tube.



The upward pressure may be experimentally illustrated in a still more simple manner. It is only necessary to take a wine glass and fill it with water, and then place a

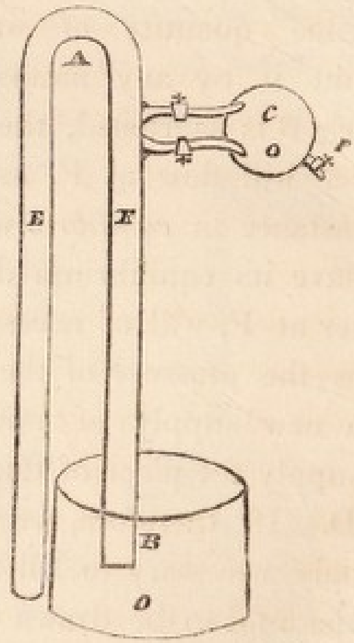
piece of paper on the top; it will be found on inverting the glass, that the water will remain supported by the air.

The operation of a syphon may also be referred to as an illustration of atmospheric pressure. An instrument of this description, in its most perfect form, is represented beneath, consisting of a bent tube, A. B. F.



If we suppose the above tube to be divested of the cups D C, which are merely employed to keep it in a state of constant readiness for action; the legs being of the same length, they will of necessity contain the same quantity of water; but if by any means the leg B is shortened, the water will flow at F, as that column, though in the first instance in *equilibrio* with the other, will by that means have its equilibrium destroyed. The descent of the water at F, will of necessity leave an empty space at A, and as the pressure of the atmosphere is still operative at C, a new supply of water is driven up into the tube to supply the place of that which has passed out of the cup D. If, therefore, we wish to make a syphon run, it is only necessary to fill it, and immerse one of its legs in the fluid to be drawn off, and the operation will be continued by the pressure of the atmosphere. The employment of the cups C and D is a late addition, as it will be evident that the whole apparatus when once filled, may be preserved in a perpendicular direction by resting upon its base at B F.

The syphon will raise a stream of water to a considerable altitude in every situation where a little descent can be procured, but while the operation continues, no water can be taken directly out of the stream above the lowest part of the tube. When, however, the two open ends of a syphon are closed, a quantity of water may be let out of the highest part, and its place supplied by introducing a like quantity of no use: all the avenues for the purpose being then closed, and the stream suffered to flow through the tube, the useless water will be displaced, and a fresh quantity may be soon after drawn off. This mode of exchange may be useful in furnishing a supply for domestic purposes; but there are some cases in which the water drawn off by this arrangement would not be thought sufficiently pure. To effect the same end, the annexed apparatus has been suggested. In the upper part of the syphon E E, are inserted two small pipes, and their apertures in the inside of the tube should be divided by a projecting piece a quarter of an inch thick; wherever the pipes are inserted, the piece must be placed in such a position, that the current will strike against one of its flat sides. The pipe which opens on that side of the



obstacle, or dam, struck by the stream, may be called the water-pipe, and that on the other side the air-pipe. Insert their other ends into a circular vessel, the air-pipe opposite to *c*, must rise to near the top of this vessel, but the water-pipe *o*, need not rise above the place of its insertion;

a cock perfectly air-tight must be fixed in each pipe between the vessel and syphon; the vessel must also have a tube in its lower part for letting out water. This tube must have a cock fixed in it, or a valve, covered with leather, to close its lower end. To hasten the delivery of the water in this vessel, the external air may be admitted in such manner as is most convenient.

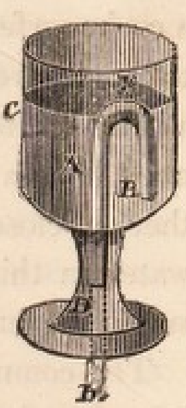
The communication between the vessel and syphon being intercepted by turning the cocks in the pipes *c o*, and the branches closed at their lower ends, the tube may be filled with water through an aperture in the top. After this aperture is closed, and a stream of water let into the cistern *o*, for supplying the syphon, the ends of the branches may be opened, and a continued stream will flow through the tube.

When it is required to fill the vessel *c o* with water, exclude the external air, and open the pipes between it and the syphon. The vessel will soon be filled, and the water may be let out by opening the tube for that purpose; after, the small pipes are again closed by turning the cocks.

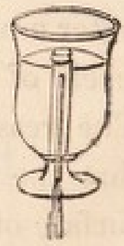
In estimating the discharge by a syphon, the head of water must be reckoned equal to the difference between the levels of the surface of the water and of the lower orifice. The reason of this will be obvious, when it is recollected that the length of the shorter leg is only measured to the surface of the water, however far it may reach below; and that, as the action of the instrument is dependant on the discharging leg being the longer of two, the greater the difference in favour of this leg, the greater will be the force employed in promoting the discharge.

To serve the purpose of amusement, a syphon is sometimes contrived to draw off the liq ıor from a drinking cup

or glass. The syphon, passing through the middle of the glass, is placed in the smallest compass possible; its branches are therefore quite close; but it is necessary that, in proportion to the size of the cup, it should have a bore sufficiently wide to draw off the contents with some degree of rapidity. The longer leg of the syphon passes through the bottom of the cup. When any fluid is poured into this cup, it will not run out till its height exceeds the level of the syphon's curvature; it may therefore be filled so high that the fluid will flow out as soon as the glass is inclined in the position for drinking; if it then be filled, and presented to a person unapprized of the trick, the liquor will, unexpectedly to him, begin to flow out, and the discharge will continue till the whole of the fluid in the cup, except the small quantity contained between the orifice of the shorter leg of the syphon and the bottom, is passed off.

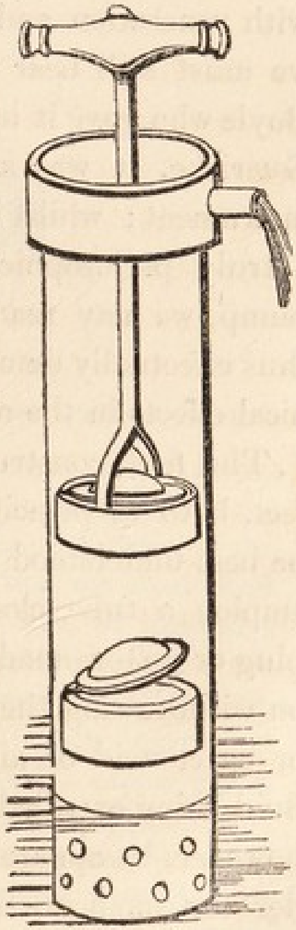


Another mode of effecting the above arrangement, which is sometimes called the *Cup of Tantalus*, consists in the employment of two tubes, as is shown in the annexed vessel. In this case, a small tube is cemented into the hollow foot at bottom, and a larger tube, with its upper end closed being dropped over it, the moment that the water is raised to the brim, it ascends between the two tubes and flows down the central aperture.



We may now advert to the common water-pump, which owes its operation to the pressure of the atmosphere. Some Italian artists in the last century having received orders to construct a common pump for the purpose of raising water to the height of fifty or sixty feet, found, to

their astonishment, that about thirty-three feet was the limit to which the water could rise. Galileo was applied to for an explanation of this circumstance, and as he had adopted the current opinion of the age, that the only reason why water rose at all in pumps, was nature's abhorrence of a vacuum; so, to this inquiry, he is said to have answered, "That nature did not entertain the horror of a vacuum beyond thirty-three feet!" Galileo afterwards acknowledged that he had not given a very philosophical answer to the question put to him; and Torricelli, a pupil of his, was the first who satisfactorily explained the cause of this apparently singular phenomenon. He instituted an experiment, that at once verified his conjecture, and this led to the origin of that important invention, the barometer.



The operation of the sucking-pump may be best understood by reference to the annexed simple diagram, in which a cylindrical tube is furnished with a movable piston, made to fit air-tight. On raising the handle, the piston also ascends, and an empty or vacuous space will of course be formed beneath. The pressure of the air upon the surface of the water beneath will then operate, and drive the fluid into the body of the pump. To prevent the return of the water, a species of trap-door, called a valve, is placed at the bottom of the tube, so that when the piston is depressed, the water must pass through a similar valve in its centre, and the next elevation brings the fluid to the reservoir at top.

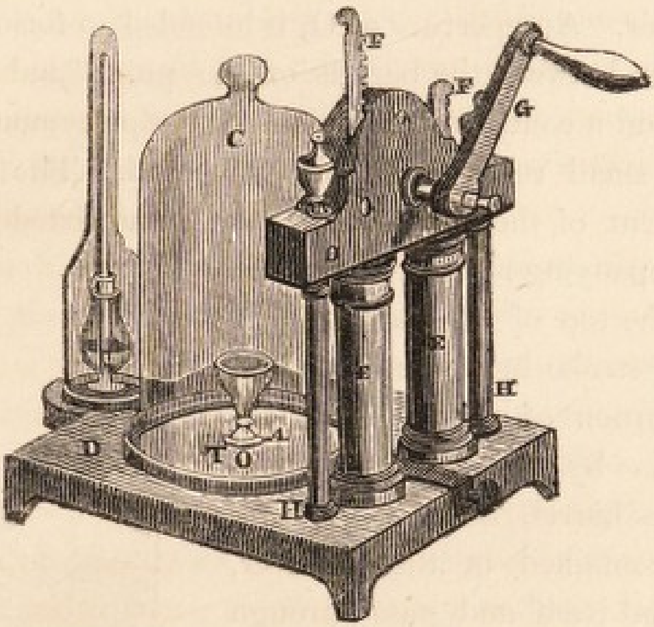
Having thus briefly reverted to the nature of atmospheric pressure, with reference to the sucking-pump and syphon, it may now be advisable to examine the principle and use of the air-pump, which is an instrument of the greatest use in this science, though its construction was not known till 1650.—Indeed, this valuable, though simple machine, has contributed more than any other apparatus to the advancement of pneumatic chemistry, as well as having afforded an easy method of illustrating the mechanical properties of the atmosphere.

We are indebted for the invention of the air-pump, to a learned German, no less distinguished for his pneumatic knowledge, than general scientific attainments: and though the memory of Otto Guericke will long be remembered with veneration and gratitude by every lover of science, we must still bear in mind that it was our countryman Boyle who gave it its present value. In the hands of Otto Guericke, it was an amusing toy, and mere mechanical instrument; whilst in those of Boyle, it was converted into a truly philosophical machine. By the use of the air-pump, we may readily exhaust a vessel of that fluid, and thus effectually demonstrate its pressure, and other mechanical effects in the most satisfactory manner.

The first construction of the air-pump was very imperfect, both in principle and execution; and its nature may be best understood by the most simple illustration. If we employ a tube closed at one end, and furnished with a plug or piston, made to fit air-tight, it will be evident, that on withdrawing the piston from the closed end, a vacuum, or space void of air, will be formed beneath—the elastic fluid being expelled at the open end of the tube. It must, however, be apparent, that the air will return to the cylinder the moment that the piston is again depressed.—To

prevent this, in the earliest air-pumps they employed a hollow ball, connected with the lower end of the tube—a communication being formed between the ball and cylinder by means of a stop-cock.*

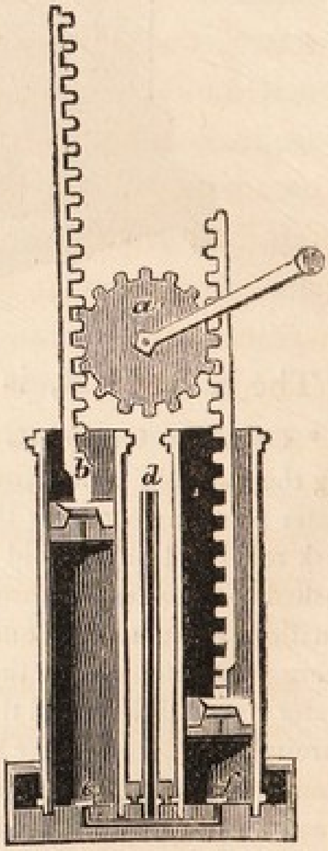
The air-pump thus constructed, was soon superseded by a more convenient apparatus, furnished with valves, to prevent the necessity of opening and shutting the cocks employed in the first instrument. The annexed general view of the common air-pump will best explain its construction.



The base, H H, is usually formed of well-seasoned ma-

* Otto Von Guericke's air-pump was really constructed by inserting the barrel of a fire-engine into a cask of water, so that when the water was drawn out by the operation of a piston, the cavity of the cask remained nearly void of all air; but finding that the elastic fluid rushed in between, or through the staves of the cask, he inclosed a smaller cask in a larger one, and made the vacuum in the internal one more complete, while the intervening space remained filled with water; yet still he found that the water was forced into the inner vessel through the pores of the wood. He then procured a copper globe, about two feet in diameter, and was exhausting it in the same way, when the pressure of the circumambient air crushed it with a loud noise. So that this machine was more properly a water than an air-pump.

hogany; and to this is firmly screwed the brass plate T. E E are two brass barrels, each containing a piston, made to fit air-tight, and furnished with a valve, opening upwards. The pistons are worked by means of the winch G, and racks F F, so that when the one piston is ascending, the other is making its downward stroke. The glass vessel C, intended to be exhausted of air, and which is called a receiver, is ground perfectly flat on its lower rim, so as completely to cut off the communication between the vessel A, and the external air. An aperture at O, is intended to form a communication between the barrels of the pump and the receiver; and a continuation of the same pipe communicates with the small receiver D, placed behind. The internal arrangement of the valves may now be adverted to. In the accompanying section, the piston *b* is at the top of its barrel. The ascending stroke being produced by the revolution of the wheel *a*. A vacuum is by this means formed within the barrel, and the air previously contained in the receiver, will expand itself and pass through the valve *e*. When the direction of the handle is changed, and the piston *b* depressed, the air which had previously passed down the pipe *d* from the receiver, will then be driven into the atmosphere by the descent of the piston. We have now to conceive the opposite piston elevated, and the valve *f* elevated by the expansion of the air in the receiver; and it will be evident, that by a series of repetitions of the same



operation, the rarefying process will go on, till the density of the air in the receiver is so much diminished as to cease to overcome the adhesion of the valves.

We have seen that the common air-pump is materially defective in the principle on which its valves are constructed, so that it ceases to operate long ere a perfect vacuum is formed in the receiver. It may now, however, be advisable to examine an instrument contrived by Mr. Styles, the ingenious mathematical instrument maker, employed by the London Institution; which unites, in a very eminent degree, all the advantages of those that have hitherto been constructed, with the very important desideratum of performing exactly twice the work of a common double-barrel pump.

Fig. 1. Plate II. Represents a section of the principal parts of the pump, from which it will be seen, that it is worked in the usual way, by means of a winch with wheel and racks; this part therefore requires no explanation. But to the end of each rack is firmly attached, by means of the connecting pieces of brass marked *a a*, the cylindrical rods *b b* passing through the collars of leather *c c*, which have reservoirs of oil in the cups above them, for the purpose of more effectually rendering them air-tight. The pistons *d d* are solid, having no valve in them, and consist of disks of leather steeped in oil and tallow, and screwed up fast between their shoulders; they are then turned to fit the bore of the barrels.

The positions assumed by them, as shown in the section, must next be attended to. The one in barrel A, is shown nearly at the end of its ascending stroke, while the piston in barrel B, is equidistant from the bottom in its descending motion; the piece C is fitted in between the caps which contain the collars of leathers, and is screwed

firmly to them. The barrel B is withdrawn from its cap E, in order to explain the mode of connexion between the cap and the barrel, as each cap D and E are similarly fastened by screws, placed at convenient distances to the flanges of the respective barrels A and B. The angular perforated passages *e e*, as seen in the piece C, communicate with the main inlet pipe, or passage, from the receiver: the one leading into barrel B, is seen open, and allows a free and unobstructed way for the air to enter above the piston *d*, in its descending stroke, as marked by the darts pointing downwards; while the air is also passing down the pipe F, whose connexion with the piece C, is more clearly shown in the perspective view of the instrument, and through the horizontal way or channel communicating with barrel A, as shown by the letters *f f*. Here the air passes through an oiled silk valve, which consists of a brass valve piece, having a hole perforated through its centre, and a small groove or nick cut in the upper part, a piece of oiled silk is strained over its surface, and secured by silk thread twisted round in the groove; this piece, with the valve, is shown in the bottom of barrel A, opening upwards, permitting the air to enter beneath the piston in its ascending motion, as shown by the darts pointing in that direction. Having thus traced the inlet ways to the top of barrel B, and bottom of barrel A, we may now describe the mechanism by means of which the top inlet valves are connected with their respective barrels. The valves we are now about to describe, consist of the two metallic cylinders F and G, the first being closed, and G, which is shown open; the rods or cylinders pass through the small collars of leather *g g*, with an oil cup to each cap, as shown by the curved lines above them; which caps may be screwed up when requisite, in order to press the collars of leather more close,

and render them air-tight; the cylindrical valves or rods are kept in the vertical position by passing through a piece of brass, which is attached by means of screws to the under side of the head of the pump marked H; to this piece are attached two levers I and K, revolving upon the steel pins of the milled head nuts *h h*. The levers work in a mortice cut to receive them in that part of the piece H, shown by the letters *i i*. Attached to one end of each of those levers, are seen the small steel screws *k k*. Two small plates of brass *l l*, (the front plate of each being only seen in the section,) whose extremities are again attached by the screws *m m*, to the pieces *n n*, answer the purpose of sling rods for connecting the motion here requisite for raising and depressing the cylinders or valves according to the alternate motion of the levers I and K. The pieces *n n*, are perforated, and slide freely on the vales F and G. The way in which this alternate motion takes place, may easily be explained. On the back part, or opposite edge, of each toothed rack, as seen in Fig. 2, is placed a plate of steel (fastened by small screws,) the length of which is limited by the working stroke of each piston, and projects on that side of each rack on which the levers are represented. The lever K is shown in the position with the valve G open, for permitting the air from the receiver to enter the top of barrel B, and the bottom of barrel A, as before described: while the lever I, with the valve F, is seen as thrown down, closing the top inlet of barrel A. We shall now suppose the piston of barrel B, to conclude its descent to the bottom, having expelled the air beneath, through the outlet valve *s*, and the piston of barrel A, its ascent to the top of its barrel; the rods and racks will also pass through the same space, and the moment the pistons reach their respective limits, the levers I and K are relieved from the

opposite ends of the plates or fillets of steel; the lever I, by the action of the spiral spring *o*, which is coiled round the cylindrical valve F, and pressing between the turned shoulder *p*, and the under side of the perforated or sliding piece *n*, is then returned to an horizontal position. The lever K, by a like action, produced by the spring *q*, which is also coiled round the cylindrical valve G, and pressing between the piece of brass H, and shoulder piece *n*, closes the cylindrical valve G by its pressure, and its lever K, of course, takes an horizontal position. By reversing the motion of the winch for the next stroke of the pistons, the positions of those levers are again changed by the ends of the fillets of steel placed on the back edge of the racks, coming in contact with their extremities. The lever I is thrown up in the direction of the dotted lines, carrying with it the cylindrical valve F, which is consequently opened, and a free access for the air to enter the barrel A, above the piston *d*, on its downward motion now takes place; the valve f, placed at the bottom, closes, and the air received by it is expelled through the valve *s*, which is similar in construction with the valve *f*, but in this case opens outwards, while the lever K, in consequence of the ascending motion of the rack and the fillet of steel, must come into contact with its extremity, and is thrown down on the spiral spring *o*, coiled round the cylindrical valve G, which still more effectually secures the valve in this position; the return of the air by the upward motion of the piston being also prevented. The lever K, will now be in the position shown by the dotted lines, and the air received above the piston in its former downward stroke, is thus expelled through the top outlet valve *t*, and passes through the side, or leading off pipe, L, in the direction as shown by the darts pointing downwards, and which communicates

with the same general outlet as the bottom discharging valves *s s*. A reference to the above description will show, that while one barrel is discharging its contents by the upward motion of its piston, it is at the same time filling to discharge by the downward stroke. The other barrel is discharging by the downward action of the piston, and also filling through the ways described to discharge again by its upward motion, so that it performs the work of two pumps of the same capacity of barrel, constructed on the common principle. In addition to the above advantages, the mode of working the top inlet valves mechanically ensures a much more perfect vacuum than could otherwise be obtained. Thus, if we suppose the bottom inlet valves *f f*, and also the discharging valves *s s*, to have become leaky, by simply turning off the cock M, we cut off all communication between them and the receiver; the pump then becomes a single acting pump, with all the advantages of the common instrument. If we now suppose the top valves to be bad, in order to cut them off, detach the centre screws *h h*, from the levers I and K, permitting those parts to hang loose down by the sides of the cylindrical valves; the spiral springs *q q* will then press those valves close down over the top angular inlet ways, and prevent the access of air from the receiver above the piston. If we then open the cock M, which in the former case was closed, the pump may be worked from the bottom set of valves alone.

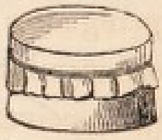
The air-pump offers a variety of very beautiful illustrations, tending to prove the materiality, weight, pressure, and elasticity of our atmosphere. One of the first of these experiments consists in placing a glass vessel on the plate of the air-pump, and on withdrawing the air it will be found that the receiver is held down with a force equal to about as many times fifteen pounds as there are square

inches in that part of the plate which the receiver covers. By turning the cock of the pump, we shall re-admit the air, and, as such, loosen the receiver.

In order to prove that the small receiver is really held down by the pressure of the air, we may place it within a larger one, and furnished with a sliding wire. On withdrawing the air, the small receiver will be loose, while the outer one will be fixed by the pressure of the atmosphere; but on re-admiting the air into the larger receiver, the small one will be held down by its pressure, while the larger one may be removed. The small receiver is moved by means of a wire passing through an air-tight collar of leathers.

To practically illustrate the amazing pressure exerted by the atmosphere upon the human body, we need only place an open vessel or box upon the pump-plate, and, covering the upper end with the hand, exhaust the air. The pressure of the atmosphere will now become sensible, and by depressing the muscles, must of necessity produce a very painful effect.

We may now substitute a piece of bladder, or any other animal membrane, for the hand. This should be tied over the mouth of the box when wet, as is shown in the diagram. After a few hours it may be placed on the pump-plate; and, the air being exhausted, the downward pressure will cause it to burst with a loud report.

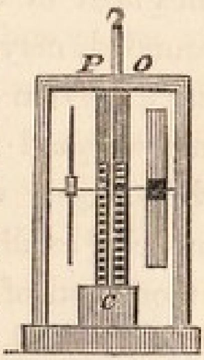


A slight consideration of this experiment will show how the human body is enabled to support a pressure equal to from twenty to thirty thousand pounds, and that, too, without the slighest inconvenience. The bladder was in the first instance pressed with a force equally great with what it was when exhausted of air, and it might be moved through the air with the utmost facility; the moment,

however, that the pressure is taken from within, that without becomes sensible, and the destruction of the membrane is the consequence.

One of the most striking and self-evident proofs of the materiality of air, will be found in the resistance that it offers to the motion of any body whose surface is large. The sails of a ship, and a windmill, are affected in the same way as the minutest blade of grass; and this will be equally apparent in the motion of smoke, and the devastating effects of the African or West Indian tornado. When the air is at rest, or in a quiescent state, we can move in it with the utmost facility; but when the motion is quick, or the surface extensive, as in the fly of a clock, its resistance then becomes obvious to the senses.

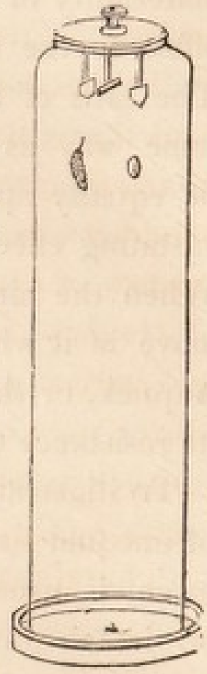
To illustrate this, a double fly, with vanes of unequal size, similar to the annexed diagram, is usually placed beneath the receiver of the air-pump, and so constructed, that motion may be communicated when the air is withdrawn. When this is effected, it is found that the fly that exposes a large surface to the action of the atmosphere, passes round as swiftly as the smaller vanes; but, on re-admitting the air, its velocity will be much diminished, if not destroyed altogether.



The utility of a fly in machinery, may, upon this principle, be very readily explained. A fly is an equaliser of motion; and if we suppose that motion to be too quick, a larger surface is exposed to the resisting media, or air, and *vice versâ*.

Another mode of showing the air's resistance by means of the air-pump, may now be adduced. It is well known that, bulk for bulk, feathers are lighter than gold; and

in proof of this we find, that if a feather and a guinea be dropped from the hand at the same instant of time, the latter will reach the ground first. If, however, the experiment be performed *in vacuo*, a very different result is obtained. Annexed is shown a tall receiver, furnished with a plate at top, and provided with an apparatus for supporting and lowering a guinea and a feather at pleasure. When this is exhausted, the guinea and feather may be discharged, and they will reach the bottom at the same instant of time: thus proving, that all bodies would descend to the earth, from equal heights, in equal times, were it not for the resistance of the air. That bodies float in the air by which they are surrounded, may also be exhibited by withdrawing a portion of the air from a large receiver, and we shall find that the weight of any enclosed body will be increased. The usual mode of exhibiting this is, to suspend a bunch of feathers at one end of the beam of a delicate balance, and attach a piece of lead of equal weight at the other. Now it will be evident that the bulk of the feathers must be much greater than that of the lead, and, as such, that their buoyancy must be the greatest; so that on withdrawing the air they will cease to float *in equilibrio*, the feathers will descend, and we shall find that one of the lightest substances there is will apparently become the heaviest.



The exceeding minuteness of the particles of which air is composed, may readily be shown by placing a brass plate upon an open receiver, and forcing a plug of dry wood through its centre, so that the end may be immersed beneath a vessel of water. If the receiver be now exhausted,

bubbles of air will be seen rapidly rising through the water, having previously passed though the pores of the wood. In proof of this, the ebullition may be immediately and entirely stopped by closing the aperture; and if this be effected with the thumb, it may be afterwards withdrawn, and the motion renewed.

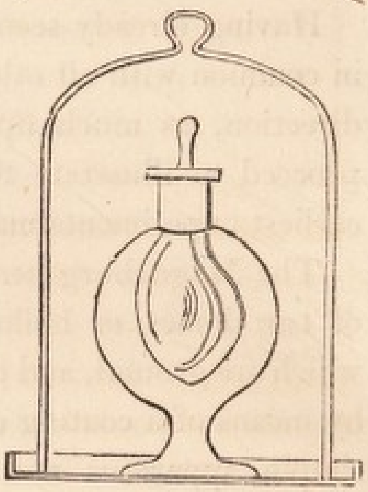
A nearly similar effect may be produced by merely immersing a piece of marble in water; as, on placing it beneath an exhausted receiver, its whole surface will be found studded with bubbles of air, which have passed through a variety of minute pores in its apparently solid surface.

Having already seen that air possesses weight, and that, in common with all other fluids, it presses equally in every direction, as much upwards as downwards, we may now proceed to illustrate this fact with reference to one of the earliest experiments made by the German philosophers.

The Magdeburg hemispheres, as they are called, consist of two domes, or hollow half balls of brass, the edges of which are ground, and made to fit air-tight by means of a coating of pomatum. This simple apparatus will easily be understood: *b* and *d* represent the two hemispheres of brass, connected together at the ground surfaces in the centre; while *a* is a stop-cock, by which it is attached to the pump-plate. On withdrawing the air from the globe, the atmosphere will press above and beneath, with a force proportioned to the area of the circle; and if this contain twelve square inches, it will require a force equal to nearly two hundred pounds to separate the two surfaces—a degree of resistance which could never have been conceived without the aid of experiment.

To experimentally ascertain the power with which the hemispheres are held together, the stop-cock *a* must be closed, and the handle beneath attached by its screw. The upper handle *e* may now be suspended by a rope, and a weight attached to the lower end. This, on being increased till the hemispheres are pulled asunder, will be found exactly equivalent to the prescribed amount.

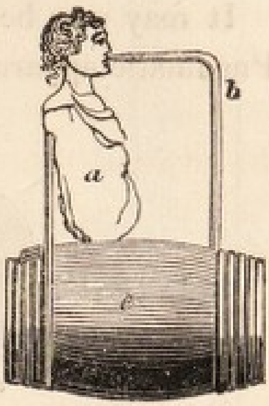
The *lungs-glass* is an ingenious apparatus which has been contrived so as partially to represent the operation of that part of the human frame. It consists of a bladder tied round a small tube, which passes into a bottle, and sealed so tight, that the air cannot escape any way but through the tube. When this machine is put under a receiver, and the air begins to be exhausted, the spring of that which is contained in the bottle, and which cannot escape, compresses the bladder; and when air is again let in, the bladder expands; and these alternate motions of compression and dilatation, have been supposed analogous to those of the lungs.*



* Having by the aid of the above apparatus briefly illustrated the nature of respiration, a few facts connected with this important process may not be out of place. Inspiration and expiration are not performed by the lungs themselves, since air would be equally drawn into and expelled from the cavity of the thorax when deprived of lungs, supposing that the parts of the thorax could be able to perform their motions perfectly well after death. The lungs may therefore be compared to the cavity of a pair of common bellows, filled with any downy substance, the bones of the thorax to the boards of the bellows, and the muscles of the thorax to the hands by which the bellows are moved.

Respiration may be divided into four stages: first, inspiration;

The *Bacchus* apparatus, here represented, is usually employed as an amusing mode of illustrating the action of the lungs-glass, already described. The figure is seated on a cask, with a tube proceeding from the mouth to the barrel: this is filled with red wine, or coloured water; so that being put under a receiver, when the air is exhausted, the liquor is thrown up to his mouth by the expansion of the air, which is thus imprisoned, and the deity seems to be at his usual employment; while he is

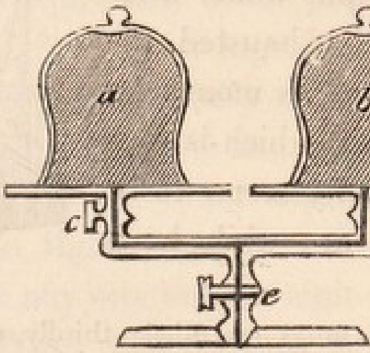


secondly, a pause when the lungs are filled; thirdly, expiration; and lastly, a pause when the lungs are emptied. We are equally stimulated to inspiration and expiration by a sensation of uneasiness; but that which is felt when the lungs are kept too long inflated after a full inspiration, is of a different kind from that which is perceived when they are preserved too long empty after expiration. In the former case, the uneasiness is referred to the head; in the latter, to the chest. To what these sensations are owing, we cannot altogether determine; they are probably, however, to be attributed to the anterior cavities of the heart, and the vessels of the head being overloaded with blood, which cannot so readily pass through the lungs while their motion is suspended. The truth of this opinion is much confirmed by the flushing of the face, and the bursting of blood-vessels, which sometimes happens from impeded respiration.

The air, after passing through the wind-pipe, is conveyed through its ramifications to the air-vessels of the lungs. After inspiration, the air-vessels, which are to be considered as very minute bladders with thin coats, are fully distended. The minute and very numerous ramifications of the pulmonary arteries are distributed on the membranes of these air-vessels, and through the membranes, coming into direct contact with the blood, the air produces those changes on it which are found to be absolutely necessary for the continuance of life. The chief uses of respiration, as far as our knowledge extends, are, first, to effect certain changes in the mass of blood; and secondly, to produce animal heat.

drinking, his stomach expands, which is effected by a bladder containing a small quantity of air concealed under his external silk covering.

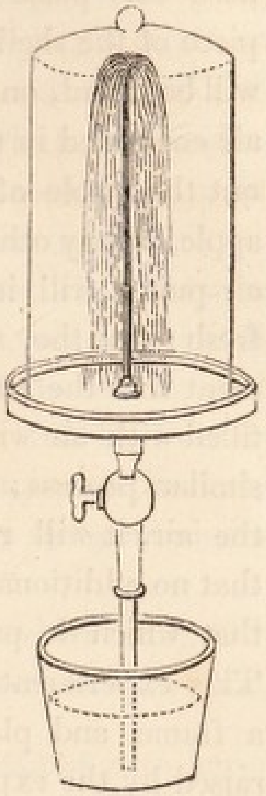
It may now be advisable to notice that portion of the Pneumatic apparatus called the *Double Transferrer.*

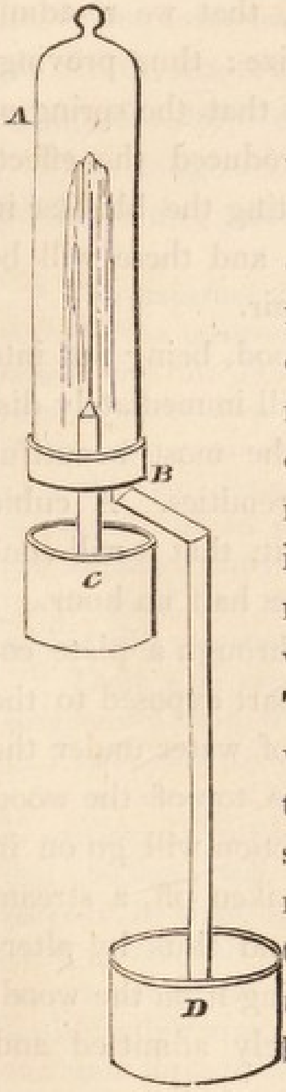


A connexion is in the first instance formed with the air-pump by the stop-cock *e*; the receiver *a* is then exhausted by the operation of the pump, the stop-cock *d* having been closed while this operation is going on. The communication with the air-pump is then cut off by the lower stop-cock, and the whole apparatus removed from the pump. If we then open the communication with the receiver *b*, a portion of the air will pass to *a*, and the two vessels will be held down with equal force upon their respective plates by the pressure of the atmosphere. And it will be found that a force equal to half the elastic power of common air will act within the receivers against the entire pressure of the external air.

A very elegant hydro-pneumatic fountain may be formed by employing the air-pump. The arrangement of the apparatus when in operation, will be easily understood by reference to the annexed diagram. The brass plate is fur-

nished with a receiver made to fit air-tight, and the whole may be connected with the air-pump by the stop-cock beneath. If the receiver be now exhausted of air, the stop-cock turned, and the lower extremity of the tube immersed in a vessel of water, the moment a communication is opened with the receiver, a jet of water will be seen to ascend in a continuous stream. There





is another mode of producing the same effect without the intervention of an air-pump. To exhaust the receiver A in this apparatus, the lower part of the glass must in the first instance be filled with mercury, and a communication opened by the pipe B, with the cup of mercury D. If the pipe be thirty inches in length, it is evident that the fluid metal must sink; and as it descends, a partial vacuum will be formed within the receiver. The air, pressing on the surface of the water at C, will then drive the water up the perpendicular tube, and a jet exactly similar to the one described will be the result. That the air's spring causes it to expand when the external pressure is reduced, may now be rendered apparent by the air-pump. To effect this, we

need only place an egg beneath the receiver, from which a piece of the shell has been broken at the small end, and it will be found, on rarefying the air, that the small bubble of air contained in the large end will, by its expansion, drive out the whole of the contents of the shell. A withered apple, or any other fruit, placed beneath the receiver of the air-pump, will immediately expand, and appear perfectly fresh; but they will return to their original bulk the moment that the air is re-admitted; and a bladder about half filled with air will expand, and in some cases burst, by a similar process; the moment, however, that we re-admit the air, it will return to its original size; thus proving, that no additional air was admitted, but that the spring of that which it previously contained produced the effect. This experiment may be varied by putting the bladder in a frame, and placing weights upon it, and these will be raised by the expansion of the enclosed air.

A piece of dry wainscot, or other wood, being put into water, and covered with a receiver, will immediately discharge air, and appear studded with the most beautiful spherules, especially about its two extremities. A cubic inch of dry wainscot has so much air in it, that it will continue to produce this effect for more than half an hour.

If a piece of wood be made to pass through a plate covering the top of a receiver, with one part exposed to the air, and the other immersed in a vessel of water under the receiver, and the hand be placed on the top of the wood whilst the pump is working, the rarefaction will go on in the ordinary way; but if the hand be taken off, a stream of air will flow in through the wood; and thus by alternately withdrawing the hand and replacing it on the wood, the influx of the air will be alternately admitted and interrupted.

If a clean receiver be placed upon the pump-plate, slightly moistened and partially exhausted,* on holding a candle to the side of the receiver opposite to the observer, an artificial halo will appear about the candle, which is occasioned by the vapour that rises from the moistened metal beneath, and the refraction by means of the light.

There is a very interesting experiment that may be easily performed with a common air-pump, which is intended to illustrate the facility with which fluids boil beneath an exhausted receiver. If water below 212° of Fahrenheit's thermometer be placed on the pump-plate, and the air withdrawn, it will instantly boil; but, on the re-admission of air, ebullition will cease.†

Place a lighted candle under a tall receiver; and, if it holds about a gallon, the candle will continue to burn about

* This experiment will serve to illustrate a fact of much importance in the construction of the air-pump, for every substance containing moisture should be removed from beneath the receiver, as the removal of the atmosphere causes all fluids to assume an elastic form. In the old pneumatic machines the receiver was invariably placed upon the pump-plate, on leathers soaked in water or oil; but it was discovered that an elastic vapour arose from the moist leather, that considerably injured the effect of the pump. To prevent this, both the plate and glass receiver should be ground perfectly flat, and then rubbed with pomatum, which will entirely exclude the air.

† There is an experiment nearly analogous to this, which may be performed without the aid of an air-pump. If we half-fill a Florence flask with water, and place it over a lamp, letting it boil briskly for a few minutes, and then cork the mouth of the flask as expeditiously as possible, it will be found, on removing the flask from the lamp, that ebullition will still continue. The boiling may be afterwards renewed, by wrapping round the empty or upper end of the flask a cloth wetted with cold water, or by gradually pouring cold water upon its external surface; but if hot water be applied to the flask, the boiling instantly ceases. In this manner the ebullition may be renewed, and again made to cease, alternately, by the mere application of hot and cold water.

a minute, and its light will gradually decay and at length be extinguished. The smoke of the candle will ascend, and form a kind of cloud at the top of the receiver; but, upon exhausting it, the dense vapour will fall down to the bottom; thus showing, that smoke does not ascend because it is positively light, but merely because it is lighter than air.

By connecting the wire that passes through the collar of leathers of a receiver, with the trigger of a pistol-lock placed under it, exhausting the air, and then drawing the trigger, the flint will strike the steel, and produce sparks of fire, which will not be so visible as in the open air. Or, if two iron bullets be made red-hot, and one of them be under an exhausted receiver, it will not appear as luminous as the other which remains in the open air.

To ascertain the degree of rarefaction in the receiver of the air-pump, a variety of gauges have been employed, the most satisfactory of which is that called the *long barometer-gauge*. When a barometer is first placed beneath the glass receiver of the air-pump, the mercury will of course stand at the same height as in the open air; but when the pump is put in motion, and the rarefaction commences, the mercury will descend, and rest at a height which is, in its proportion to its former height, as the spring of the air remaining in the receiver is to its spring before exhaustion. Thus, if the height of the mercury, after exhaustion, is the thousandth part of what it was before, the air is said to be rarefied 1000 times. The descent of the mercury in the barometer-tube, when attached to the air-pump, affords an additional illustration of the nature of atmospheric pressure. We know that in the air the mercurial column is seldom less than from 28 to 30 inches; and yet we find that, on withdrawing a portion of the atmosphere, that is, reducing the pressure upon the basin in which the tube is immersed,

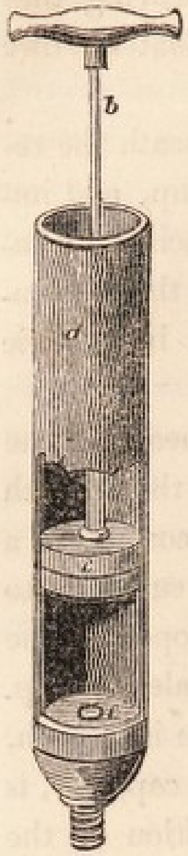
it immediately descends; thus satisfactorily proving that it is to the pressure of the atmosphere alone that we owe its previous elevation.

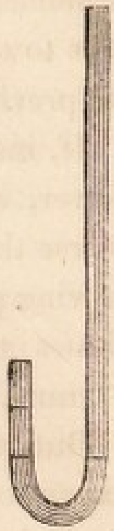
If, instead of placing a perfect barometer beneath the receiver, we connect an empty tube with the pump, and immerse the lower end in mercury, upon commencing the rarefying process the mercury will ascend: and this it continues to do, till it forms a nearly perfect barometric vacuum.

But Mr. Smeaton contrived a gauge, which measured the expansion with certainty, to much less than the 1000th part of the whole capacity of the receiver. It consists of a bulb of glass, in shape resembling a pear, and sufficient to hold about half a pound of quicksilver. It is open at one end, and at the other is a tube hermetically sealed at top. A scale divided into parts of about a 10th of an inch each, and answering to a 1000th part of the whole capacity, is annexed to it. This gauge, during the exhaustion of the receiver, is suspended in it by a slip-wire. When the pump is worked as much as is thought necessary, the gauge is pushed down, till the open end is immersed in a cistern of quicksilver placed underneath. The air being then let in, the quicksilver will be driven into the gauge, till the air remaining in it becomes of the same density with the external; and as the air always takes the highest place, the tube being uppermost, the expansion will be determined by the number of divisions occupied by the air at top.

The air-pump, as we have already seen, serves to show that air can be rarefied, or made to expand, beyond its original bulk. We may now examine the construction of a still more simple apparatus by which that bulk may be reduced in a very material degree. The instruments used for this purpose are called *Condensers*.

If we pour water or mercury into a tube bent in this

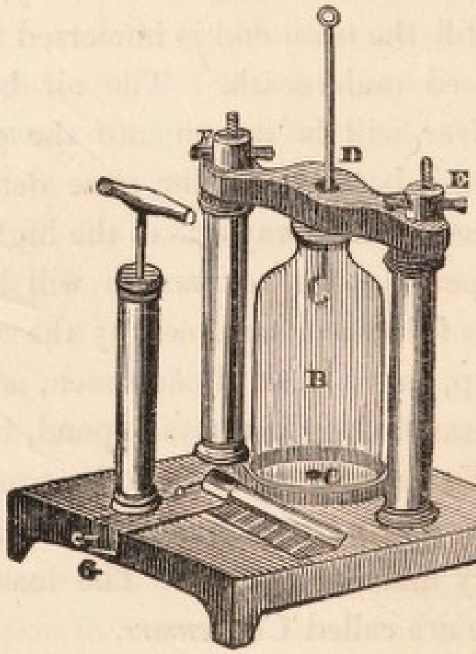




form, and close the lower end with a cork, the air between the fluid and cork will be compressed in proportion to the attitude of the column, and its elasticity increased in a proportionate degree.

The common form of the condensing syringe may, however, be best understood by reference to the annexed diagram, in which *d* represents the condensing syringe, furnished with a solid piston *c*, made to fit air tight, while a valve *e* in the screw beneath opens in a downward direction, and allows the air to pass from the tube, but prevents the return of any new portion from the vessel into which it is to be condensed.

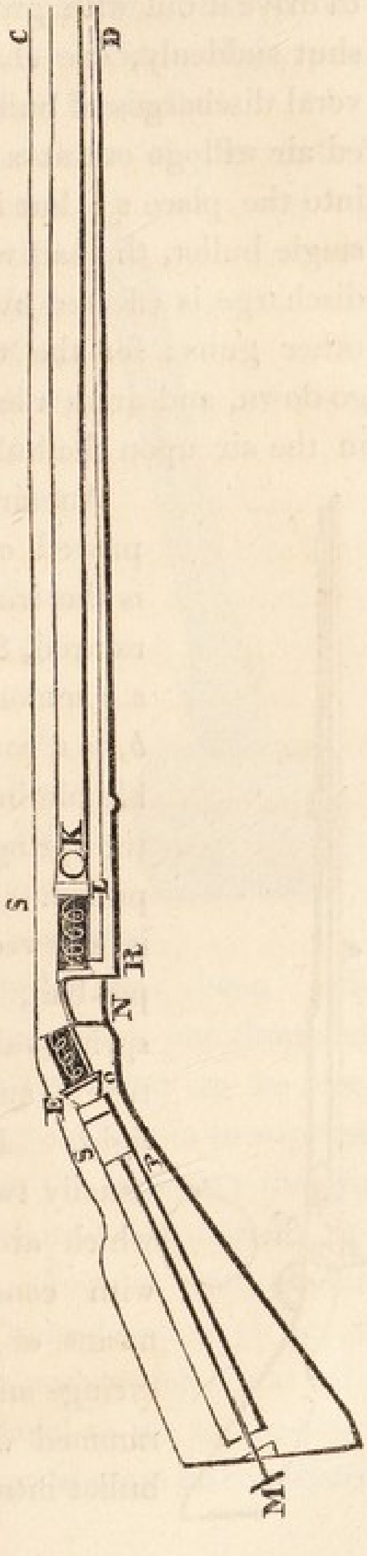
We may now turn to the complete condensing apparatus, as it is employed for experimental purposes.



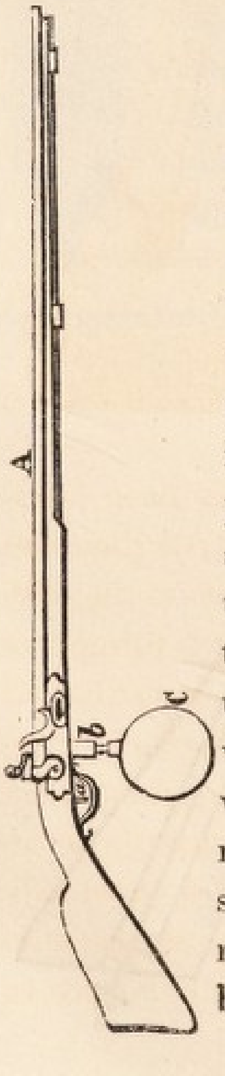
The receiver B is held down to the pump plate C by the pillars and screws E F; D represents the slide-wire passing through a collar of leather, so that a communication may readily be effected between the operator and the body to be experimented upon within the receiver.

If a full bladder be now placed in the glass, its elasticity may be so increased by working the piston, that it will scarcely occupy half of its original bulk. The *air-gun* is the best example of the surprising force which air is capable of exerting when condensed to a considerable degree; for, by means of this instrument, bullets may be propelled with a force nearly equal to that of fired gunpowder.

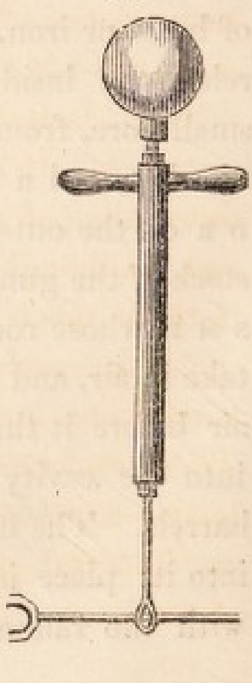
The common air-gun is made of brass or iron, and has two barrels; the inside barrel, K, of a small bore, from which the bullets are shot, and a larger barrel, E G D R on the outside of it. In the stock of the gun there is a syringe, S M P, whose rod M draws out to take in air, and piston S drives the air before it through the valve O into the cavity between the two barrels. The ball K is put down into its place in the small barrel with the rammer, as in another



gun. There is another valve at L, which, being opened by the trigger, permits the air to come behind the bullet, so as to drive it out with great force. If this valve be open and shut suddenly, one charge of condensed air may make several discharges of bullets; because only part of the injected air will go out at a time, and a new bullet may be put into the place K; but if the whole air be discharged on single bullet, the ball will be expelled more forcibly. This discharge is effected by means of a lock placed here as in other guns; for the trigger being pulled, the cock will go down, and drive a lever that will open the valve, and let in the air upon the bullet K.

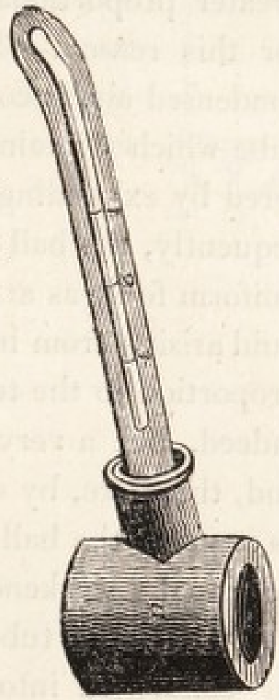


An air-gun of the most modern and approved construction is here represented. A is the iron gun-barrel with the lock, stock, ramrod, &c. of about the size and weight of a common fowling-piece. Under the lock at *b*, is a round steel tube, with a small moveable pin in the inside, which is pushed out by the spring of the lock, when the trigger *a* is pulled. To this tube, *b*, is screwed a hollow copper-ball, *c*, containing a spring-valve at its aperture; and perfectly air-tight. Each gun has usually two of these balls, which are fully charged with condensed air by means of the condensing syringe annexed. Having rammed down the leaden bullet into the barrel, and



attached it to the ball c, by the tube and screw *b*; the finger is applied to the trigger, and a very moderate degree of force is sufficient to discharge the internal mechanism which is intended to raise the valve, and, by permitting the escape of the air, discharge the bullet.

A gauge is sometimes employed to show the amount of compression in pneumatic machines; and an apparatus of the above description may advantageously be applied to the air-gun. It must be attached at *a*, and the graduated glass tube will shew by the advancement, or recession, of a small globe of mercury within it, the precise degree of compression.



The first account we meet with of an air-gun, is in the "Elemens d' Artillerie" of David Rivaut, who was preceptor to Louis XIII. of France. He ascribes the invention to Morin, of Lisseau; who presented one to Henry IV. Instruments of this kind were, however, not wholly unknown to the ancients.

The elasticity of fired gunpowder has been estimated, by Mr. Robins, as equal to about one thousand times that of common air; admitting that to be correct, (although there seems to be great reason to suppose it to be much underrated,) it would be necessary that air should be condensed one thousand times more than its natural state, to produce the same effect as gunpowder. There is, however, an important consideration to be attended to, viz.—That the velocities with which equal balls are impelled, are directly proportional to the square-roots of the forces; so that, if the air in an air-gun be condensed

only ten times, the velocity with which it will project a ball, will be one-tenth of that arising from gunpowder; and if the air were condensed twenty times, it would communicate a velocity equal to that of one-seventh of that of gunpowder, and so on.

Air-guns, however, project their balls with a much greater proportionate velocity than that stated above, and for this reason.—That as the reservoir, or magazine of condensed air, is commonly very large, in proportion to the tube which contains the ball, its density is very little altered by expanding through that narrow tube, and, consequently, the ball is urged all the way by nearly the same uniform force as at the first instance; whereas, the elastic fluid arising from inflamed gunpowder, is but very small in proportion to the tube, or barrel of the gun; occupying, indeed, but a very small portion of it next the but-end, and, therefore, by dilating into a comparatively large space as it urges the ball along the barrel, its elastic force is proportionally weakened, and it acts always less and less on the ball in the tube; and on this account it happens, that air condensed into a large machine only ten times, will project its ball with a velocity but little inferior to that given by gunpowder; if the valve of communication be suddenly shut again by a spring, after opening to let out air. It is requisite to have the condensing syringe of a small bore, perhaps not more than half an inch in diameter; otherwise the force requisite to produce the compression will become so great, that the operator cannot work the machine; for, as the pressure against every square inch is but 15lbs, and against every circular area of an inch in diameter, about 12lbs; if the syringe be an inch in diameter, it will require a force of as many times 12lbs., as the density of the air in the receiver exceeds that of the common

atmosphere: so that, when the condensation is ten times, the force required will be 120lbs.; whereas, with a half-inch bore, it will only amount to 30lbs.

A very important application of the condensing syringe has lately been suggested by Mr. Gordon. The object of this ingenious philosopher is to employ condensed carburetted-hydrogen-gas for domestic purposes; and this he effects by compressing the gas in a cylindrical or globular vessel, similar to that shown in the accompanying engraving.

PRESSURE AND EQUILIBRIUM OF FLUIDS.

Nature of Fluidity.—Compressibility of Water.—Florentine Experiment.—Apparatus employed by Mr. Perkins.—Tendency to Equilibrium.—Hydrostatic Paradox.—Bellows.—Bramah's Press.—Diving Bell.—Modes of ascertaining the Specific Gravity of different Bodies.

Hydrostatics is a very important science. In its more limited sense, it is confined to that part of the doctrine of fluids, which relates to their weight and pressure only: *Hydrodynamics*, on the contrary, treats of fluids in motion. In the present and succeeding sections, these two branches of science will be so combined, as to make them mutually explanatory of each other.

The nature of fluidity* must be examined. There is one property essential to all bodies that belong to this class, namely, a freedom of motion amongst the particles of which they are composed. Liquids may, indeed, be considered as compounds of solids with heat, as nearly all the fluid bodies, both gaseous and liquid, have been converted into solids, either by the abstraction of heat, (by the refrigeratory process,) or by compression.

* "Fluidity is distinguished from liquidity, or humidity, in that the idea of the first is absolute, and the property contained in the thing itself; whereas, that of the latter is relative, and implies wetting, or adhering, i. e. somewhat that gives us the sensation of wetness or moisture, and which would have no existence but for our senses. Thus melted metals, air, or ether, and even smoke, are fluid bodies, but not liquid ones; their parts not leaving any sense of moisture: whereas water, milk, wine, &c. are at the same time both fluids and liquids."

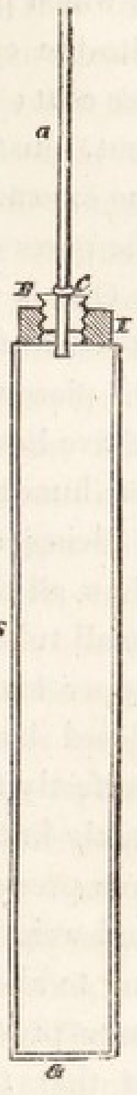
The *compressibility of water* was a subject which engaged the attention of philosophers at a very early period. The Florentine academicians, from the following experiment, inferred that it could not be diminished in bulk: they took a globe of gold, which was the least porous of any body at that time known; and, having filled it with water, they closed it up. They then subjected the globe to a great compressive force, which squeezed the water through its pores, before any indentation could be made in it. As a hollow sphere has a greater capacity than any other form, under the same surface, the academicians supposed that the compressive power, which was applied to the globe, must either force the particles of the fluid closer together, or drive them through the metal, before the globe yielded in the slightest degree to compression. With respect to its precise object, therefore, this celebrated experiment is not entirely conclusive, because they had no means of determining whether the diminution of the internal capacity of the globe by pressure, was exactly equal to the quantity of water forced through its pores; but they certainly proved the extreme minuteness of the particles that could be forced through so dense a metal as gold. The inference, drawn by the Florentines, remained uncontradicted by any experiment till about 1762, when Canton published some experiments on the subject. With the barometer at 29½, and the thermometer at 50, he states the following to be the results obtained :—

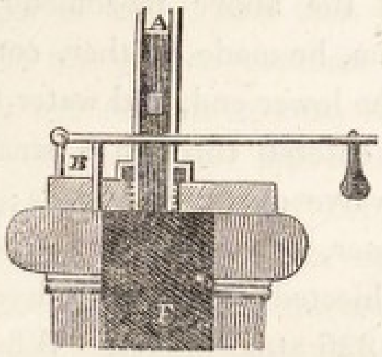
Compression of Spirit of Wine . .	66 parts in a Million.
Oil of Olives . . .	48 ditto.
Rain-water . . .	46 ditto.
Sea-water . . .	40 ditto.
Mercury	3 ditto.

These results he obtained in the following manner: he

took a glass tube, about two feet long, with a ball at one end, of an inch and a quarter in diameter; he filled the ball and part of the tube with water, which had previously been deprived of air as much as possible; he then placed it under the receiver of an air-pump, and removed the pressure of the atmosphere: under this treatment, he observed that the water rose a little in the tube. On the contrary, when he placed the apparatus upon a condensing engine, and, by condensing the air in the receiver, increased the pressure upon the water, he observed that the water descended in the tube. In this manner, he proved that water expanded one part in 21740, when the pressure of the atmosphere was removed; and submitted to a compression of one part in 10870, under the weight of a double atmosphere. He also observed, that water possessed the remarkable property of being more compressible in winter than in summer; contrary to the effect on spirit of wine and oil of olives. Lest it might be supposed the compressibility, thus discovered, might be owing to air lodged within the fluids employed, a quantity of water was caused to imbibe more air than it contained in a preceding trial, but its incompressibility was not increased. These experiments, although, upon the whole, so apparently decisive of the questions they were instituted to determine, are not yet to be received without some caution; and, in particular, the remark that the addition of a portion of so compressible a fluid as air, did not render water more compressible than before, is rather staggering; and is calculated to throw a veil of doubt over all the rest. It remained, therefore, for future investigators to determine the data for this branch of the science; but even granting all the compressibility that has been contended for, the quantity of it is too small to be noticed in practice.

The *Piezometer* employed by Mr. Perkins in his experiments on the compressibility of water, is represented in the annexed diagram. The end I, of a cylinder S, three inches wide and eighteen long, being made water-tight by a plate firmly soldered to it: a cap, also water-tight, was screwed on the extremity. The rod *a*, $\frac{3}{16}$ths of an inch in diameter, and carrying a flexible ring C, was made to pass through a tight stuffing-box F. The compression was effected in a cannon, the top of which (the top is shown beneath) was capable of containing the piezometer.





It was fixed vertically in the earth, the touch-hole being plugged tight, and the muzzle about eighteen inches above ground. A strong cap was firmly screwed on at the mouth, and in the centre of it a small forcing pump A, with a piston $\frac{3}{8}$ths of an inch in diameter, was tightly screwed, and a valve introduced at the aperture B, to ascertain the degree of pressure, one pound of pressure on that valve indicating an atmosphere. In performing experiments with this apparatus, the piezometer was introduced into the cannon, the water being forced in till the cap showed signs of leakage: the valve at the same time indicating a pressure of one hundred atmospheres; when the riezometer was taken out of

the cannon, the flexible ring C, was eight inches up the rod *a*, which proved that the rod had been forced that length into the cylinder, and that the compression was about one per cent; in order to produce this compression, three per cent. must be pumped into the gun; an effect arising from the expansion of the gun, or the entrance of the water into the pores of the cast iron.

On his voyage to England, Mr. Perkins repeated this experiment frequently, and with the same result; by sinking the piezometer with fifty-four pounds of lead, to the depth of five hundred fathoms, which gives nearly a pressure of one hundred atmospheres.

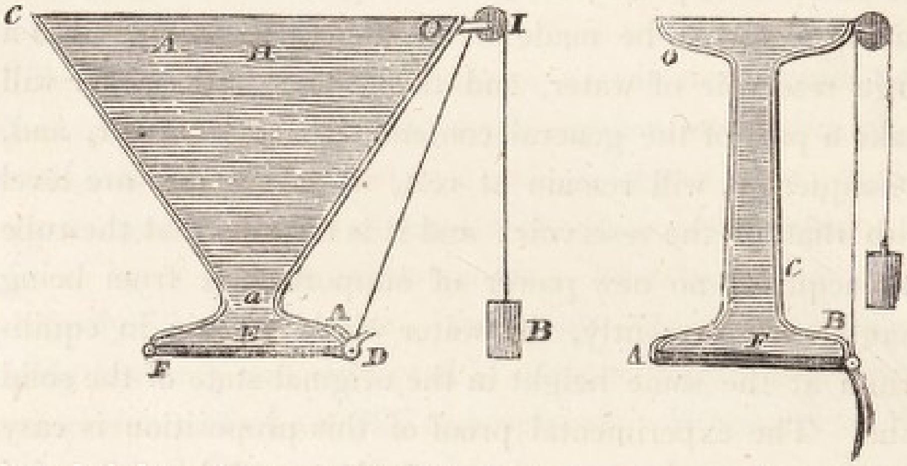
Being satisfied that the above piezometer would not show all the compression, he made another, consisting of a small tube, closed at the lower end, and water-tight; at the upper end, the water entered through a small aperture, closed by a sensible valve opening inwards; it was then perfectly filled with water, (the weight of which was accurately known,) and subjected in a common hydraulic press to a pressure of about 326 atmospheres. When taken out and weighed, there was found an increase of water, amounting to about three and a half per cent. This water had been previously boiled and cooled down to 48°, and kept at that temperature during the experiment, which was performed before many scientific individuals.

* In examining Mr. Perkins experiments on the compressibility of water, Dr. Roget has found that he has committed a mistake in the calculation, by which he makes the compression about 1 per cent. It is actually but little more than one-half per cent. This result agrees most singularly with Canton's experiments, as Dr. Roget has shown; for the modulus of elasticity of water, according to Dr. Thomas Young's method, is 750,000, as deduced from Canton's results; while it is 743,260 deduced from Perkins's results.

The most obvious law of hydrostatics, and one on which nearly all our experiments are founded, is this, that the surface of every homogeneous gravitating fluid, when at rest, is horizontal. If any part of the surface were inclined to the horizon, the particles would necessarily tend towards its lowest part, in the same manner as if they moved without friction on the inclined surface of a solid. And if any two portions of the surface of the fluid are separated, as in two branches of a tube, or pipe, however they may be situated, the fluid cannot remain at rest, unless the surfaces be in the same level plane; for if we imagine such a tube, containing water, to be made of ice, and to be immersed in a large reservoir of water, and then thawed, the water will make a part of the general contents of the reservoir, and, consequently, will remain at rest, if its surfaces are level with that of the reservoir: and it is obvious that the tube has acquired no new power of supporting it from being thawed: consequently, the water would remain in equilibrium at the same height in the original state of the solid tube. The experimental proof of this proposition is easy and obvious, and the property affords one of the most usual modes of determining a horizontal surface. But when we compare the heights of fluids occupying tubes of different magnitudes, it is necessary, if the tubes are small, to apply a slight correction on account of the actions of the tubes on the fluids which they contain, which are more apparent, as their diameters are smaller.

There is a very singular paradoxical experiment illustrative of this part of our subject. It is this, that any quantity of water, or any other fluid, however small, may be made to balance and support any quantity, or any weight, how great soever. Thus, water in a pipe, or canal, open at both ends, always rises to the same height at both ends,

whether those ends be wide or narrow, equal or unequal. And since the pressure of fluids is directly as their perpendicular heights, without any regard to their quantities, it follows, that whatever the figure or size of the vessels may be, provided their heights be equal, and the areas of their bottoms equal, the pressures of equal heights of water are equal upon the bottoms of those vessels, even though the one should contain a thousand, or ten thousand times as much as the other. Mr. Ferguson has illustrated this matter by the following apparatus. Let two vessels, such as



C and O be of equal heights, but very unequal capacity; let each vessel be open at both ends, and their bottoms E and F of equal widths; let the brass bottoms be exactly fitted to each vessel, not so as to go into them, but for each vessel to rest upon respectively; and let a piece of wet leather be put between each vessel and its brass bottom, for the sake of keeping them close. Join each bottom to its vessel by a hinge A F, so that it may open like the lid of a box; and let each bottom be kept up to its vessel by equal weights B I, hung to lines which pass over the pulley as at I, the blocks being fixed to the sides of the vessel, and the lines tied to hooks at D B, fixed in the brass bottoms opposite to the hinges. Things being thus prepared, hold

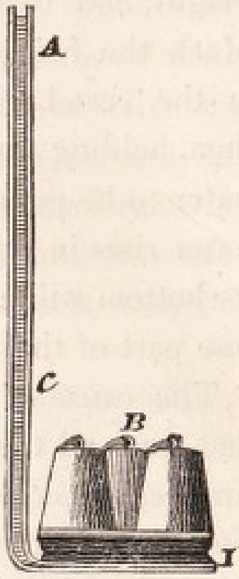
one vessel upright in the hand over a basin on a table, and cause water to be poured slowly into it, till the pressure of the water bears down its bottom at the side, and raises the weight, and then part of the water will run out beneath. Mark the height at which the surface of the water stood in the vessel when the bottom began to give way; and then, holding up the other vessel in the same manner, cause water to be poured into it, and it will be seen that when the water rises in this vessel just as high as it did in the former, its bottom will also give way at the same height, and it will lose part of the water.

The cause of this apparently surprising phenomenon is, that since all the parts of a fluid at equal depths below the surface, are equally pressed in all directions, the water immediately below the fixed part will be pressed as much upward against its lower surface within the vessel, by the action of the column in the centre, as it would be by a column of the same height, and of any diameter whatever; and therefore, since action and re-action are equal, and contrary to each other, the water immediately below the surface B, will be pressed as much downwards by it as if it were immediately touched, and pressed by a column of the whole height, and of the diameter A B; and therefore the water in the cavity beneath will be pressed as much downwards upon its bottom F, as the bottom of the other vessel is pressed by all the water above it.*

When a machine is constructed expressly for the purpose of showing, in the most striking manner, that the pressure of fluids is as their perpendicular heights, and that a quantity, however small, may be made to support a weight, or another quantity, however large, it may be most advan-

* Vide Ferguson's Lectures. Edit. by C. F. Partington.

tageously made in the form of what is called the hydrostatical bellows. This apparatus may now be examined. It consists of two circular boards I, about sixteen inches in diameter; these boards are connected by means of a strong leather, which entirely surrounds them, and permits them to open and close like a pair of common bellows, with this difference, that they open equally all round, and therefore the boards always remain parallel to one another. The leather, at its junctures, is well secured, and the whole machine is water-tight. In the upper board is fixed a pipe A C, communicating with the interior, and reaching above to a considerable height, suppose five feet. Through this pipe let some water be poured into the bellows, and the upper board will be observed to rise a little; place a weight B upon it, pour in more water, and it will still rise, though we increase the weight very considerably. Indeed, we may add water till the leathers are at their utmost extension; the water will then fill in the tube, and the upper board cannot be depressed, nor the water forced out of the small tube, until the pressure upon it is more than that of a column of water, whose diameter is equal to that of the interior of the bellows, and its height equal to that in the tube; by increasing, therefore, the length of the tube, a most enormous weight might be raised by the pressure of a few ounces of water.*



To illustrate this singular experiment, we may suppose

* It will probably be understood, that an equal bulk of any fluid denser than water, such as mercury, would, with this machine, produce a greater effect; and any lighter fluid, such as spirit of wine, not so great an effect.

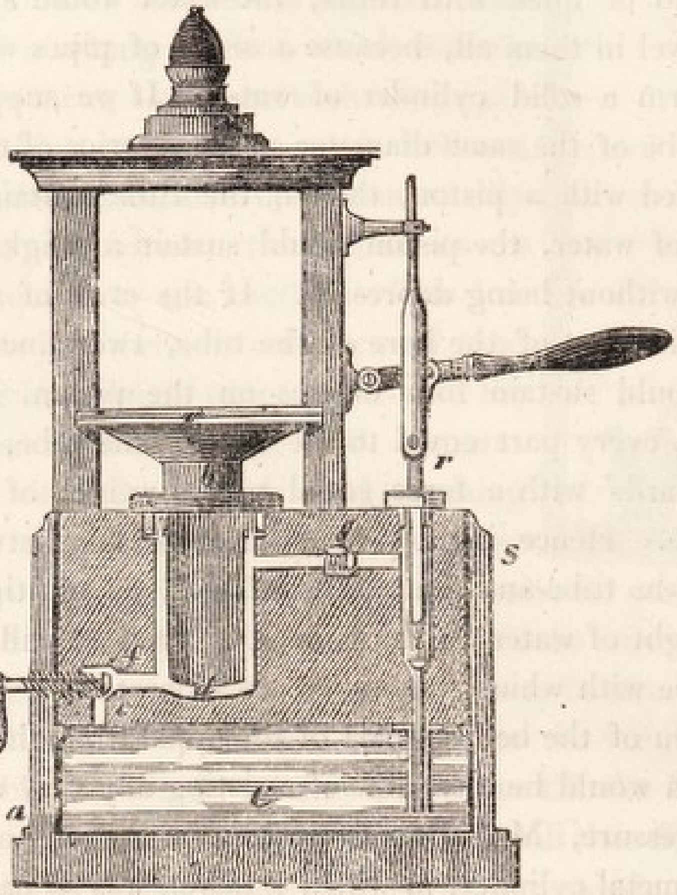
a hole to be made in any part of the upper board, and another tube to be inserted there; the water would certainly rise to the same level in them both; and supposing the board to be filled with tubes, the water would attain the same level in them all, because a series of pipes would, in fact, form a solid cylinder of water. If we suppose the hole to be of the same diameter as the interior of the tube, and fitted with a piston, then if the tube contained two ounces of water, the piston would sustain a weight of two ounces without being depressed. If the area of the hole were twice that of the bore of the tube, two ounces in the tube would sustain four ounces on the piston. In this manner, every part equal to the bore of the tube, is pressed upwards with a force equal to the weight of fluid in the tube. Hence, if the proportion subsisting between the area of the tube and that of the bellows, be multiplied by the weight of water in the tube, the product will express the force with which the boards are separated.*

In lieu of the bellows part of the apparatus, the leather of which would be incapable of resisting any very considerable pressure, Mr. Bramah suggested the use of a very strong metal cylinder, in which a piston was so packed, as to move water-tight; and as a substitute for the high column of water, he employed a small forcing pump, to which any power can be applied; and thus, the pressing column becomes indefinitely long, although the whole apparatus is of itself comparatively small.

In the diagram we have a section of one of these presses,

* A man, standing upon the upper board of the hydrostatic bellows, may, by blowing into the tube, condense the air sufficiently to raise himself up; and by having a stop-cock near the top of the tube, to prevent the egress of the air thus forced in, he will continue to be supported as long as he may choose.

in which *b* is the piston of the large cylinder, formed of a solid piece of metal turned truly cylindrical, and carrying the lower board *v*, of the press upon it : *r* is the piston of

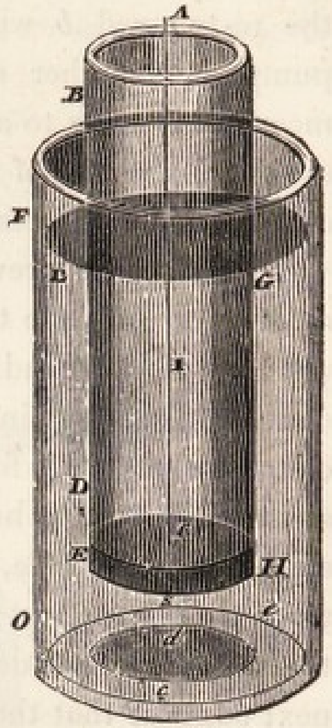


the small forcing pump, being also a cylinder of solid metal, moved up and down by a handle, or lever. The whole lower part of the press is sometimes made to stand in a case S *a*, containing more than a sufficient water as at C, to fill both the cylinders; and the suction pipe of the forcing-pump dipping into this water will be constantly supplied. Whenever, therefore, the handle is moved upwards, the water will rise through the conical metal valve, opening upwards into the bottom of the pump *t* ; and when the handle is depressed, that water will be forced through another similar valve *g*, opening in an opposite direction in

the pipe of a communication between the pump and the great cylinder *d*, which will now receive the water by which the piston rod *b* will be elevated at each stroke of the pump *t*. Another small conical valve *f*, is applied by means of a screw to an orifice in the lower part of the large cylinder, the use of which is to release the pressure whenever it may be necessary; for, on opening this valve, any water which was previously contained in the large cylinder *d*, will run off into the reservoir by the passage *c*, and the piston *b* will descend; so that the same water may be used over and over again. The power of such a machine is enormously great; for, supposing the hand to be applied at the end of the handle with a force of only ten pounds, and that this handle, or lever, be so constructed as to multiply that force but five times, then the force with which the piston *r* descends, will be equal to fifty pounds: let us next suppose that the magnitude of the piston *b* is such, that the area of its horizontal section shall contain a similar area of the smaller piston *r*, 50 times, then 50 multiplied by 50, gives 2500 pounds, for the force with which the piston *b* and the presser *v* will rise. A man can, however, exert ten times this force for a short time, and could therefore raise 25,000 pounds; and would do more if a greater disproportion existed between the two pistons *b* and *r*, and the lever or handle of the pump was made more favourable to the exertion of his strength.

If we immerse a solid in a vessel of water, and the pressure of the fluid on one side of the body be prevented, then the pressure on the other sides of it will be rendered manifest; and by this means, a body actually heavier than an equal bulk of water may be supported in the vessel; while on the other hand, a body actually lighter than an equal bulk of water, may be pressed downwards by the

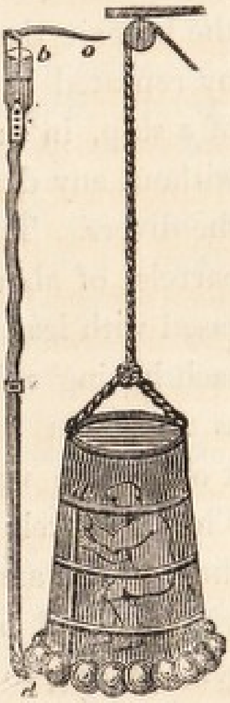
water. To perform this experiment we may take a glass tube about eighteen inches long, as B D, open at both ends, and with its lower end ground quite flat and smooth. Let a brass plate E H, a little larger than the diameter of the tube, be ground likewise very flat, and fix a hook to its middle, to which a string C A must be attached. Place the brass plate against the aperture of the tube, and by pulling the string at A, keep the plate tight against the tube. In this situation immerse the tube in the water, until the plate is below the surface to the depth of about ten times its thickness. If, in this arrangement of the apparatus, the string be let go, the plate will not fall off, but will remain adhering to the glass tube; the reason of which is, that now the water presses only against the under part of the brass plate. But if water be poured into the tube, then the plate will be immediately separated from it, and will fall to the bottom of the vessel O F.



Another experiment, the reverse of the preceding, may now be noticed. It is performed with nearly the same apparatus, and it is necessary merely to cement a very flat plate of brass *c s*, to the bottom of the glass vessel, and upon this place a perfectly smooth cork *d*. If water be now poured as high as L G, the weight of the superincumbent column will retain it in its place. Should we, however, but admit the least portion of water by partially raising the cork, the water beneath will counterbalance that above, and it will rise to the surface.

We have now to examine a very important hydrostatic machine, by the use of which we may descend into the depths of the ocean, and prepare the foundations of bridges, and other processes connected with hydraulic architecture, with nearly as much facility as in the air.

The diving bell is frequently alluded to by Lord Bacon, and other authors of a much earlier period. The father of English Philosophy observes, "that it was invented to facilitate labour under water;" but its first successful application appears to have been effected by an adventurer of the name of Phipps, who was enabled to raise a vast quantity of treasure from the wreck of a vessel on the coast of St. Domingo.



One of the simplest forms of the diving bell is shown in the annexed diagram. A wooden vessel encircled by a series of hoops forms the body of the machine; and it is in this case suspended by a strong tackle, which may be attached to the side of a vessel. The forcing pump *b* is furnished with a handle at *o*, by means of which the air is injected, as in the common condenser; while the flexible pipe enters beneath the bell, and is intended to supply the diver with air in lieu of that which has been rendered unfit for respiration.

To familiarly illustrate the principle of this machine, we may take a glass tumbler, and plunge it into water with the mouth downwards. It will then be found that very little water can rise within the vessel. This may be rendered more apparent, if we lay a piece of cork upon the surface of the water, as it will be seen floating at the

bottom of the vessel, and yet its upper side will not be wetted; the air which is in the glass having prevented the entrance of the water; but as air is compressible, it could not entirely exclude the water, which, by its pressure, partially condenses the air. With regard to the early form of the apparatus, it may be proper to state that the diving bell constructed by Dr. Halley was very similar to a common bell, and was coated with lead, so as to sink when empty: weights being distributed about the lower part, to keep it in an inverted position. It was three feet wide at top, five wide at bottom, and eight feet high. In the top was fixed a strong clear glass, to let in the light from above, and likewise a cock, to let out the hot air that had been deprived of its vital principle by repeated breathing. It was suspended from the mast of a ship, in such a manner as to be let down over its side without any danger. Within there was a circular seat for the divers. To supply the bell with air under water, two barrels, of about sixty-three gallons each, were made, and cased with lead sufficient to make them sink when empty, each having a hole in its lower part to let in the water, as the air in them condensed in their descent, and to let it out again when they were drawn up full from below. The air barrels were furnished with cords so as to enable them to rise and fall alternately, and in their descent they were directed by lines fastened to the under edge of the bell, passing to the man standing on the stage to receive them, who, by raising the ends of the pipes above the surface of the water in the bell, permitted the water in the barrels to force all the air in the upper parts into the bell, while it entered below, and filled the barrels. And as soon as one was discharged, by a signal given, it was drawn up, and the other descended to be ready for use. As the

cold air rushed into the bell from the barrel below, it expelled the hot air (which was lighter) through the cock at the top, which was then opened for that purpose. By this method, air was communicated so quick and in such plenty, that the inventor tells us that he "himself was one of five who were together at the bottom in nine or ten fathoms water, for above an hour and a half at a time, without experiencing any ill effects;" and that he "might have continued there as long as he pleased."*

* Dr. Lewis Colladon, who descended in a diving-bell at Howth in 1821, furnishes a very accurate description of the apparatus, &c. employed on that station. The bell was six feet in length by four broad, and five feet high, and resembled an oblong iron chest. It was cast in one piece, and weighed about four tons; the entire cost, including the necessary apparatus and air pump, was estimated at two hundred pounds. The upper part was pierced with eight or ten holes, furnished with thick convex glasses for the transmission of light; while a pipe descending from the surface of the water with a valve opening inwards, served to convey fresh supplies of air to those beneath. In the interior were two small benches on opposite sides of the bell, and sufficient room for four persons. The middle of the roof was furnished with several strong chains, intended to sustain a kind of iron basket, constructed for the reception of stones, &c.

Dr. C. thus describes the sensations he experienced during the descent. "We descended so slowly, that we did not notice the motion of the bell; but as soon as the bell was immersed in water, we felt about the ears and forehead a sense of pressure, which continued increasing during some minutes. I did not, however, experience any pain in the ears; but my companion suffered so much, that we were obliged to stop our descent for a short time. After some minutes we resumed our descent. My friend suffered considerably: he was pale, his lips were totally discoloured; his appearance was that of a man on the point of fainting; he was in involuntary low spirits, owing, perhaps, to the violence of the pain, added to that kind of apprehension which our situation unavoidably inspired. This appeared to me the more remarkable, as my case was totally the reverse. I was in a state of excitement resembling the effect of some spirituous liquor. I suffered no pain; I experienced only a strong pressure round my

We may now examine that branch of our subject which relates to the *specific gravities of bodies.*

The mere weighing of a body in a balance in the open air, as is commonly practised, simply gives the weight, or gravitating power of the body weighed, without respect to its density, or the mechanical arrangement of its particles; for a pound of cork will gravitate as powerfully as a pound of lead, but the bulk of the cork must be much greater than that of the lead ere they can be brought into a state of equilibrium. So that if equal bulks of cork and lead were weighed against each other, the lead would appear to have a much greater gravitating force belonging specifically to itself, than the cork. The specific gravity therefore of a body is merely a comparison of its gravitating force against that of some other body which has been previously ascertained; and of course the material used for making this comparison should be one as little liable to change in itself as the nature of things will admit of. Pure rain, or distilled water, is found, by general experience, to be the material best suited to this purpose, as being the least liable to a change in its density at the ordinary temperature of the atmosphere.

Obtaining the specific gravity of a substance is, therefore, nothing more than ascertaining how much it is heavier or lighter than its own bulk of pure water, an

head, as if an iron circle had been bound about it. I spoke with the workmen, and had some difficulty in hearing them. This difficulty of hearing rose to such a height, that during three or four minutes I could not hear them speak. I could not, indeed, hear myself speak, though I spoke as loudly as possible; nor did even the great noise caused by the violence of the current against the sides of the bell reach my ears. I thus saw confirmed by experience what Dr. Wollaston had foreseen by theory in his curious and interesting paper on Sounds inaudible to certain ears.

operation which would be in ordinary circumstances attended with great difficulty and nicety. For to obtain the comparative weight of an irregular piece of metal, and its equal bulk of water, it would be necessary to have an exact measure of its capacity to be filled a certain number of times with water, which would be difficult or even impracticable with precision and certainty; but since every substance capable of sinking in water loses as much weight by immersion, as is equal to the exact weight of its own bulk of water, it becomes easy and certain of success.

This, however, will be best understood from the following account of the manner of taking the specific gravity of all such solids as are heavy enough to sink in water. Suspend the substance to be examined by means of a hair from one of the hooks of a common balance, in such a manner that it may hang two or three inches within a large glass jar placed beneath. This being effected, it should be balanced exactly by weights put into the opposite scale, and then they must note down its weight in air. On filling the jar with pure rain or distilled water, the suspended substance will be raised up by the fluid; after which the horizontal position of the balance must be restored by placing weights in the scale over the suspended substance, which will, of course, depress it under the water, and these weights will indicate the weight of a bulk of water equal to that of the suspended body. The original weight must now be divided by the weight last employed, and the quotient will be the specific gravity required; or, in other words, will show how many times the suspended body is heavier than its own bulk of pure water. For example, suppose the suspended substance was a guinea; this weighed in air would be found equal to

129 grains; by submersion in water, the guinea would appear to lose rather more than seven grains, or so much weight must be placed in the scale to restore the former balance. Then 129 grains divided by seven grains gives a quotient of 18.00, which is about the specific gravity of guinea gold. A hair is mentioned as the most convenient mode of suspension, because it possesses the greatest strength with the least bulk to affect the accuracy of the experiment, and is not liable to absorb any perceptible quantity of water.*

* In the use of the hydrostatical balance it will be proper to observe the following general precautions. The water in which the solid is to be weighed, besides its either being distilled or rain water, must be quite clean. Its temperature, as well as that of the solid, must be as near as possible to 62 of Fahrenheit's thermometer; for which purpose the ball of the thermometer must be placed in the water, and the temperature adjusted by the addition of hot or cold water. If the solid body be soluble in water, or if it be porous enough to absorb any water, then it must be varnished, or coated with some oily substance; but in that case some allowance must be made on account of the varnish, &c. When the solid is weighed in water, its upper part ought to be a little way below the surface of the water; and it must by no means be suffered to touch the sides or bottom of the jar. Care must be taken that no bubbles of air adhere to the solid under water; for they would partly buoy it up. The solid must be of a compact form, and free from accidental or artificial vacuities, otherwise its specific gravity cannot be ascertained by weighing it in water. Thus a piece of silver, which is much heavier than water, may be formed in a hollow sphere, which will appear to be much lighter than water; for if this sphere were immersed in water, it would displace a quantity of water which is not only equal to the silver, but also to the space contained in the sphere. It is for this reason that a ship may be made of iron, or of copper, or, in short, of any substance whose specific gravity far exceeds that of water, and yet it would float as well as a ship which is made of wood, in the usual way.

Thus we find that although steel has a greater specific gravity than water, and as such being bulk for bulk heavier, must, under

When the body to be examined is in the state of filings, or pieces too small to be separately attached to the balance, a glass bucket may be made use of; and we have only to attach the bucket by a hair to the hook of the scale; find its weight in air while empty; then put into it the substance whose specific gravity is to be found, and weigh it again: when the weight of the bucket by itself has been subtracted from its weight when loaded, the remainder will, of course, show the precise weight of the substance in air. The bucket must then be weighed in water, both loaded and empty, and its weight, in the latter case, deducted from that in the former. Having thus obtained the weight of the substance alone, both in air and water, the case becomes the same as if the intervention of the bucket had not been required; viz. the weight in air must be divided by the weight lost in water, and the product will be the specific gravity sought.

When substances are lighter than water, a different mode of treatment to that which has been described, must be adopted for obtaining their specific gravities; for now some force is necessary for producing their submersion. To effect this, a small pulley moving with little friction may be attached to the bottom of the water jar, or to a weight sufficiently heavy to cause it to remain steadily there; and the hair attached to the substance, must in this

ordinary circumstances, sink in the fluid in which it is immersed; yet there are a variety of exceptions to this apparently self-evident law. By taking a single instance, we may, however, sufficiently illustrate the matter. The floating of a steel wire is alluded to as a proof of some repulsive force in the needle; that, however, is not the fact, as the phenomenon may readily be accounted for by reference to the cohesion existing between the particles of the water, which being greater than the gravitating force of so light a body, admits of a partial hollow being formed, without allowing the needle to sink.

case pass downwards under the pulley, and rise again so that its opposite end may fix to the hook of one of the scale pans. The substance is first to be weighed in the scale in the ordinary manner, and afterwards placed in the jar; water must then be added, until the substance, by floating, draws the scale beam into an horizontal position; after which weights must be placed in the opposite scale until the substance is drawn under the water.

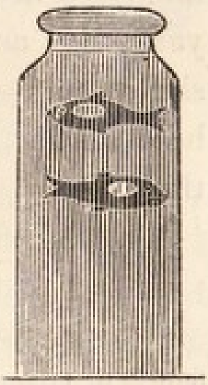
In order to determine the specific gravity of living men, Mr. Robertson prepared a cistern, 78 inches long, 30 inches wide, and 30 inches deep; and having procured ten men for his purpose, the height of each was taken, and his weight; and afterwards they plunged successively into the cistern. A ruler, graduated to inches and decimal parts of an inch, was fixed to one end of the cistern, and the height of the water noted before each man went in, and to what height it rose when he immersed himself under its surface.

The following table contains the several results of his experiments.

No. of Men.	Height.		Weight.	Height of water before immersed.	Height of water when immersed.	Water raised.	Solidity.	Weight of water.
	Ft.	In.	Pounds.	In.	In.	In.	·	Pounds.
1	6	2	161	19.30	21.20	1.90	2.573	160.8
2	5	10$\frac{3}{8}$	147	19.25	21.16	1.91	2.586	161.6
3	5	0$\frac{1}{2}$	156	19.21	21.06	1.85	2.505	156.6
4	5	6$\frac{3}{4}$	140	19.17	21.21	2.04	2.763	172.6
5	5	5$\frac{7}{8}$	158	19.13	21.21	2.08	2.817	176.0
6	5	5$\frac{1}{2}$	158	19.09	21.26	2.17	2.939	183.7
7	5	4$\frac{3}{8}$	140	19.05	21.06	2.01	2.722	170.1
8	5	3$\frac{1}{8}$	132	19.01	20.86	1.85	2.505	156.6
9	5	4$\frac{1}{8}$	121	18.97	20.76	1.79	2.424	151.5
10	5	3$\frac{1}{4}$	146	18.93	20.66	1.73	2.343	146.4

One of the reasons, Mr. Robertson says, that induced him to make these experiments, was a desire to know what quantity of fir or oak timber would be sufficient to keep a man afloat in river or sea water, thinking that most men were specifically heavier than river or common fresh water; but the contrary appears from the trials before recited; for, except the first and last, every man was lighter than his equal bulk of fresh water, and much more so than his equal bulk of sea-water: consequently, if persons who fall into the water could preserve their presence of mind, many might be preserved from drowning; and a piece of wood, not larger than an oar, would buoy a man partly above water as long as he could adhere to it.*

The air bladder in aquatic animals may be considered as a most important hydrostatic contrivance to vary the specific gravity of the body at pleasure. There is a philosophical toy commonly constructed to illustrate the internal mechanism by which this is effected. It consists of a glass jar, and two or three small hollow fish made of the same material. The fish are so balanced by the introduction of water within, that they just float on the surface of the water. If a piece of bladder be now drawn tightly over the mouth of the jar, and the hand afterwards applied to the animal membrane, so



* The cork jacket which was originally contrived by the Abbé de la Chapelle, owes its principle of safety to its power of diminishing the specific gravity of the body it is intended to encase. The cork being considerably lighter than water, compensates for any want of buoyancy that might be found in the solid and fluid materials of which the human frame is composed.

as to compress the water within, they will descend, owing to their increased specific gravity.*

Dr. Coates has invented an hydrostatical balance, the object of which is to ascertain the specific gravity of minerals, &c. without the aid of calculation. It consists of a common steel-yard, the shorter arm of which is undivided, while the longer has engraven on it a scale, every division of which, reckoning from the extremity of the steel-yard, is marked with a number which is the quotient of the length of the whole scale, divided by the distance of the division from the end. Thus, 2 is placed at half the length, 3 at one-third of the length, the figures being continued up to the specific gravity of platinum. When the instrument is used, any convenient weight is suspended by a hook from the notch at the end of the longer arm. The mineral is then hung at the other end by a horse-hair, until it is in equilibrio with the weight. It is then immersed in water, without changing its place on the steel-yard, and an equilibrium is obtained a second time by shifting the weight; so that, when this is obtained, the hook of the weight will point out the specific gravity on the scale.

The specific gravity of a fluid body is usually found by

* The mathematical instrument makers also construct small hollow figures of enamel; but in the lower parts representing the feet, leave a small hole, through which a small portion of water may be introduced, or apply to the back part of each a sort of appendage in the form of a tail, pierced at the lower extremity. They then bring the figure into equilibrium with the fluid in which it is intended to float, and filling the bottle with water to the orifice, cover it with parchment or leather, which must be closely tied round the neck. To put the figures in motion, it is only necessary to press the parchment over the orifice, and the figures will descend, and, on the hand being removed, they will again rise.

immersing a light solid body of any known bulk, so as to show on a graduated rod, the depth to which it sinks in the fluid; and as this will depend on the buoyancy of the supporting media, which varies with its strength, the specific gravity may thus be ascertained.

The *hydrometer* generally resorted to, may first be shown in its simplest form. It consists of a hollow ball, either of metal or glass, with a graduated stem A B C. Beneath this is another stem and ball F. which preserves the apparatus in a perpendicular direction. When this instrument is swimming in any fluid, the part of the fluid displaced by it, as in other cases of swimming bodies, is equal in bulk to the part of the instrument under water, and equal in weight to the whole instrument. Now suppose the weight of the whole to be 4000 grains, it is evident we can use it to compare the different dimensions of 4000 grains of several sorts of fluids. For if the weight be such as to cause the ball to sink in water, until its surface come to the middle point of the stem; and afterwards, when immersed in some other fluid, the surface is observed to stand at one-tenth of an inch below the middle point; it is apparent that the same weight of the fluid in either case, differs only in bulk, by the magnitude of one-tenth of an inch in the stem. Suppose the stem to be ten inches long, and to weigh 100 grains, that every tenth of an inch will weigh one grain; and if the stem be of brass, which is about eight times heavier than water, the same bulk of water will be equal to one-eighth of a grain, and consequently to one-eighth of $\frac{1}{4000}$ that is, $\frac{1}{32000}$ part of the whole bulk. When the instrument is chiefly

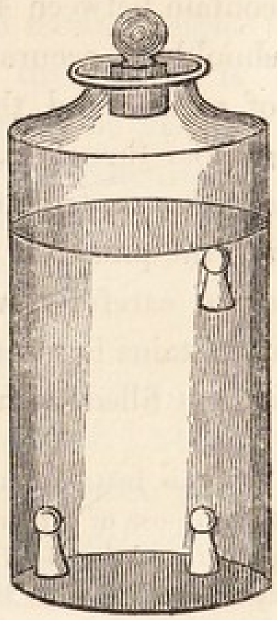
designed for proving the strength of spirituous liquors, the weight of it is such that it sinks in proof-spirit to the middle point, of the stem, while in alcohol it sinks to the top, A, and in water the ball at E. is only just covered: then by dividing the upper and the lower parts into ten equal parts each, when the instrument is immersed in spirituous liquor, it will immediately show how much it is above or below proof. Proof-spirit consists of about half water and half pure spirit, or alcohol; and if poured out on gunpowder and set on fire, will all burn away, and the powder will take fire with a flash as in the open air; but if the spirit be not so highly rectified, the powder will be wet, and unfit to take fire.

The hydrometer constructed in the ordinary way, cannot have a very extensive range; for if the stem be made heavy, it will scarcely be possible to detect any small difference in the density of the fluid under examination; and if it be long, its length will diminish the portability of the apparatus. To increase the range of the hydrometer, it has been proposed to change the ballast or weight in the secondary ball, but this would be inconvenient in practice.

Fahrenheit's hydrometer, like the common one, consists of a hollow ball, with a counterpoise *c*, but the stem B is very slender, and terminates in a small dish, A. Round the middle of the stem is drawn a fine line; and there are no divisions on the stem, which is always immersed in the fluid to be tried, up to the mark, by placing as much weight as may be required in the small dish A. Hence, as the part immersed is constantly of the same magnitude, and the whole weight of the hydrometer is known; this last weight, added to the weight in the dish, will be equal to the weight of fluid displaced by

the instrument. This instrument is much superior to the hydrometer first mentioned: the greatest impediment to its accuracy arises from the attraction or repulsion between the surface of the fluid and that of the stem; so that if the instrument has a tendency to sink, there will be a depression of the fluid in the neighbourhood of the stem; or if, on the contrary, its tendency be to rise, the fluid at that part will be higher than the rest of the surface. When, however, the surface of the fluid is exactly flat, the reflection of any straight lines, as of the frame-work of a window, will not be distorted, and by taking notice of such reflection from the part surrounding the stem, the adjustment may be made to the fortieth or fiftieth part of a grain.

One mode of ascertaining the specific gravities of fluids, differing but little from each other in density, is to have a series of globules of glass so loaded, as to correspond to the specific gravities indicated by as many numbers, which are marked on them, and throwing several of them together into the fluid, and to observe which of them remains nearly stationary, without either rising to the surface or sinking to the bottom of the vessel that contains them.



Annexed is a valuable though simple hydrometer, suggested by Mr. London, constructed with reference to this principle; and its usefulness arises from the facility with which the hollow globules may be brought to any required specific gravity, by grinding

away small portions of the pendulous end attached to the ball above.*

The process of ascertaining specific gravities by means of the hydrometer, though generally resorted to for that purpose, is not the most accurate. Indeed, the only method of effecting this with certainty, is to weigh a certain portion of the fluid in a bottle against a similar quantity of pure water. Thus we may employ a thin phial, holding 1000 grains of distilled water, at the temperature of 60°. If filled with any other liquid, and weighed, we learn its specific gravity, and we shall find that it would contain 13,500 grains of mercury; 1850 grains of sulphuric acid; 1420 grains of nitric acid, &c., which numbers, of course, represent the specific gravities of those liquids.

A bottle, however, holding 1000 grains is often inconveniently large, and a small and thin globular phial, with a piece of thermometer tube ground into it by way of stopper, will be found more useful: such a phial should not weigh more than from 50 to 60 grains, and may contain between 4 and 500 grains of water. To use it, it should be accurately counterbalanced in a delicate pair of scales, and then filled with distilled water, and the stopper thrust in, the capillary opening in which allows a little to ooze out, and prevents the likelihood of bursting the phial; it is then to be wiped clean and dry, and again carefully weighed, by which the quantity of water it contains is ascertained; the water being poured out, it is next filled with the liquid whose specific gravity is re-

* This instrument is so delicate, that it will be found to answer the purpose of a thermometer; for the slightest increase in the temperature of the fluid will diminish its specific gravity; and as such, cause the ball to sink, and *vice versa*.

quired, taking care that it is of the same temperature as the water; we then weigh as before, and divide the weight by the former weight of water: the product gives the specific gravity required.

Having in a previous page described the apparatus employed in ascertaining the weight of atmospheric air, it may be enough in the present place to point out the mode of discovering, by direct experiment, the specific gravity of any other gaseous body. This is readily effected when we have once determined its absolute weight. Thus, if 100 cubic inches of air weigh 30.5 grains, and the same quantity of oxygen gas weighs 34 grains, we say,

$$30.5 : 34 :: 1.000 : 1.1147.$$

The specific gravity of oxygen gas will, therefore, be as 1.1147 to 1.000. We may determine, also, the specific gravity of gases more simply by weighing the flask, first, when full of common air, and again when exhausted; and afterwards by admitting into it as much of the gas under examination as it will receive, and weighing it a third time. Now as the loss between the first and second weighing is to the gain of weight on admitting the gas, so is common air to the gas whose specific gravity we are estimating. Supposing, for example, that by exhausting the flask, it loses 30.5 grains, and that by admitting carbonic acid it gains 47; then

$$30.5 : 47 :: 1.000 : 1.5409.$$

The specific gravity of carbonic acid is therefore 1.5409, air being taken at 1.000. And knowing its specific gravity, we can, without any farther experiment, determine the weight of 100 cubic inches of carbonic acid; for, as

the specific gravity of air is to that of carbonic acid, so is 30.5 to the number required; or

1.000 : 1.5409 : : 30.5 : 47.

100 cubic inches, therefore, of carbonic acid will weigh 47 grains.

A table of Specific Gravities is of the greatest possible use to the experimentalist in this science, and the most valuable list that has yet been compiled is from the pen of Dr. Brewster. The data thus furnished have in most cases been adopted in the present table, and generally verified by actual experiment.

Acid, nitric	1.272
—— muriatic	1.194
—— red acetous	1.025
—— white acetous	1.014
—— distilled acetous	1.010
—— acetic	1.0626
—— sulphuric, highly concentrated	2.125
—— nitric, highly concentrated	1.580
—— fluoric	1.500
—— formic	0.9942
—— phosphoric	1.5575
—— citric	1.0345
—— arsenic	1.8731
—— of oranges	1.0176
—— of gooseberries	1.0581
—— of grapes	1.0241
Æther, sulphuric	0.7396
—— nitric	0.9088
—— muriatic	0.7296
—— acetic	0.8664
Agate, oriental	2.5901
—— onyx	2.6375
—— speckled	2.607
—— cloudy	2.6253
—— stained	2.6324
—— veined	2.6667
—— Icelandic	2.348
—— of Havre	2.5881
Air, atmospheric, Barom. 29.75. Thermom. 32.	0.00122

Air, Barom. 22.85 Thermom. 54°.5	Lavoisier	0.0012308
Alabaster of Valencia		2.638
——— veined		2.691
——— of Malaga pink		2.8761
——— of Dalias		2.6110
Alcohol, highly rectified		0.8293
——— commercial		0.8371
——— 15 parts water 1 part		0.8527
14 2		0.8674
13 3		0.8815
12 4		0.8947
11 5		0.9075
10 6		0.9199
9 7		0.9317
8 8		0.9427
7 9		0.9519
6 10		0.9594
5 11		0.9674
4 12		0.9733
3 13		0.9791
2 14		0.9852
1 15		0.9919
Alder wood	Muschenbroek	0.8000
Aloes, hepatic		1.3586
——— socotrine		1.3795
Alouchi, odoriferous gum		1.0604
Alumine, sulphate of	Muschenbroek	1.7140
——— saturated solution of, Tem. 42°	Watson	1.033
Amber, yellow, transparent		1.0780
——— opaque		1.0855
——— red		1.0834
——— green		1.0829
Ambergris		0.7800 0.9263
Amethyst, common. *See* Rock Chrystal		2.750
Amianthus, long		0.9088
——— penetrated with water		1.5662
——— short		2.3134
——— penetrated with water		2.3803
Amianthinite from Raschau		2.584
——— from Bayreuth		2.916
Ammoniac		0.8970
——— muriate of	Muschenbroek	1.4530
——— saturated solution of, Temp. 42°	Watson	1.072
Antimony, glass of		4.9464
——— in a metallic state, fused		6.624 6.860
——— native	Klaproth	6.720
——— sulphur of		4.0643
Antimonial ore, grey and foliated	Kirwan	4.368
Apple tree	Muschenbroek	0.7930
Aquamarine. *See* Beryl.		
Arcanson		1.0857
Areca, inspissated juice of		1.4573

Arctizite, or Wernerite	Dandrada	3.606
Argillite, or slate clay	Kirwan	2.600 / 2.680
Arnotto		0.5956
Arragon spar	Häuy	2.946
Arsenic bloom, Pharmacolite	Selb.	2.536
	Klaproth	2.640
——— fused	Bergman	8.310
——— native	Brisson	5.725 / 5.763
	Kirwan	5.670
——— pyrites, common	Stiltz	4.791
	Brisson	6.522
	La Metherie	5.600
	Gellert	5.753
——— native, orpiment		5.452
——— glass of (arsenic of the shops)		3.5942
Asbestos, mountain cork	Bergman	0.6806 / 0.9933
——— penetrated with water		1.2492 / 1.3492
——— ripe	Brisson	2.5779
——— penetrated with water		2.6994
——— starry		3.0733
——— penetrated with water		3.0808
——— unripe		2.9958
——— penetrated with water		3.0343
Ash trunk	Muschenbroek	0.8450
Asphaltum, cohesive		1.450 / 2.060
——— compact		1.070 / 1.165
Assafœtida		1.3275
Augite, octaedral Basaltes	Häuy	3.226
———	Werner	3.471
———	Reuss	3.777
Azure stone, or Lapis Lazuli	Brisson	2.7675
———	Kirwan	2.896
——— oriental		2.7714
——— of Siberia		2.9454
Barolite, or Witherite		4.300 / 4.338
Baroselenite, or Barytes		4.400 / 4.865
——— white		4.4300
——— grey		4.4909
——— Rhomboidal		4.4434
——— Octaedral		4.4712
——— in Stalactites		4.2984
Basaltes	Kirwan	2.979
———	Bergman	3.000
Basaltes, from the Giants' Causeway		2.864
——— prismatic, from Auvergne		2.4215
Baras, a juice of the pine		1.0441
Bay tree, Spanish	Muschenbroek	0.8220
Bdellium		1.1377

Beech-wood	Muschenbroek	0.8520
Beer, red		1.0338
—— white		1.0231
Benzoin		1.0924
Beryl, oriental Aquamarine		3.5491
—— occidental		2.723
—— or Aquamarine	Werner	2.650 2.759
—— schorlous, or Shorlite	Häuy	3.514
——————	Klaproth	3.530
Bezoar, oriental		1.666
—— occidental		2.233
Bismuth, native	Brisson Kirwan	9.020 9.570
—— sulphurated	Brisson Kirwan	6.467 6.131
Bismuth, ochre	Brisson	4.371
—— in a metallic state, fused		9.756 9.822
Bitumen, of Judea		1.104
Black coal, Pitch coal	Wiedemann	1.308
—— Slate Coal, English	Kirwan	1.250 1.370
—— Cannel coal	Kirwan La Metherie	1.232 1.270
Blende, yellow	Gellert Kirwan	4.044 4.048 4.067
—— brown, iated	Gellert Kirwan	3.770 4.048 3.963
—— black	Gellert Brisson	3.967 3.930 4.166
Blood, human		1.054
—— crassamentum of		1.126
Boles	Kirwan	1.400 2.000
Bone of an ox		1.656
Boracite	Westrumb	2.566
Borax, saturated solution of, Temp. 42°.	Watson	1.010
Bournonite		5.576
Boxwood, French	Muschenbroek	0.9120
—— Dutch	——	1.3280
Brass, common cast		7.824
—— wiredrawn		8.544
—— cast, not hammered		8.396
Brazil wood, red	Muschenbroek	1.0310
Brick		2.000
Butter		0.9423
Cacao butter		0.8916
Calamine	Brisson La Metherie	3.524 4.100
Campechy wood, or log-wood	Muschenbroek	0.9130
Camphor		0.9887
Caoutchouc, elastic gum, or India rubber		0.9335

Caragna, resin of the Mexican tree Caragna		1.1244
Carbon of compact earth		1.3292
Carnelian, stalactite		2.5977
——— speckled		2.6137
——— veined		2.6234
——— onyx		2.6227
——— pale		2.6301
——— pointed		2.6120
——— herborisèe		2.6133
Cat's-eye	Klaproth	2.600
		2.625
Catchew, the juice of an Indian-tree		1.3980
Caustic ammoniac, solution of, or fluid volatile alkali		0.897
Cedar tree, American	Muschenbroek	0.5608
——— wild	———	0.5960
——— Palestine	———	0.6130
——— Indian	———	1.3150
Celestine	Klaproth	3.830
——— foliated		3.500
Ceylanite	Häuy	3.765
		3.793
Chalcedony, bluish		2.5867
——— onyx		2.6151
——— veined		2.6059
——— transparent		2.6640
——— reddish		2.6645
——— common	Kirwan	2.600
		2.655
	Blumenbach	2.615
Chalk	Muschenbroek	2.252
	Kirwan	2.315
	Watson	2.657
Cherry-tree	Muschenbroek	0.7150
Chrysoberyll	Werner	3.600
		3.720
	Klaproth	3.710
	Häuy	3.796
Chrysolite of the jewellers	Brisson	2.782
——— of Brasil		2.692
———	Werner	3.340
———		3.410
———	Häuy	3.428
Chrystal. *See* Rock.		
Chrystalline lens		1.100
Cinnabar, dark red, from Deux Ponts	Kirwan	7.786
——— from Almaden	Brisson	6.902
——— chrystallized	———	10.218
Cinnamon, volatile oil of		1.044
Citron tree	Muschenbroek	0.7263
Clinkstone	Klaproth	2.575
Cloves, volatile oil of		1.036
Cobalt, in a metallic state, fused		7.645
		7.811
——— ore, gray	Häuy	5.511
		7.721
	Kirwan	5.309

Cobalt ochre, black, indurated	Gellert	2.019 / 2.425
—— vitreous oxide of		2.4405
Cocoa wood	Muschenbroek	1.0403
Copal, opaque		1.1398
—— transparent		1.0452
—— Madagascar		1.0600
—— Chinese		1.0628
Copper, native	Kirwan	7.600 / 7.800
—— from Siberia	Häuy	8.5084
—— Hungary	Gellert	7.728
Copper ore, compact vitreous	Kirwan	4.129
—— Cornish	——	5.452
Copper ore, purple, from the Bannat	——	4.956
—— ore from Lorraine	——	4.983
	La Metherie	4.300
	Wiedemann	5.467
—— pyrites	Kirwan	4.080
	Brisson	4.344
—— ore, white	La Metherie	4.500
—— gray	Häuy	4.865
—— foliated, florid, red	Wiedemann	3.950
—— azure, radiated	——	3.231
	Brisson	3.608
—— emerald	La Metherie	2.850
	Häuy	3.300
Copper, arseniate of		2.549
—— sulphate of, saturated sol. of, Temp. 42°	Watson	1.150
—— drawn into wire		8.878
—— fused		7.788
Copper-sand, muriate of copper	La Metherie	3.750
	Herrgen	4.431
Cork	Muschenbroek	0.2400
Corundum of India	Klaproth	3.710
	Häuy	3.873
	Bournon	3.875
—— of China		3.981
Cross Stone, or Staurolyte	Kirwan	2.355 / 2.361
	Heyer	2.353
	Häuy	2.333
Cryolite	——	2.949
	Karsten	2.957
Cube Iron ore	Bournon	3.000
—— spar	Häuy	2.964
Cyanite	Saussure, jun.	3.517
	Hermann	3.622
Cyder		1.0181
Cypress-wood, Spanish	Muschenbroek	0.6440
Diamond, oriental, colourless		3.5212
—— rose-coloured		3.5310
—— orange-coloured		3.5500
—— green-coloured		3.5238
—— blue-coloured		3.5254
—— Brazilian		3.4444
—— yellow		3.5185

Dragons blood		1.2045
Ebony, Indian	Muschenbroek	1.2090
—— American	————	1.3310
Elder tree	————	0.6950
Elemi		1.0182
Elm trunk	Muschenbroek	0.6710
Emerald	Werner	2.600
—— of Peru	Brisson	2.7755
————	Häuy	2.723
—— of Brasil		3.1555
Euclase	Häuy	3.062
Euphorbium		1.1244
Fat of beef		0.9232
—— veal		0.9342
—— mutton		0.9235
—— hogs		0.9368
Felspar, fresh	Häuy	2.438
—— Adularia	Struve	2.500 2.600
	Morell	2.561
—— Labrador stone	Brisson	2.607 2.704
—— glassy		2.518 2.589
Filbert tree	Muschenbroek	0.6000
Fir, male	————	0.5500
—— female	————	0.4980
Fishes eye, name of a mineral		2.5782
Flint	Gellert	2.581
	Blumenbach	2.594
—— olive		2.6057
—— spotted		2.5867
—— onyx		2.6644
—— of Rennes		2.6538
—— of England		2.6087
—— variegated of Limosin		2.2431
—— veined		2.6122
—— Egyptian		2.5648
—— black		2.582
Fluor, white		3.155
—— red		3.191
—— green		3.182
—— blue		3.169
—— violet		3.178
Fluor spar		3.100 3.200
Gadolinite	Häuy	4.050
Galbanum		1.2120
Galena. *See* Lead Glance.		
Galipot, a juice of the pine		1.0819
Gamboge		1.2220
Garnet, precious of Bohemia	Klaproth	4.085 4.188
————	Werner	4.230
————	Kastner	4.352
—— volcanic 24 faces		2.468

Garnet, of Syria		4.000
—— in dodecahedral chrystals		4.0637
—— common	Kastner	3.688
	Werner	3.576
Gas, azotic, pure, Barom. 29.75		0.001146
Barom. 29.85, Therm. 54½	Lavoisier	0.001189
—— oxygenous		0.001305
—— ——	Davy	0.001387
—— ——		0.001356
—— hydrogenous		0.000099
—— ——	Lavoisier	0.000095
—— ——	Dalton	0.000123
—— carbonic acid	Brisson	0.001862
—— ——	Lavoisier	0.001845
—— nitrous		0.001411
—— —— Barom. 29.85, Therm. 54½	Kirwan	0.001463
—— ——	Brisson	0.001302
—— ammoniacal		0.000706
—— ——	Brisson	0.000654
—— —— Barom. 29.85, Therm. 54½	Kirwan	0.000735
—— vapour aqueous	Dalton	0.000862
—— ——	Saussure	0.000874 / 0.000923
—— ——	Pictet	0.000751
—— ——	Watt	0.000825
—— sulphurous, Barom. 29.85, Therm. 54½	Kirwan	0.001886 / 3.131
—— acid, sulphurous		0.002539
—— acid muriatic		0.002135
Girasol	Brisson	4.000
Glance-coal, slaty	Klaproth, Kirwan	1.530
	Metherie	1.300
Glass, white flint		3.300
—— crown		2.520
—— common plate		2.760
—— yellow plate		2.520
—— white or French chrystal		2.8922
—— bottle		2.7325
—— Leith crystal		3.189
—— green		2.6423
—— borax		2.6070
—— fluid		3.329
—— of Bohemia		2.3959
—— of Cherbourg		2.5596
—— of St. Cloud		3.2549
—— animal		2.5647
—— mineral		2.2694
Gold, pure, of 24 carats, fine, fused, but not hammered		19.258
—— the same hammered		19.342
—— English standard, 22 carats, fine, fused, but not hammered		18.888

Gold, guinea of George II.		17.150
—— guinea of George III.		17.629
—— Parisian standard 22 carats, not hammered		17.486
—— the same hammered		17.589
—— Spanish gold coin		17.655
—— Holland ducats		19.352
—— trinket standard, 20 carats, not hammered		15.709
—— the same hammered		15.775
—— Portuguese coin		17.9664
—— French money $21\frac{2}{3}$ carats fused		17.4022
———— coined		7.6474
—— French in the reign of Louis XIII.		17.5531
Granite, red Egyptian		2.6541
—— grey, Egyptian		2.7279
—— beautiful red		2.7609
—— green, of Dauphiny		2.6836
—— radiated, ditto		2.6678
—— red of Semur		2.6384
—— grey of Bretagne		2.7378
—— yellowish		2.6136
—— of Carinthia, blue	Kirwan	2.9564
Granitelle		3.0626
—— of Dauphiny		2.8465
Graphic ore	Muller	5.723
Gum Arabic		1.4523
—— Trajacanth		1.3161
—— seraphic		1.201
—— cherry tree		1.4817
—— Bassora		1.4346
—— Acajou		1.4456
—— Monbain		1.4206
—— Gutte		1.2216
—— ammoniac		1.2071
—— Gayac		1.2289
—— lac		1.1390
Gunpowder in a loose heap		0.836
—— shaken		0.932
—— solid		1.745
Gypsum, opaque		2.1679
—— compact, specimen in the Leskean collection		2.939
—— compact		1.872 2.288
—— impure		2.473
—— foliated, mixed with granular limestone	Kirwan	2.725
—— alabaster	Ward	1.872
—— semitransparent		2.3062
—— rhomboidal		2.3114
—— ditto, 10 faces		2.3117
—— cuniform, chrystallised		2.3060
—— striated of France		2.3057
———— of China		2.3088
—— flowered		2.3059
—— granularly foliated, in the Leskean collection	Kirwan	2.900
—— mixed with marl, of a slaty form	——	2.473

Hazel	Muschenbroek	0.606
Heavy spar, fresh, straight, lamellar		4.300 4.500
——— columned, not above		4.500
Heliotropium	Kirwan	2.620 2.700
———	Blumenbach	2.633
Hollow spar, Chiastolite		2.944
Hone, razor, white		2.8763
——— penetrated with water		2.8839
—— razor, white and black		3.1371
Honey		1.4500
Honeystone, or Mellilite		1.586 1.666
Hornblende, common	Kirwan	3.600 3.830
——— resplendent, Labradore	———	3.350 3 434
——— Schiller spar	———	2.882
——— Schistose	———	2.909 3.155
——— basaltic	Reuss	3 150 3.220
———	Häuy	3.250
———	Kirwan	3.333
Hornstone, or Petrosilex		2.530 2.653
——— ferruginous		2.813
——— veined		2.747
——— blackish grey		2.744
——— yellowish white		2.563
——— bluish, and partly yellowish grey		2.626
——— dark purplish red iron shot		2.638
——— greenish white, with reddish spots from Lorraine		2.532
——— iron shot, brownish red, outside blueish, grey inside		2.813
Hyalite	Kirwan	2.110
Hyacinth	Karsten	4.000
———	Häuy	4.386
———	Klaproth	4.545 4.620
Jade, or Nephrite, white		2.9502
—— green		2.9660
—— olive		2.9829
—— from the East Indies	Kirwan	2.977
Of Switzerland	Brisson	3.310 3.389
—— combined with the Boracic acid and Boracited calx		2.566
Jasmin, Spanish	Muschenbroek	0.7700
Jasper, veined		2.6955
——— red		2,6612
——— brown		2.6911
——— yellow		2,7101
——— violet		2.7111

Jasper grey		2.7640
—— cloudy		2.7354
—— green		2.6274
—— bright green		2.3587
—— deep green		2.6258
—— brownish green		2.6814
—— blackish		2.6719
—— blood coloured		2.6277
—— heliotrope		2.6330
—— onyx		2.8160
—— flowered, red and white		2.6228
———— red and yellow		2.7500
———— green and yellow		2.6839
———— red, green, and grey		2.7323
———— red, green, and yellow		2.7492
—— universal		2.5630
—— agate		2.6608
Jet, a bituminous substance		1.2590
Indigo		0.7690
—— penetrated with water		1.0095
Iridium, ore of, discovered by Mr. Tennant	Wollaston	19.500
Iron, chromate of, from the department of Var,		4.0326
———— from the Ouralian mountains, in Siberia	Lauguier	4.0579
—— sulphate of, saturated solution, Temp. 42	Watson	1.157
—— fused, but not hammered		7.200
—— forged into bars		7.600 7.788
—— pyrites, dodecahedral	Hatchet	4.830
———— from Freyberg	Gellert	4.682
———— Cornwall	Kirwan	4.789
———— cubic	Brisson	4.702
———— radiated	Hatchet	4.698 4.775
—— sand, Magnetic sand, from Virginia		4.600
—— ore specular	Kirwan	4.793 5.139
————	Brisson	4.939 5.218
———— micaceous	Kirwan	4.728 5.070
Ironstone, red, ochrey	Wiedemann	2.952
———— compact	Kirwan	3.423
———— from Siberia	——	3.760
———— Lancashire	Brisson Wiedemann	3.573 3.863
———— compact, brown, from Bayreuth	Kirwan	3.551
———— Tyrol	——	3.753
———— cubic	Brisson	3.503 3.477
———— red hematites	Kirwan	5.005
————	Gellert	4.740
———— brown hematites	Kirwan	3.951
————	Gellert	3.789
————	Wiedemann	4.029
———— sparry, or calcareous	Kirwan	3.640 3.810

Ironstone, sparry, or calcareous	Brisson	3.672
——— decomposed	Kirwan	{ 3.300 3.600 }
——— black, compact	Wiedemann	4.076
——— clay Reddle	Brisson	3.139
———————	Blumenbach	3.931
——— clay lenticular	Kirwan	2.673
——— Roscommon in Ireland	Rotheram	3.471
——— Carron in Scotland	———	{ 3.205 3.357 }
——— clay, reniform iron ore	Wiedemann	2.574
——— ——— pea ore	Molinghof	5.207
Iron ore, lowland, from Sprottau	Kirwan	2.944
Iserine, a mineral from the Isre in Bohemia		4.500
Juniper tree	Muschenbroek	0.5560
Ivory, dry		1.8250
Ivy gum, from the hedera terrestris		1.2948
Keffekil, or Meerschaum	Klaproth	1.6000
Kinkina	Muschenbroek	0.7840
Labdanum, Resin		1.1862
——— *in tortis*		2.4933
Lapis nephriticus		2.894
—— hæmatites		4.360
—— judaicus		2.500
—— manati		2.270
—— hepaticus		2.666
—— obsidianus		2.348
Lard		0.9478
Lavender, volatile oil of		0.894
Lead glance, or Galena, common	Gellert	7.290
——— from Derbyshire	Watson	{ 6.565 7.786 }
——— compact	Gellert	{ 6.886 7.444 }
———————	Kirwan	{ 4.319 5.052 }
——— chrystallized	Brisson	7.587
——— radiated	La Metherie	5.500
——— from the Hartz	Kirwan	7.448
——— Kautenbach	Vauquelin	6.140
——— Kirschwalder	———	6.820
—— ore, corneous	Chenevix	6.065
——— reniform	Bindheim	3.920
——— of black lead		6.745
——— blue	Gellert	5.461
——— brown	Wiedemann	6.974
——— ——— from Huguelgoet	Klaproth	6.600
———————	Häuy	6.909
——— black	Gellert	5.770
——— white from Leadhills	Chenevix	7.236
———————	Häuy	6.559
——— Zschoppau	Klaproth	6.270
——— Breisgaw	Häuy	6.941
Lead ore red, or red lead spar	Bindheim	5.750
———————	Brisson	6.027
——— yellow, molybdenated		5.092

Lead	Brisson	11.352
——	Gellert	11.445
—— acetite of . . .	Muschenbroek	2.3953
—— vitriol from Anglesea . .	Klaproth	6.300
Lemon tree	Muschenbroek	0.7033
Lenticular ore (arseniate of copper) .	Bournon	2.882
Lepidolite, Lilalite . . .	Klaproth	2.816
————	Häuy	2.854
Lignum vitæ	Muschenbroek	1.3330
Limestone compact		{ 1.3864 2.7200
——— foliated		2.710
————		2.837
——— granular		2.700
————		2.800
——— green		3.182
——— arenaceous . . .		2.742
——— white fluor . . .		3.156
——— calc. spar		2.700
Linden wood	Muschenbroek	0.604
Logwood, or Campechy wood . .	————	0.9130
Madder root	————	0.7650
Mahogany		1.0630
Magnesia	Kirwan	2.3300
——— sulphate of, satur. solution, Tem. 42°	Watson	1.232
Magnetic pyrites	Hatchet	4.518
——— Ironstone . . .		{ 4.200 4.939
Malachite	Brisson	3.572
——— compact	———	3.641
————	Muschenbroek	3.994
Manganese	Bergman	6.850
———	Hielm	7.000
——— grey ore of, striated . .	Brisson	{ 4.249 4.756
———————— . . .	Rinmann	4.181
———————— . . .	Hagen	4.143
——— grey foliated . . .	———	3.742
——— red from Kapnick . .	Kirwan	3.233
——— black	Dolomieu	{ 2.0000 3.0000
————	Brisson	3.7076
———— penetrated with water .		3.9039
———— scaly		4.1165
Maple wood	Muschenbroek	0.7550
Marble, Pyrenean		2.726
——— black Biscayan . . .		2.695
——— Brocatelle		2.650
——— Castilian		2.700
——— Valencian		2.710
——— Grenadian, white . . .		2.705
——— Siennian		2.678
——— Roman violet . . .		2.755
——— African		2.708
——— Italian violet . . .		2.858
——— Norwegian		2.728
——— Siberian		2.728

Marble French		2.649
——— Switserland		2.714
——— Egyptian, green . . .		2.668
——— yellow of Florence . . .		2.516
Mastic		1.0742
——— tree	Muschenbroek	0.8490
Medlar tree	———————	0.9440
Meerschaum. *See* Keffekil.		
Melanite, or black garnet . .	Karsten	3.691
———	Werner	3.800
Menachanite	Gregor	4.427
———	Lampadius	4.270
Mercurial hepatic ore, compact .	Kirwan	7.186 7.352
——————————— . .	Gellert	7.937
Mercury at 32° of heat . . .		13.619
——— at 60°		13.580
——— at 212°		13.375
——— corrosive muriate of, saturated solution, Temp. 42° . . .	Watson	1.037
——— natural calx of . . .		9.230
——— precipitate per se . .		10.871
——————— red . . .		8.399
——— mineralized by sulphur, native Ethiops,	Hahn	2.233
Mica, or glimmer	Brisson	2.791
———	Blumenbach	2.934
Milk, human		1.0203
—— mare's		1.0346
—— ass's		1.0355
—— goat's		1.0341
—— ewe's		1.0409
—— cow's		1.0324
Mineral from Cornwall, supposed to be zeolite at 55° Fahr. . . .	Gregor	2.253
Mineral pitch, elastic, or asphaltum .	Hatchet	0.905 1.233
——————————— . .	La Metherie	0.930
——————————— .	Jordan	0.902
Mineral tallow		0.770
Molybdena in a metallic state, saturated with water		7.500
——— native	Brisson	4.7385
Mulberry tree, Spanish . . .	Muschenbroek	0.8970
Muricalcite chrystallized, or Rhomb spar .		2.480
Myrrh		1.3600
Naphtha		0.8475
Nickel in a metallic state . . .		7.421 8.500
———————	Bergman	9.3333
——— copper	Brisson	6.6086 6.6481
———————	Gellert	7.560
Nickel, ore of, called Kupfernickel of Saxe .		6.648
——————— Kupfernickel of Bohemia		6.607
——— sulphurated		6.620
Nickeline, a metal discovered by Richter, cast	Richter	8.55
——————————— forged	Richter	8.60

Nirgine, or calcareo-siliceous Titanic ore	Vauquelin	3.700
———	Klaproth	4.445
———	Lowitz	4.673
Nitre	Muschenbroek	1.9000
—— quadrangular	———	2.2460
—— saturated solution of, Temp. 42°	Watson	1.095
Oak, sixty years old, heart of	Muschenbroek	1.1700
Octahedrite	Häuy	3.857
Oil of Filberts		0.916
—— walnut		0.9227
—— hemp-seed		0.9258
—— poppies		0.9238
—— rape-seed		0.9193
—— lint-seed		0.9403
—— poppy-seed		0.929
—— whale		0.9233
—— Ben, a tree in Arabia		0.9119
—— Beechmast		0.9176
—— codfish		0.9233
—— olives		0.9153
—— almonds, sweet		0.9170
—— volatile of mint, common		0.8982
—— volatile of sage		0.9016
——— thyme		0.9023
——— rosemary		0.9057
——— calamint		0.9116
——— cochlearia		0.9427
——— wormwood		0.9073
——— tansy		0.9328
——— stragan		0.9949
——— Roman camomile		0.8943
——— sabine		0.9294
——— fennel		0.9294
——— fennel-seed		1.0083
——— coriander-seed		0.8655
——— carraway-seed		0.9049
——— dill-seed		0.9128
——— anise-seed		0.9867
——— juniper-seed		0.8577
——— cloves		1.0363
——— cinnamon		1.0439
——— turpentine		0.8697
——— amber		0.8865
——— the flowers of orange		0.8798
——— lavender		0.8938
——— hysop		0.8892
Olibanum, gum		1.1732
Olive tree	Muschenbroek	0.9270
—— copper ore foliated }	Bournon	4.281
——— fibrous }		
Olivine	Werner	3.225
———	Klaproth	3.265
Opal precious	Blumenbach	2.114
—— common }	Klaproth	{ 1.958
——— }		{ 2.015
———	Kirwan	2.144
—— semiopal, reddish from Telkobanya	Klaproth	2.540

Opal, ligniform, or wood		2.600
Opium		1.3365
Opoponax		1 6226
Orange tree	Muschenbroek	0.7050
Orpiment	Bergman	3.315
———	Kirwan	3.048
———	Kirwan	3.435
Orpiment red. *See* Realgar		
Pear tree	Muschenbroek	0.6610
Pearls, oriental		2.683
Peat, hard		1.329
Peruvian bark		0.7840
Petrol		0.8783
Petrosilex. *See* Hornstone.		
Phosphorite, or Spargel stone, whitish from Spain, before absorbing water		2.8249
——— after absorbing water		2.8648
——— greenish from Spain		3.098
——— Saxon		3.218
Phosphorus		1.714
Pierre de volvic		2.320
Pinite	Kirwan	2.980
Pitch ore, or sulphurated Uranite	Guyton	6.378
———	Häuy	6.530
———	Klaproth	7.500
Pitch-stone, black	Brisson	2.0499
——— yellow	———	2.0860
——— red	———	2.6695
——— brick, red from Misnia	Kirwan	2.720
——— leek, green, inclining to olive	———	2.298
——— pearl grey	———	1.970
——— blackish	Brisson	2.3191
——— olive	———	2.3145
——— dark green	———	2.3149
Pitchy, iron ore		3.956
Platina drawn into wire		21.0417
——— in grains purified by boiling in nitrous acid		17.500 18.500
——— native		15.601 17.200
——— fused		14.626
——— purified and forged		20.336
——— compressed by a flatting-mill		22.069
Plumb tree	Muschenbroek	0.7850
Plumbago, or Graphite	Kirwan	1.987 2.267
Pomegranate tree	Muschenbroek	1.3540
Poplar wood	———	0.3830
——— white Spanish	———	0.5294
Porcelain from China		2.3847
——— Seves, hard		2.1457
——— ——— tender		2.1654
——— Saxony, modern		2.4932
——— Limoges		2.341
——— of Vienna		2.5121
Porphyry green		2.6760
——— red		2.7651

Porphyry red of Dauphiny		2.7933
——— red from Cordova		2.7542
——— green from ditto		2.7278
——— hornblende, or ophites		2.9722
——— itch-stone		2.452
——— mullen		2.600 2.728
——— sand-stone		2.564
Potash, carbonate of		1.4594
——— muriate of	Muschenbroek	1.8365
——— tartrite of acidulous	———	1.9000
——— ——— antimonial		2.2460
——— sulphate of		2.2980
Prasium		2.5805
Prehnite of the Cape	Häuy	2.697
———	Brisson	2.9423
——— of France	Häuy	2.610
Proof spirit, according to the English Excise laws		0.916
Pumice stone		0.9145
Pyrites, coppery		4.9539
——— cubical		4.7016
——— ferruginous cubic		3.900
——— ditto round		4.101
——— ditto of St. Domingo		3.440
Pyrope	Klaproth	3.718
———	Werner	3.941
Quartz chrystallized, brown, red		2.6468
——— brittle		2.6404
——— chrystallized		2.6546
———		2.647
——— milky		2.652
——— elastic	Gerhard	3.750
———	Kirwan	2.6240
Quince tree	Muschenbroek	0.7050
Realgar, or red orpiment	Bergman	3.225
———	Brisson	3.338
Resin, or Guiacum		1.2289
——— of Jalap		1.2185
Rock, or Mountain chrystal from Madagascar		2.6530
——— clove brown	Karsten	2.605
——— chrystal, European pure, gelatinous		2.6548
——— of Brasil		2.6526
——— rose coloured		2.6701
——— yellow Bohemian		2.6542
——— blue		2.5813
——— violet, or Amethyst		2.6535
——— violet purple, or Carthaginian Amethyst		2.6570
——— pale violet, white Amethyst		2.6513
——— brown		2.6534
——— black		2.6536
Roucou		0.5956
Ruby, oriental		4.2833
——— Brazilian, or occidental		3.5311
———	Klaproth	3.5700
——— Ballas		3.6458

Rutile, or Titanite	Häuy	4.102
———	Klaproth	4.180
Sahlite	Dandrada	3.234
Salt of vitriol		1.9000
—— sedative of Homberg		1.4797
—— Polychreste		2.1410
—— de Prunelle		2.1480
—— volatile of hartshorn		1.4760
Sandarac		1.0920
Sapagenum		1.2008
Sapphire, oriental white		3.991
——— of Puys		4.076
——— oriental		3.994
——— Brazilian, or occidental		3.1307
———————	Werner	3.980
		4.180
———————	Häuy	3.994
		4.283
———————	Hatchet	4.000
	Greville	4.083
Sarcocolla		1.2684
Sardonyx pure	Brisson	2.6025
——— pale	———	2.6060
——— pointed	———	2.6215
——— veined	———	2.5951
——— onyx	———	2.5949
Sassafras	Muschenbroek	0.4820
Scammony, of Aleppo		1.2354
——— Smyrna		1.2743
Scapolite	Dandrada	3.6800
		3.7000
Schorl, black, prismatic, hexahedral		3.3636
——— cruciform		3.2861
——— violet of Dauphiny		3.2956
——— green		3.4529
——— common	Brisson	3.092
———	Gerhard	3.150
———	Kirwan	3.212
——— tourmaline	Brisson	3.086
——— green	Häuy	3.362
——— blue	Brisson	3.130
———	Werner	3.155
Selenite, or broad foliated gypsum		2.322
Serpentine, opaque, green, Italian		2.4295
——— penetrated with water		2.4729
——— ditto red and black veined		2.6273
——— ditto veined, black and olive		2.5939
——— semi-transparent grained		2.5859
——— ditto fibrous		2.9997
——— ditto from Dauphiny		2.6693
——— opaque, spotted black and white		2.3767
——— spotted black and grey		2.2645
——— spotted red and yellow		2.6885
Siderocalcite, or brown spar		2.837
Silver ore sulphurated	Brisson	6.910
———	La Metherie	7.200

Silver ore sulphurated, brittle . . .	Gellert	7.200
——— red	Brisson	5.564
——— light red	———	5.5886
———————	Gellert	5.443
——— sooty	Vauquelin	5.592
—— native, common	Gellert	10.000
——————— . . .	Selb	10.333
———— antimonial . . .	Häuy	9.4406
——————— . . .	Selb	10.000
———— auriferous	Kirwan	10.600
—— ore, dark red	Gellert	5.684
———	Brisson	5.5637
——— arsenicated, ferruginous .		2.178
—————— penetrated with water		2.340
—— ore, corneous, or horn ore . .	Brisson	4.7488
——————— . .	Gellert	4.804
—— virgin, 12 deniers, fine, not hammered .		10.474
——— ditto, hammered . .		10.510
——— Paris, standard, 11 deniers, 10 grains, fused . . .		10.175
——— hammered . . .		10.376
—— shilling of George II. . . .		10.000
——— George III. . . .		10.534
—— French money, 10 deniers, 21 grains, fused .		10.048
——— coined . . .		10.408
Sinople, coarse jasper		2.6913
Slate clay. *See* Argillite.		
—— common		2.6718
—— or Schistus, common . . .		2.6718
——— penetrated with water		2.6905
—— stone		2.1861
—— fresh polished . .		2.7664
—— adhesive	Klaproth	2.080
—— new		2.8535
—— siliceous	Kirwan	{2.596 2.641
—— horn, or Schistose porphry .	Kirwan	{2.512 2.700
Smalt, or blue glass of Cobalt . .		2.440
Soda, sulphate of	Muschenbroek	2.2460
—— muriate of	———	2.1250
——— saturated solution, Temp. 42°	Watson	1.198
—— Tartrite of, saturated solution of .	———	1.114
——— fossil . .		2.1430
——— saturated solution of, Temp. 42°,	Watson	1.054
Sommite, or Nepheline . . .	Häuy	3.2474
Spar, common		{2.693 2.778
—— heavy		4.430
—— white sparkling		2.5946
—— red ditto		2.4378
—— green ditto		2.7045
—— blue ditto		2.6925
—— green and white ditto . .		3.1051
—— transparent ditto . .		2.5644
—— adamantine, or diamond . .		3.873

Spar, fluor, white		3.1555
——— red, or false ruby		3.1911
——— octahedral		3.1815
——— yellow, or false topaz		3.0967
——— green, or false emerald		3.1817
——— octahedral		3.1838
——— blue, or false sapphire		3.1688
——— greenish blue, or false aquamarine		3.1820
——— violet, or false amethyst		3.1757
——— violet, purple		3.1857
——— English		3.1796
——— of Auvergne		3.0943
——— in Stalactites		3.1668
—— pearled		2.8378
—— calcareous rhomboidal		2.7151
——— of France		2.7146
——— prismatic		2.7182
——— and pyramidal		2.7115
Spermaceti		9.9433
Spinelle	Klaproth	3.570
———	Wiedemann	3.700
Spodumene	Häuy	3.192
———	Dandrada	3.218
Stalactite transparent		2.3239
——— opaque		2.4783
——— penetrated with water		2.5462
Staurotite, or Grenatite	Häuy	3.286
Steatites of Bareight		2.6149
——— penetrated with water		2.6657
Steel, soft		7.8331
—— hammered		7.8404
—— hardened in water		7.8163
—— hammered and then hardened in water		7.8180
Strontian	Kirwan	3.400 / 3.644
———	Klaproth	3.675
Stone, sand, paving		2.4158
——— grind		2.1429
——— cutlers		2.1113
——— Fontainbleau, glittering		2.5616
——— crystallized		2.6111
——— scythe of Auvergne, mean grained		2.5638
——— fine grained		2.6090
——— coarse grained		2.5686
——— Mill		2.4835
—— Bristol		2.510
—— Burford		2.049
—— Portland		2.496
—— Rag		2.470
—— rotten		1.981
—— St. Cloud		2.201
—— St. Maur		2.034
—— Notre Dame		2.378
—— Clicard from Brachet		2.357
——— Ouchain		2.274
—— rock of Chatillon		2.122

Stone, hard paving		2.460
—— Siberian blue		2.945
—— touch		2.415
—— prismatic Basaltes		2.722
—— of the quarry of Bourè		1.3864
—— of Cherence		2.4682
Storax		1.1098
Sugar, white	Muschenbroek	1.6060
Sulphur, native		2.0332
—————— fused		1.9907
Sulphuric, or vitriolic acid		1.841
Sulphurate, triple, of lead antimony and copper	Hatchet	5.766
Sylvanite, or Tellurite, in a metallic state, twice fused		6.343
Sylvan, native	Jacquin, jun.	4.107
————————	Muller	5.723
————————	Klaproth	6.115
——— ore, yellow	Muller	10.678
————— black	Jacquin, jun.	6.157
—————————	Muller	8.9193
Tacamahaca, resin		1.046
Talc, black crayon		2.080
—— ditto German		2.246
—— yellow		2.655
—— white		2.704
—— of mercury		2.7917
—— black		2.9004
—— earthy		2.6325
—— common Venetian		2.700 2.800
Tallow		0.9419
Tantalite	Eckeberg	7.953
Tartar	Muschenbroek	1.8490
Terra Japonica		1.3980
Thumerstone	Häuy	3.213 3.300
———————	Gerhard	3.250
———————	Kirwan	3.2956
Tin, pure, from Cornwall, fused	Watson	7.170 7.291
——————————— fused and hammered		7.299
—— of Malacca, fused		7.296
——————— fused and hammered		7.306
—— of Gallicia	Gellert	7.063
—— of Ehrenfriedensdorf in Saxony	———	7.271
—— pyrites	Klaproth	4.350
—— stone	Gellert	6.300 6.989
—————	Brunich	6.750
—————	Leysser	6.880
————— black	Brisson	6.901
————— red	———	6.9348
—————	Klaproth	5.845 6.970
————— fibrous	Werner	7.000
—————	Brunich	5.800
—————	Blumenbach	6.450

Tin, new, fused		7.3013
——— fused and hammered		7.3115
—— fine, fused		7.4789
——— fused and hammered		7.5194
—— common		7.9200
—— ore, Cornish	Brunich	5.800
————	Klaproth	6.450
—— stone, white		6.008
Topaz, oriental		4.0106
—— Brazilian		3.5365
—— from Saxony		3.5640
—— oriental pistachio		4.0615
—— Saxon white		3.5535
Tungsten	Leysser	4.355
———	Kirwan	5.800 6.028
———	Brisson	6.066 6.015
———	Klaproth	5.570
Turpentine, spirit of		0.870
——— liquid		0.991
Turquoise, ivory tinged by the blue calx of copper		2.500 2.908
Uranite in a metallic state	Klaproth	6.440
Uranitic ochre indurated	La Metherie	3.150
————————	Häuy	3.2438
Uranium, stone of		7.500
Urine, human		1.015
Vesuviane	Wiedemann	3.575
———	Klaproth	3.420
——— of Siberia	Klaproth	3.365 3.390
———————	Häuy	3.407
Vinegar, red	Muschenbroek	1.0251
——— white		1.0135
Water distilled at 32° temperature		1.0000
—— sea		1.0263
—— of dead sea		1.2403
—— well		1.0017
Water of Barages		1.00037
—— of the Seine filtered		1.00015
—— of Spa		1.0009
—— Armeil		1.00046
—— Avray		1.00043
—— Seltzer		1.0035
Wavellite, or Hydrarjillite	Davy	2.7000
Wax, Ouarouchi		9.8970
—— bees		0.9648
—— white		0.9686
—— Shoemakers		0.897
Whey, cows		1.019
Willow	Muschenbroek	0.5850
Wine of Torrins, red		0.9930
———— white		0.9876
—— Champagne, white		0.9979
—— Pacaret		0.9997
—— Xerez		0.9924

Wine Malmsey of Madeira		1.0382
—— Burgundy		0.9915
—— Jurancon		0.9932
—— Bourdeaux		0.9939
—— Malaga		1.0221
—— Constance		1.0819
—— Tokay		1.0538
—— Canary		1.033
—— Port		0.997
Wolfram	Gmelin	5.705
——	Elhuyar	6.835
——	Leonhardi	7.000
——	Hatchet	6.955
——	Häuy	7.333
Woodstone		2.045
Yew tree, Dutch	Muschenbroek	0.7880
—— Spanish	—— ——	0.8070
Yttertantalite	Eckeberg	5.130
Zeolite from Edelfors, red scintillant		2.4868
—— white scintillant		2.0739
—— compact		2.1344
—— radiated	Häuy	2.083
—— cubic	——	2.716
—— siliceous		2.515
Zinc, pure and compressed		7.1908
—— in its usual state		6.862
—— formed by sublimation, and full of cavities	Kirwan	5.918
—— sulphate of	Muschenbroek	1.9000
—— —— saturated solution of, Tem. 42°	Watson	1.386
Zircon	Klaproth	4.615
——	Karsten	4.666
——	Wiedemann	4.700

HYDRAULIC AND PNEUMATIC MACHINES.

Water employed as a prime-mover in Machinery.—Water Wheel.—Improvement by Perkins.—Practical Rules.—Persian Wheel.—Sarjeant's Pump.—Barker's Mill.—Morosi on the force of Water.—Pumps.—Boring for Water.—Spiral Pump.—Air Vessel.—Fire Engine.—Lahire's Pump.—Ship's Pump by Perkins.—Apparatus for the Mines.—Mode of diminishing Friction.—Water Screw.—Wirtz's Pump.—Endless Cord for Raising Water.—Hydraulic Ram.—Apparatus at Schemnitz.—Hero's Fountain.

HAVING in the preceding section examined the general principles of hydrostatics, we may now apply those data to the construction of hydraulic machines.

The use of water as an impelling power, both for the turning of machinery and other purposes connected with the useful arts, appears to have been known at a very early period. Vitruvius describes a variety of machines for this purpose; the earliest of which were employed merely to raise a portion of the fluid by which they were impelled. The most simple method of applying this element as a mechanical agent, evidently consisted in the construction of a wheel, the periphery of which was composed of float-boards. This, on being exposed to the action of a running stream, was afterwards employed to give motion to a variety of mills, and is at the present time employed in almost every species of machinery.

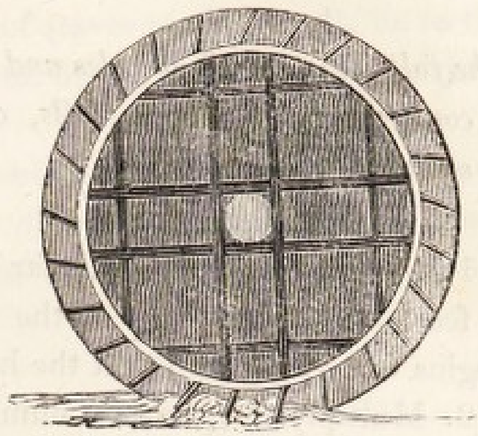
Among the most celebrated hydraulic machines, we may enumerate the machine of Marly. This, when first constructed, appears to have produced one-eighth of the power expended, so that seven-eighths of its power were usually lost. This misapplied power has been injurious to the engine; and the wear it has occasioned has reduced the mechanical effect very materially. But this may be considered as an extreme case, and we select it merely as an instance of that total ignorance of the first principles of mechanics, which characterized some foreign engineers of the last century.

It may, however, be advisable to examine the ratio of power expended in comparison with that of the effect produced in some of the most simple hydraulic machines; and by this calculation, the amount of friction, &c. may be accurately ascertained.

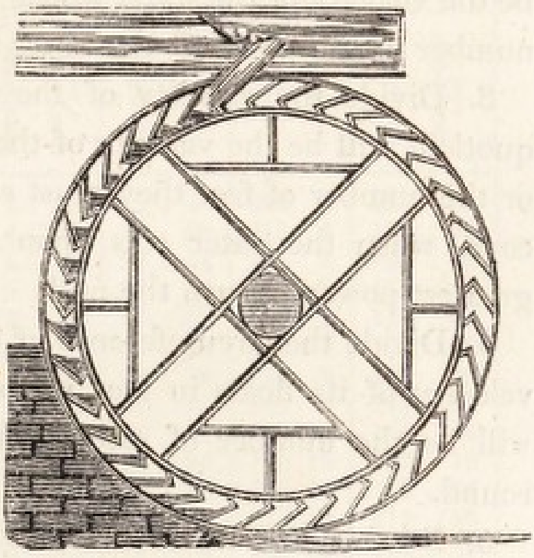
	Power.	Effect.
Undershot water-wheel . . .	9	3
Overshot ditto	10	8
Hydraulic ram. (This machine will make from 20 to 100 strokes per minute) . . .	10	6
Large machine at Chremnitz (each stroke occupying about three minutes)	9	3

The *water-wheel* may justly be considered as the most important of all hydraulic prime-movers, and it acts either by the direct impulse, or the weight of the fluid by which it is propelled. The *under-shot* water-wheel is that in which a running stream operates against a series of float-boards placed round the periphery of a large wheel, to

which the water gives motion. It is represented in the annexed diagram. The *overshot* water-wheel, on the contrary, owes its power to the weight of a body of water placed on a level higher than the top of the wheel; and a reference to this fact will show that its application can never be so general as that of the undershot-wheel.



In certain seasons of the year, hydraulic machinery of this description ceases to be effective; to prevent the above inconvenience, Mr. Perkins has suggested a method of keeping off the back-water at the time of floods, which in ordinary cases impedes the motion of the wheel. To effect this, Mr. Perkins boards up the wheel against the back-water, but leaves a channel at the bottom, through which it would rush upon the wheel, if it were not prevented, and driven back by a superior force. This force is obtained by taking off from the mill-head a part of the superabundant water, and allowing it to rush by a new channel, through the channel left in the boarding. Its superior momentum drives away the back-water from the wheel, and Mr. P. states that this is effected as fully and completely as though no flood existed.



*The following practical rules and observations relative to the construction of Water-Mills, are plain and popular, so should not be omitted.**

1. Measure the perpendicular height of the fall of water in feet, above that part of the wheel on which the water begins to act, and call that the height of the fall.

2. Multiply this constant number 64.2882 by the height of the fall in feet, and the square-root of the product will be the velocity of the water at the bottom of the fall, or the number of the feet that the water there moves per second.

3. Divide the velocity of the water by three, and the quotient will be the velocity of the flat-boards of the wheel, or the number of feet they must each go through in a second, when the water acts upon them, so as to have the greatest power to turn the mill.

4. Divide the circumference of the wheel in feet, by the velocity of its floats in feet per second, and the quotient will be the number of seconds in which the wheel turns round.

5. By this last number of seconds divide 60, and the quotient will be the number of turns of the wheel in a minute.

6. Divide 120 (the number of revolutions a mill-stone, four feet and a half in diameter, ought to have in a minute,) by the number of turns of the wheel in a minute, and the quotient will be the number of turns the mill-stone ought to have for one turn of the wheel.

7. Then, as the number of turns of the wheel in a mi-

* Vide new edition of Ferguson's Lectures, by C. F. Partington; and Imison's Elements of Science and Art.

nute, is to the number of turns of the mill-stone in a minute, so must the number of staves in the trundle be to the number of cogs in the wheel, in the nearest whole numbers that can be found.

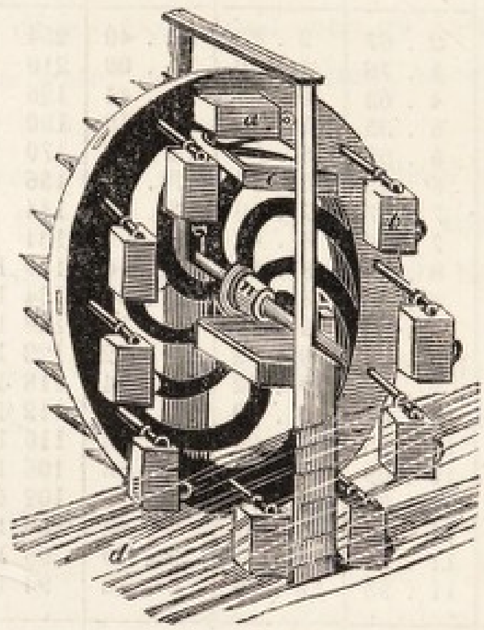
By these rules, the following table is calculated to a water-wheel eighteen feet in diameter, whose size has been found by experience, to be the most eligible for general use.

Ht of the fall of water	Velocity of the fall of water per second.		Velocity of the wheel per second.		Revolutions of the wheel per minute.		Revolution of the mill-stone for one of the wheels.		Cogs in the wheel, and staves in the trundle.		Revolutions of mill-stone per minute by these staves and cogs.	
Feet.	Feet.	100th parts of a foot.	Feet.	100th parts of a foot.	Revolutions.	100th parts of a rev.	Revolutions.	100th parts of a rev.	Cogs.	Staves.	Revolutions.	100th parts of a rev.
1	8	02	2	67	2	83	42	40	254	6	119	84
2	11	34	3	78	4	00	30	00	210	7	120	00
3	13	89	4	63	4	91	24	44	196	8	120	28
4	16	04	5	35	5	67	21	16	190	9	119	74
5	17	93	5	98	6	34	18	92	170	9	119	68
6	19	64	6	55	6	94	17	28	156	9	120	20
7	21	21	7	07	7	50	16	00	144	9	120	00
8	22	68	7	56	8	02	14	96	134	9	119	34
9	24	05	8	02	8	51	14	10	140	10	119	14
10	25	35	8	45	8	97	13	38	134	10	120	18
11	26	59	8	86	9	40	12	76	128	10	120	32
12	27	77	9	26	9	82	12	22	122	10	119	80
13	28	91	9	64	10	22	11	74	118	10	120	36
14	30	00	10	00	10	60	11	32	112	10	118	72
15	31	05	10	35	10	99	10	98	110	10	120	96
16	32	07	10	09	11	34	10	58	106	10	120	20
17	33	06	11	02	11	70	10	26	102	10	119	34
18	34	02	11	34	12	02	9	98	100	10	120	20
19	34	95	11	65	12	37	9	70	98	10	121	22
20	35	86	11	95	12	68	9	46	94	10	119	18
1	2		3		4		5		6		7	

To construct a mill by this table, find the height of the fall of water in the first column, and against that height in the sixth column is given the number of cogs in the wheel

and staves in the trundle, for causing a mill-stone, four feet six inches in diameter, to make 120 revolutions in a minute as nearly as possible, when the circumference of the wheel moves with one-third part of the velocity of the water. And it appears by the seventh column, that the number of cogs in the wheel, and staves in the trundle, are so nearly adapted to the required purpose, that the least number of revolutions of the mill-stone in a minute is 118, and the greatest number exceeds not 121, which is according to the speed of some of the best mills.

While speaking of the water-wheel, we must not forget to illustrate its practical application to the general business of life. One instance will suffice, as it is still commonly employed in the East for the purpose of raising water.



In the Persian wheel, water may be raised by means of a stream *d*, turning a series of floats, and furnished with buckets *a b*, suspended by strong pins fixed in the side of the rim; but the wheel must be made as high as the water

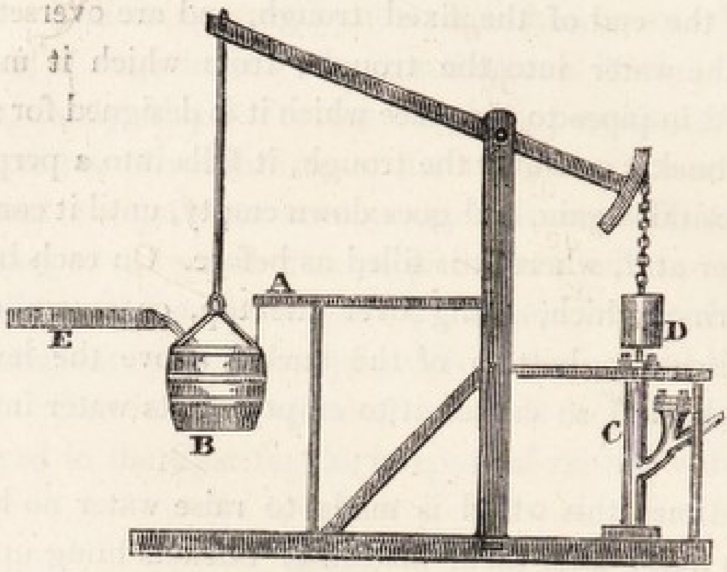
is intended to be raised above the level of that part of the stream in which the wheel is placed. As the wheel turns, the buckets on the one side descend into the water, and then go up full on the other; when they arrive at C, they strike against the end of the fixed trough, and are overset, and empty the water into the trough; from which it may be conveyed in pipes to the place which it is designed for; and as each bucket gets over the trough, it falls into a perpendicular position again, and goes down empty, until it comes to the water at *d*, where it is filled as before. On each bucket is a spring, which, going over the top, or crown of the bar, raises the bottom of the bucket above the level of its mouth, and so causes it to empty all its water into the trough.

Sometimes this wheel is made to raise water no higher than its axis; and, then, instead of buckets hung upon it, its spokes are made of a bent form, and hollow within; these hollows opening into holes in the outside of the wheel, and also into those in the box upon the axis. So that, as the holes dip into the water, it runs into them; and as the wheel turns, the water rises in the hollow spokes and runs out in a stream from the holes at *n*, thus falling into the trough, from whence it is conveyed by pipes to its destination.

Sarjeant's pump may be considered as a cheap and useful prime-mover. It was originally applied to the raising of water at Irton Hall; and a small stream in the neighbourhood was brought by a wooden trough, into which was inserted a piece of two-inch leaden pipe, a part of which is seen at A, on the next page.

The stream of the pipe is so directed as to run into the bucket B, when the bucket is elevated; but so soon as it

begins to descend, the stream flows over it, and goes to supply the wooden trough, or well, in which the foot of the forcing-pump C stands, of three inches bore.

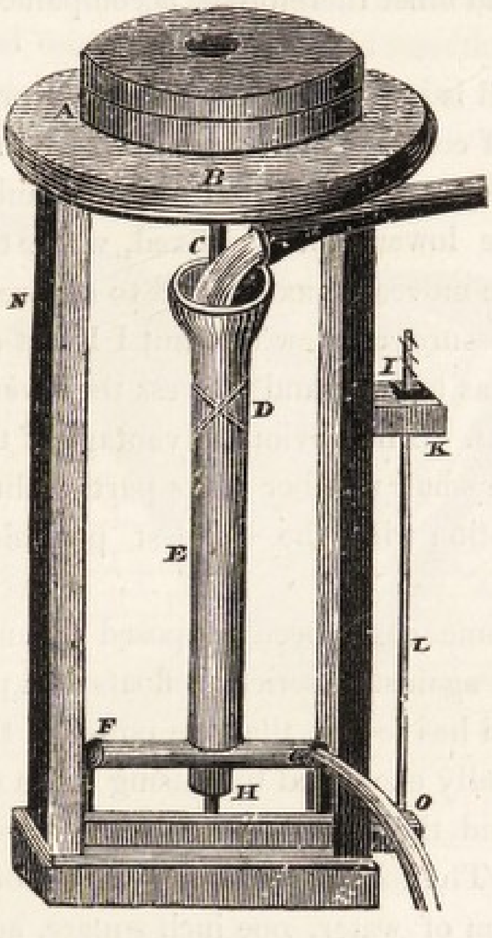


D is an iron cylinder attached to the pump-rod, which passes through it. It is filled with lead, and weighs about 240 lbs. This is the power which works the pump, and forces the water through 420 feet of inch pipe from the pump up to the house.

At E is fixed a cord, which, when the bucket comes to within four or five inches of its lowest projection, becomes stretched, and opens a valve in the bottom of it, through which the water empties itself.

The pressure of a column of water is sometimes employed to produce a rotatory motion without the intervention of a crank. An apparatus of this description is known in this country by the name of *Barker's Mill.* It consists of an upright pipe, or trunk E, communicating with two horizontal branches F G, which have each a hole near the end, opening in opposite directions, at right angles to their

lengths. If we suppose water to be poured in at the top from the horizontal tube, it will run out by the holes F and G, with a velocity corresponding to the depth of those holes beneath the surface. The consequence of this must be, that the arms will be pressed backwards; as there is



no resisting surface at the holes F G, on which the lateral pressure of the water can be exerted, while it acts with its full force on the opposite side of the arm. This unbalanced pressure is equal to the weight of a column having the orifice for its base, and twice the depth under the surface of the water in the trunk for its height. This mode of measuring the height might at first view appear erroneous, because if the orifice were shut, the pressure on it is the

weight of a column reaching from the surface. But when it is open, the water issues with nearly the velocity acquired by falling from the surface, and the quantity of motion produced, is that of a column of twice this length, moving with this velocity. This is actually produced by the pressure of the fluid, and must therefore be accompanied by an equal reaction.

Barker's mill is sometimes employed as a prime-mover in the grinding of corn and other grain: and in the present case, two stones A are supported by the plank B, for this purpose. The lower stone is fixed, while the upper one revolves on the moveable axis; and to ensure the required amount of pressure, a screw and nut I K act on the rod L, in such a way as to raise and depress the lever O on which the axis E rests. The obvious advantage of this apparatus arises from the small number of its parts; thus producing a rotatory motion with the smallest possible expense of power.

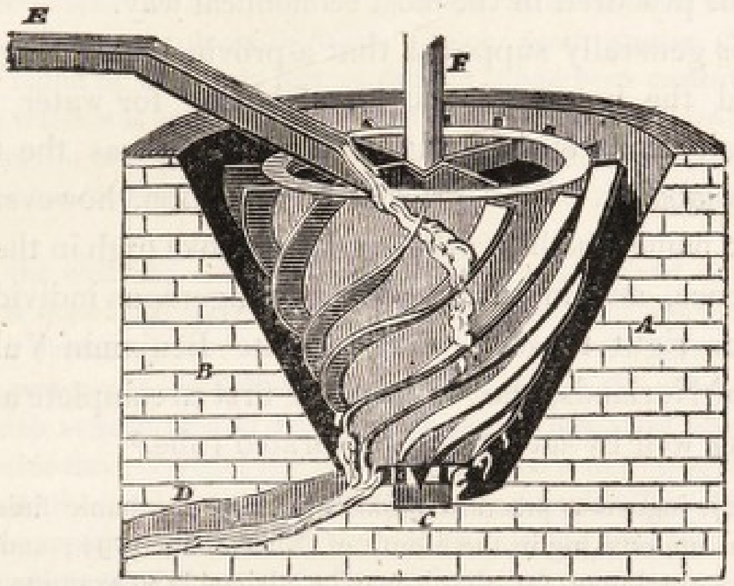
It has in some cases been proposed to employ a jet of water striking against a series of floats as a prime-mover; and M. Morosi has found, that the power of this apparatus may be materially encreased by raising a rim about half an inch high round the circumference of the disc upon which it is thrown. The following results were obtained by directing a stream of water, one inch square, against a plain disc, and one with a raised edge.

Height of the water in the reservoir.	Force exerted on the plain disc.	Force exerted on the disc with raised edge.
6 feet	5 lb.	11 lb.
8	7	15
10	9	20

M. Morosi applied rims two inches high with great success to the vertical float-boards of a horizontal wheel, leaving

an aperture below, to allow the water to escape after it had expended its force on the float-boards. This construction may be considered as an extension of the principle of concave float-boards, which have been long used in horizontal wheels, and which Chevalier Borda found to give in practice a greater effect than plain ones, in the ratio of 3 to 2.

A cheap and useful prime-mover is sometimes formed by coiling a series of thin metal plates round a conical frame



turning on an axis F C. If a stream of water descend from E, and strike against the spirals, a rotatory motion will be the result; and a considerable increase of power is found to arise from the solid wall of brick-work A B, completely surrounding the spiral. The water is allowed to escape at D, and the machinery to be turned is connected with the shaft F.

The construction of those machines which are exclusively employed for the purpose of raising water for useful purposes, may be now examined; the mode of procuring a supply of this useful element, by a comparatively modern

process called *boring for water*, should, however, first be adverted to.

The antiquity of wells in rural economy, as well as for domestic purposes, is so great, that the earliest records extant speak of this mode of perforating the earth for the use of man. The ordinary process of digging for water is, however, in many cases both tedious and expensive; and it was left to an ingenious individual in the last century to suggest a contrivance, by which a copious supply of water may be procured in the most economical way.

It is generally supposed that a provincial well-digger invented the improved process of boring for water now so generally employed; and that Tottenham was the theatre of his labours. The priority of invention, however, rests with a name which in other respects ranks high in the world of science, and in justice to a very ingenious individual, it may be right to state, that the late Benjamin Vulliamy, Esq. of Norlands, was, in fact, the first to complete an overflowing well by means of a perforated tube.*

* This ingenious practical philosopher and mechanic finished his arduous undertaking in the month of November, 1794; and the results were so important, that it may be adviseable to examine the process he pursued, somewhat in detail, and as near as possible in his own words.

" In beginning to sink this well, which has a diameter of four feet, the land-springs were stopped out in the usual manner, and the well was sunk and steined to the bottom. When the workmen had got to the depth of two hundred and thirty-six feet, the water was judged not to be very far off, and it was not thought safe to sink any deeper. A double thickness of steining was made about six feet from the bottom upwards, and a borer of five and a quarter inches diameter was made use of. A copper pipe of the same diameter with the borer was driven down the bore-hole, to the depth of twenty-four feet, at which depth the borer pierced through the rock into the water; and by the manner of its going through, it must probably have broken into a stratum containing water and sand. At the time the borer thrust through, the top of the copper pipe was about three feet above the bottom of the well; a mixture of sand and water instantly rushed in

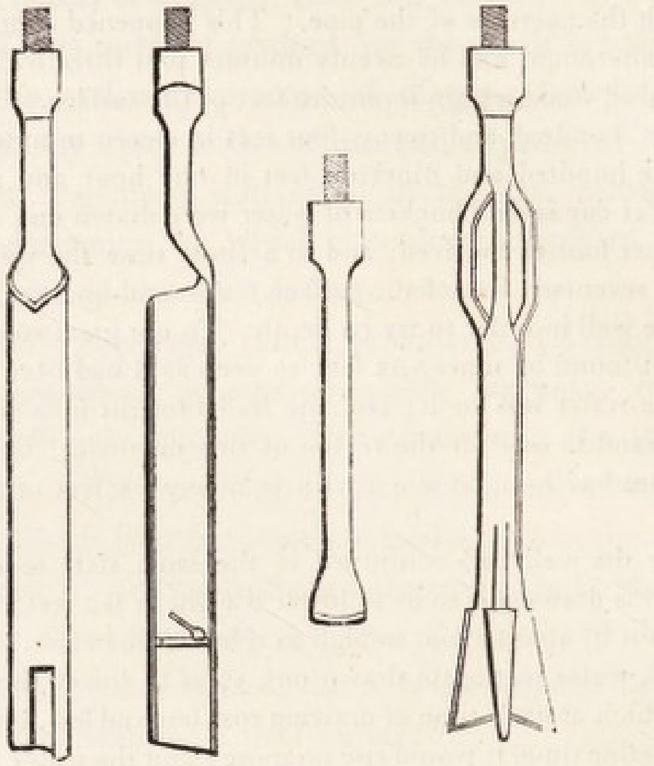
The apparatus employed in this process is exceedingly simple, and consists of little more than the iron instruments shown in the diagram on the next page.

through the aperture of the pipe. This happened about two o'clock in the afternoon, and by twenty minutes past three o'clock the water of the well stood within seventeen feet of the surface. The water rose the first hundred and twenty-four feet in eleven minutes, and the remaining hundred and nineteen feet in one hour and nine minutes. The next day several buckets of water were drawn out, so as to lower the water four or five feet; and in a short time the water again rose within seventeen feet of the surface. A sound-line was then let down into the well in order to try its depth. To our great surprise, the well was not found by ninety-six feet so deep as it had been measured before the water was in it; and the lead brought up a sufficient quantity of sand to explain the reason of this difference, by showing that the water had brought along with it ninety-six feet of sand into the well.

After the well had continued in the same state several days, the water was drawn out so as to lower it eight or ten feet; and it did not rise again by about a foot so high as it had risen before. At some days interval, water was again drawn out, so as to lower the water as before; which at each time of drawing rose less and less, until, after some considerable time, it would rise no more; and the water being then all drawn out, the sand remained perfectly dry and hard. The operation of digging was again necessarily resorted to, and the sand was drawn up in buckets until about sixty feet of it were drawn out; and, consequently, there remained only thirty-six feet of sand in the well: that being too light to keep the water down, in an instant it forced again into the well with the same violence it had done before; and the man who was at the bottom getting out of the sand, was drawn up almost suffocated, having been covered all over by a mixture of sand and water. In a short time the water rose again within seventeen feet of the surface, and then ceased to rise, as before. When the water had ceased rising, the sounding-line was again let down, and the well was found to contain full as much sand as it did the first time of the water's coming into it.

These difficulties being at length surmounted, we continued drawing out the sand and water alternately; and I had the satisfaction of seeing the water rise higher and higher, until at last it ran over the top of the well, into a temporary channel that conveyed it into the road. I then flattered myself that every difficulty was overcome; but a few days afterwards I discovered that the upper part of the well had not

They are attached by the screws at top to long rods of metal, and motion is given to the series by means of a cross bar, which is usually turned by two men.



The peculiar advantages of boring the ground for water, instead of digging, particularly at great depths, renders the former method of great importance to the public; since

been properly constructed, and it became necessary to take down about ten feet of brickwork. The water, which was now a continued stream, rendered this extremely difficult to execute. I began by constructing a wooden cylinder twelve feet long, which was let down into the well, and suspended to a strong wooden stage above, upon which I had fixed two very large pumps, of sufficient power to take off all the water that the spring could furnish, at eleven feet below the surface. The stage and cylinder were so contrived as to prevent the possibility of any thing falling into the well: and I contrived a gage, by which the men upon the stage could always ascertain to the greatest exactness the height of the water within the cylinder. This precaution was essentially necessary, in order to keep the water a foot below the work which was doing on the outside of the cylinder, to prevent the new work from being wetted too soon. After every thing was prepared, we were

water is obtained by boring at a small expense. This fact is exemplified by the following table, which shows the price of boring at every ten feet of depth, and also the cost of well-sinking at the same depth.

Depth in Ft.	Price of Boring.			Price of Well-sinking.		
10	£0	3	4	£1	5	0
20	0	10	0	3	0	0
30	1	0	0	5	5	0
40	1	13	4	8	0	0
50	2	10	0	11	5	0
60	3	10	0	15	0	0
70	4	13	4	19	5	0
80	6	0	0	24	0	0
90	7	10	0	29	5	0
100	9	3	4	35	0	0
110	11	0	0	41	5	0
120	13	0	0	48	0	0
130	15	3	4	55	5	0
140	17	10	0	63	0	0
150	20	0	0	71	5	0
160	22	13	4	80	0	0
170	25	10	0	89	5	0
180	28	10	0	99	0	0
190	31	13	4	109	5	0
200	35	0	0	120	0	0

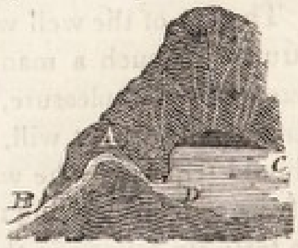
employed eight days in taking down ten feet of the wall of the well, remedying the defects, and building it up again; during which time ten men were employed, five relieving the other five, and the two pumps were kept constantly at work during one hundred and ninety-two hours. By the assistance of the gage, the water was never suffered to rise upon the new work until it was made fit to receive it. When the cylinder was taken out, the water again ran over into the temporary channel that conveyed it into the road.

The top of the well was afterwards raised eighteen inches, and constructed in such a manner as to be able to convey the water five different ways at pleasure, with the power of being able to set any of these pipes dry at will, in order to repair them whenever occasion should require. The water being now entirely at command, instead of the well discharging thirty gallons in a minute, it was now increased to forty-six gallons in the same time.

The generality of springs depend upon a supply of water furnished from the descent of rain and other causes, which will be examined in our section on Meteorology. The water so supplied sinks into, or percolates through the ground, until it meets with a stratum of soil, such as clay, or other strata, that is impervious to its further passage downwards, and which causes it to accumulate, until, by its increased pressure, it ascends to a higher situation; it then breaks through the soil, and shows itself as a spring on the surface; or should it have no such opportunity of escaping, it remains imprisoned until let loose by the sinking or digging of a well down to the depth at which it may chance to settle. Springs cannot, therefore, be considered as veins of water running through the earth in particular directions, as they have formerly been supposed to do: which is sufficiently proved by the circumstance, that pumping one deep well so as to drain it for a few weeks, will effectually dry all the other wells for a great distance around it, which could not take place were the springs disconnected, instead of being dependant upon the stratification of the country in which they occur.

Intermitting springs are in some cases supposed to arise from the operation of a natural syphon within the earth; and a case is mentioned by Mr. Farey, in which an artificial syphon had been found in the excavation of an old stone quarry. The arrangement by which this curious phenomenon may be effected, should be briefly adverted to.

If we suppose a cavity C D to be gradually filled with water from a series of minute interstices in the surface of the earth, and a natural or artificial syphon A to have its shortest leg immersed beneath the water at D, when the



water rises to C, in the large reservoir, then it will stand at the same height in A, and will continue to flow from the longer leg B, till all the water is drawn out.

Against this mode of accounting for reciprocating springs, it has been said that the water would gradually flow over the bent limb of the syphon, and thus prevent the full operation of the tube; but it should be borne in mind that the adhesion of the water in the pipe will prevent it descending the tube till the upper limb is entirely filled, and, as such, the syphon will duly perform all the conditions essential to the experiment.

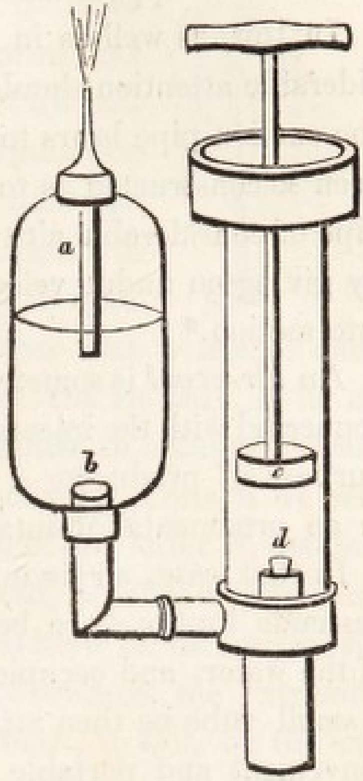
The theory of the common *sucking*, or *atmospheric-pump*, has already been illustrated, and it may be enough for our present purpose to describe its ordinary construction without reference to a diagram. The form of the pump usually consists of a pipe open at both ends, in which is placed a moveable piston, or bucket, as large as the bore of the pipe in that part in which it works, and leathered round so as to fit the bore so accurately that it may be moved up and down without admitting any air to come between it and the pipe, or pump-barrel. There are several kinds of buckets: the most simple of all, which is commonly used for ordinary pumps, consists of a cylindrical piece of wood, whose diameter is somewhat less than the bore of the barrel, that it may move in it freely, having a hole quite through the centre. Upon the top of this there is an iron piece fastened to a rod of iron, or wood, which goes quite to the top of the pump. Near the top of the bucket there is a leather ring fastened, which is raised a little above the wood: the hole being stopped by a valve, made of a round piece of leather, fastened in one part of the wood with nails. Upon this there is an iron plate, a little larger than the bore of the hole, and another iron plate under it, a little less than

the same bore, and the plates and leather are fastened together by means of a rivet, or screw, in the middle of them. When the bucket is put into the barrel, and the leather becomes wet, it will entirely occupy the sides of the barrel, and prevent the passage of the air. The use of the two iron plates is to sustain the pressure of the water, which would otherwise bend the leathers.*

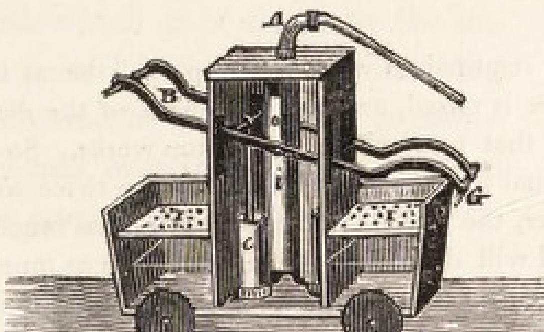
The *forcing-pump* is not very dissimilar to the sucking-pump; its arrangement will very easily be understood. When the piston *c* is elevated, a vacuum is formed in the

* For larger pumps, the bucket is made in the following manner:—there is a hollow piece of brass, almost equal at top to the bore of the barrel, but small at the bottom, furnished with a brass bar, and at the bottom are two notches to receive the ends of another brass bar; of the same figure as that at the top. Round the brass piece is placed a leather ring, fastened to it at its lower part by means of an iron ring, which, being almost at the bottom of the brass piece, is not so large as its top, and, consequently does not touch the sides of the barrel; this leather ring should go a little higher than the cross-piece at bottom. The valve consists of a piece of leather almost equal to the top of the brass piece, covered by two iron plates of the same size as the leather, and having under it two plates somewhat smaller than the bore of the brass piece at its top; these iron plates and leathers are fastened together with screws. The whole is fastened together by means of an iron piece, whose lower part goes through the holes in the middle of the valve, and the two brass rods, so that its upper part getting between the two upper iron plates of the valve, presses upon the leather, and makes it apply itself close to the upper brass bar. This iron piece, or rod, ought to have two holes, one at the bottom, just under the lower brass rod, to hold it close by means of a pin, or key; and another at its top, to fasten it to another iron rod, which is continued quite to the top of the pump, in order to give motion to the bucket. The chief advantages of this kind of buckets are, that they give the freest passage to the water, having the least friction possible, as they touch the barrel only at the upper end of the brass box; and that the sand, or gravel, which is commonly mixed with the water, cannot get between the bucket and the barrel, because the leathern ring is higher than the brass tube.

pipe beneath, and the valve *d* being raised, the water is pressed by the air from the lower level of the well. The handle is then depressed, and as the piston is solid, no air can rise through it, and it is immediately driven along the horizontal pipe into the air-vessel. The pipe *a* descends beneath the surface of the water, and the atmospheric air which is thus compressed, serves, by its expansive force, to drive the water from the air-vessel after the piston has ceased to operate. A valve placed at *b*, prevents the water returning into the pump-barrel when the piston is again elevated.



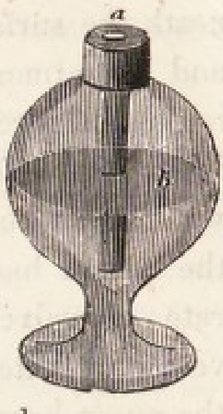
The common *fire-engine* operates on precisely the same principle as the pump already described; it is, however, furnished with a long lever B G, supported by the upright



beam *i*. The lever thus arranged, is connected with barrels, one of which is shown at *c*, and the water is driven out of the flexible main A.

The pump is provided with an air-vessel, and the great value of the apparatus arises from its portability.

In this, as well as in the pumps already described, considerable attention should be paid to the proportion that the suction pipe bears to the pump-barrel; as pumps have been so constructed as to raise iron balls through a suction-pipe of considerable altitude; but this can only be effected by giving an undue velocity to the water which is thus put into motion.*



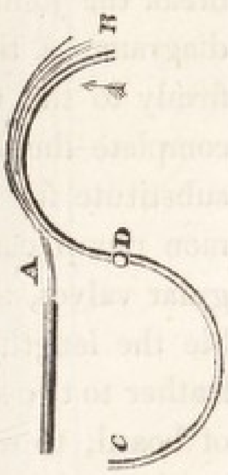
An *air-vessel* is sometimes employed, unconnected with the injection-syringe, for the purpose of producing a continuous stream in an ornamental fountain.

In that case, air is injected at *a*, which descends by the tube beneath the surface of the water, and occupies the space *b*. If a small tube be then attached at *a*, a very convenient and portable fountain is the result.

While speaking of the supply-pipe in a common fountain, we ought not to omit to notice the very beautiful experimental illustration which may readily be furnished of the friction of fluids by the ascending column thus put into motion.

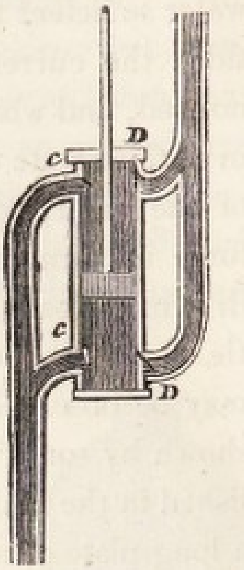
* The force required to work a pump, will be as the height to which the water is raised, and as the square of the diameter of the pump-bore, in that part where the piston works. So that, if two pumps be of equal heights, and one of them be twice as wide in the bore as the other, the widest will raise four times as much water as the narrowest; and will therefore require four times as much strength to work it. The wideness or narrowness of the pump, in any other part besides that in which the piston works, does not make the pump either more or less difficult to work; except what difference may arise from the friction of the water in the tube, which is always greater in a narrow bore than in a wide one, because of the great velocity of the water.

In the diagram, the pipe A is furnishing a supply of water sufficient to support the ball B. Besides the current of air which Venturi has noticed, and which tends to support the ball in a stable state of equilibrium, the adhesion of the water, combined with its centrifugal force in turning round the ball, assists in drawing it back, when it has declined a little on either side. Dr. Young states that a similar effect may be observed in the motions of the air only, as he has shown by some experiments, of which an account is published in the Philosophical Transactions. Thus, if we bend a long plate of metal into the form of the letter S, and suspend it in the middle by a thread, so that it may move freely on its centre, and if we then blow on its convex surface with a tube directed obliquely towards the extremity, instead of retreating before the blast, it will, on the contrary, appear to be attracted; the pressure of the atmosphere being diminished by the centrifugal force of the current which glides along the convex surface, because it finds a readier passage in the neighbourhood of the solid, towards which it is urged by the impulse of the particles of the air approaching it on one side, and by the defect of pressure on the other side, occasioned by the removal of a certain portion of the air which it carries with it.

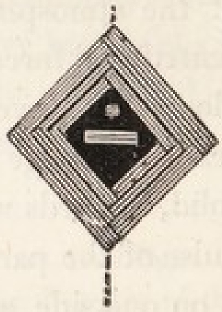


The *forcing-pump* suggested by *Lahire* is frequently employed in the draining of mines. The piston in this case performs a double purpose, the rod working through a collar of leathers, and the water being admitted and expelled in a similar manner above and below the piston by a

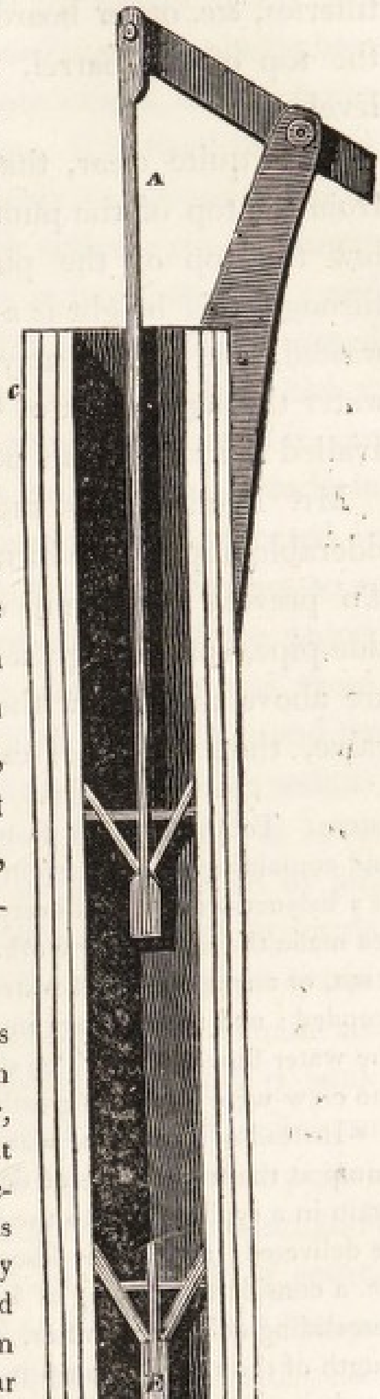
double series of valves. When the piston-rod is elevated in this pump, a vacuum is formed beneath; and on depressing it, the water that has thus been raised by the lower pipe *c*, is driven up the ascending pipe D, while a new portion is sucked from the well owing to the vacuum above the piston.



The pump contrived by *Mr. Perkins* is very readily constructed. The materials are always at hand, and its advantages as a ship's pump must be sufficiently apparent. To construct an hydraulic machine of this kind, it is necessary merely to take four strips of deal board of suitable width and length; nail them firmly together, so as to form a square trunk *e*; this trunk is next covered entirely with tarpaulin; then another layer of boards is nailed over the trunk, observing to break the joints, as is shown in the accompanying small diagram. A third layer of boards, nailed firmly to the first and second layer, will complete the body of the pump. The substitute for the upper box of the common pump consists of two isosceles triangular valves, the sides of which are double the length of the base, jointed with leather to two square pieces of boards E. These two pieces of board, to which the valves are jointed, play diagonally in the pump. Between these two pieces of board, is fastened with nails the pump-rod A, which is also made of deal. The leather which forms the joint should be extended over the sides of the valves, so as to make them air-tight as they lie obliquely in the angles of the pump. The inside of the valves may be loaded with sheet lead, if convenient;



at any rate, they should be filled with as many nails as the valves will hold without weakening them. The upper valves are furnished with a check string, to prevent friction on the sides of the pump. It should be so adjusted as to prevent the valves from resting on the wooden trunk; the leather only should touch the pump. The lower valves, which are fixed to the bottom of the pump, are made similar to the upper valves.



This pump works very easily, owing to the water-way by the valves being much greater than the water-way through common boxes; and it is not liable to choke, in consequence of the water not being wire-drawn below the boxes, or valves, which makes it very valuable for nautical purposes.*

* The following simple and ingenious method of working a ship's pump, when the crew are either too few in number, or too much exhausted to attend to that duty, when the performance is most necessary, namely, in a heavy gale, was put in practice with great success by Captain Leslie, of the ship George and Susan, on a late voyage from Stockholm to North America. He fixed a spar aloft, one end of which was ten or twelve feet above the top of his pumps, and the other projected over the stern; to each end he affixed a block, or pulley; he then fastened a rope to the spears of the pump, and after passing it through both pullies along the spar, dropped it into the sea

The usual method of working pumps, either in distilleries, &c. or on board of ships, is to force the water to the top of the barrel, and allow it to run off to a lower level.

It is quite clear, that if the water in this case descends from the top of the pump to a place of delivery much below the top of the pump-barrel, the fall of the water through this height is a mechanical force which is entirely wasted, and which may be actually employed in raising water through a part of the pump-barrel. Mr. Witty has availed himself of this power in a very ingenious manner.*

Mr. Brunton has suggested an improvement of considerable importance in raising water for the use of miners. To prevent the pump drawing air, he has introduced a side-pipe, connecting the parts of the working-barrel which are above and below the bucket, which pipe has a stop-valve, that the miner can regulate with the greatest ease,

astern. To the rope he fastened a cask, 110 gallons measurement, and containing sixty or seventy gallons of water. This cask answered as a balance-weight, and every motion of the ship from the roll of the sea made the machinery work. When the stern descended, or when a sea, or any agitation of water raised the cask, the pump spears descended; and the contrary motion of the ship raised the spears, when the water flowed out. The ship was cleared out in a few hours, and the crew were of course greatly relieved.

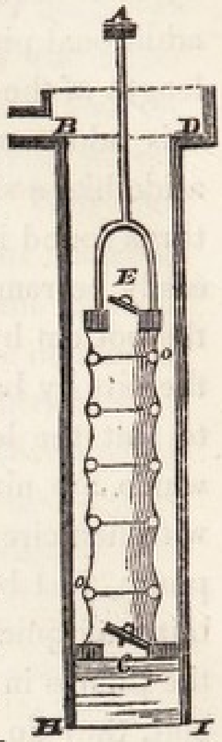
* Instead of letting the water, or other fluid, escape from a common pump at the usual place of delivery, he says, "I caused it to descend again in a syphon-pipe to the lowest level at which it can conveniently be delivered; and as this descent is considerable in ships, brewhouses, &c. a considerable saving of labour is effected in working pumps by a descending column of water, or liquor, counterbalancing as much in length of the rising column in the pump, as the height which it descends in the syphon-pipe, to the place where it can be delivered." We have no doubt that this invention will be found to be of great practical value, as it relieves the men at the pump of a very great part of their labour.

so as to keep the engine to its full stroke, without drawing air, by letting down the water from the upper part of the barrel into the lower, so that it is working again in its own water. Instead of having the whole weight of the lower lift of pumps standing on the bottom, it is fixed in the pit by cross beams, and the miner has only to lift and move an additional pipe, or wind-bore, which slides upon the lower length of the pump like a telescope, to lengthen down; and this additional wind-bore is, besides, crooked, and turned aside like a short crank, which, by the facility by which it turns round in the leathered collar above the nose of it, can easily be removed into every fresh hole which is made in the bottom by the miners. The pumps are supported in the pits by beams placed across at proper distances, so as to suit the lengths of the pipes, or lengths of the pump, which are nine feet. Short pieces are laid across these, with half circular holes in them, which being put round the pump, just beneath the flanches, firmly sustain its weight, but may quickly be removed when it is required to lower the pumps in the pit; and as they are not fastened by any bolt, they do not prevent the pumps being drawn upwards, if it becomes necessary to take out the pumps when the pit is full of water. The pumps by these means remain stationary, and the suction-pipe lengthens as the pit is sunk, until it is drawn out to its full extent; the whole column is then lowered to the next flanches, and another pipe is added to the top. The pumps being thus kept stationary till nine feet are sunk, the pipe at the top will of course deliver the water at the same level at all times, and instead of being obliged to lengthen the column every yard sunk, it will only be necessary every nine feet.

In the pumps hitherto noticed, a considerable portion of the working power is expended in the packing of the pis-

ton. It may now, however, be proper to notice a pump almost entirely exempt from this inconvenience.

B D H I represents a square trunk of wood formed of the roughest materials, but water-tight. Near the bottom there is a partition made of the same material, and perforated with a hole E, and covered with a valve. There is a long cylindrical bag, made of leather, or of double canvass, with a fold of thin leather, such as sheep-skin, between the canvass bags. This is firmly nailed to the board *e*, with soft leather between. The upper end of this bag is fixed on a round board, having a hole and valve E. This board may be turned in the lathe with a groove round its edge, and the bag fastened to it by a cord bound tight round it. The fork of the piston-rod A is firmly fixed into this board; the bag is kept distended by a number of wooden hoops, or rings of strong wire, put ¡nto it at few inches distant from each other. It will be proper to connect these hoops before putting them in, by three or four cords from top to bottom, which will keep them at their proper distances. The space between the hoops should be about twice the breadth of the rim of the wooden ring to which the upper valve and piston-rod are fixed.

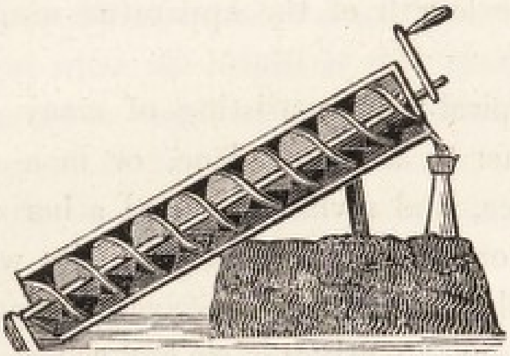


It is evident, that if the bag be stretched from the compressed form, which its own weight will give it by drawing up the piston-rod, its capacity will be enlarged, the valve E will be shut by its own weight, the air in the bag will be rarefied, and the atmosphere will press the water into the bag. When the rod is thus thrust down again, this water will come out by the valve E, and fill part of the trunk. A repetition of the operation will have a similar effect; the

trunk will be filled, and the water will at last be discharged by the spout.

It may be proper to observe, that the length of the bag must be three times the intended length of the stroke; so that when the piston rod is in its highest perfection, the angles or ridges of the bag may be pretty acute. If the bag be more stretched than this, the force which must be exerted by the labourer, becomes much greater than the weight of the column of water which he is raising. If the pump be laid in a slanting direction, it is necessary to make a guide for the piston-rod within the trunk, that the bag may play up and down without rubbing on the sides, as the friction would speedily destroy it.

The *Screw of Archimedes* is an exceedingly simple instrument; and, when constructed on a large scale, may be employed with advantage in the digging of canals, and many other branches of hydraulic architecture.



The screw, as will be seen in the accompanying diagram, has a portion of its lower extremity inserted in the water, and motion is given to the whole apparatus by means of a handle at top.

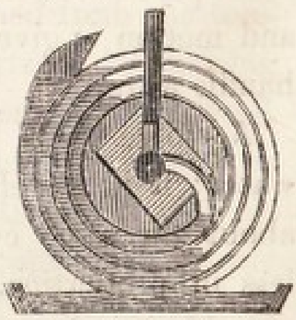
A single spiral tube will raise but a small quantity of water; it is therefore common to wrap two or more tubes about the same cylinder; as the power required will be less in proportion, although each spiral will raise an increased quantity of water.

The screw of Archimedes should always be so placed, as to fill exactly one-half of a convolution at each turn. For want of attention to this circumstance, it has been considered less effective than it really is; for when the orifice is constantly immersed, the effect is very much diminished. The machine is generally placed at an angle, varying from 45 to 60 degrees with the horizon.

A machine on this principle may be formed by means of a series of spiral projections within a hollow cylinder, in which case it will resemble the box, or socket of a screw. In this machine, which is called a *water-screw*, about one-third of the water generally runs back; yet it is equal to the screw of Archimedes, if the height of the water is so variable, that the latter cannot be placed in such a manner as to fill one-half of a convolution in each turn.

It may be proper to add, that machines of this kind are not calculated to raise water to any very considerable height, as the length of the apparatus would cause it to bend.

When a spiral-pipe, consisting of many convolutions, arranged either in a single plane, or in a cylindrical or conical surface, and revolving round a horizontal axis, is connected at one end by a water-tight joint with an ascending pipe, while the other end receives, during each revolution, nearly equal quantities of air and water. The machine is called a *spiral-pump*. It was invented about 1746, by Andrew Wirtz, a pewterer at Zurich.

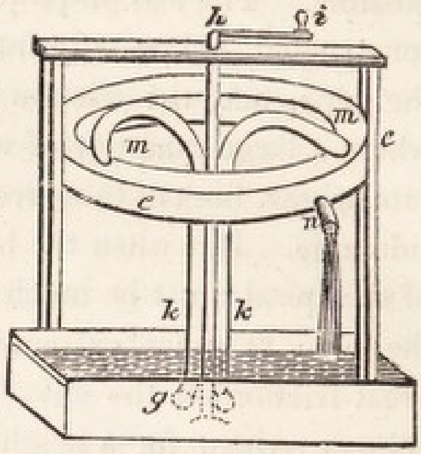


The end of the pipe is furnished with a spoon, containing as much water as will fill half a coil, which enters the pipe a little before the spoon has arrived at its highest situation; the other half remaining full of air, which

communicates the pressure of the column of water to the preceding portion, and in this manner the effect of nearly all the water in the wheel is united, and becomes equivalent to that of the column of water, or of water mixed with air, in the ascending pipe. The air nearest the joint is compressed into a space much smaller than that which it occupied at its entrance, so that where the height is considerable, it becomes adviseable to admit a larger portion of air than would naturally fill half the coil, and this lessens the quantity of water raised, but it lessens also the force required to turn the machine. The joint ought to be conical, in order that it may be tightened when it becomes loose, and the pressure ought to be removed from it as much as possible. The loss of power, supposing the machine well constructed, arises only from the friction of the water in the pipe, and the friction of the wheel on its axis; and where a large quantity of water is to be raised to a moderate height, both of these resistances may be rendered inconsiderable. But when the height is very great, the length of the spiral must be much increased, so that the weight of the pipe becomes extremely cumbersome, and causes a great friction on the axis, as well as a strain on the machinery: thus, for a height of 40 feet, Dr. Young found that the wheel required above 100 feet of a pipe which was three-quarters of an inch in diameter; and more than one-half of the pipe being always full of water, we have to overcome the friction of about 80 feet of such a pipe, which will require 24 times as much excess of pressure to produce a given velocity, as if there were no friction. The centrifugal force of the water in the wheel would also materially impede its ascent if the velocity were considerable, since it would be always possible to turn it so rapidly as to throw the whole water back into the spoon. The machine

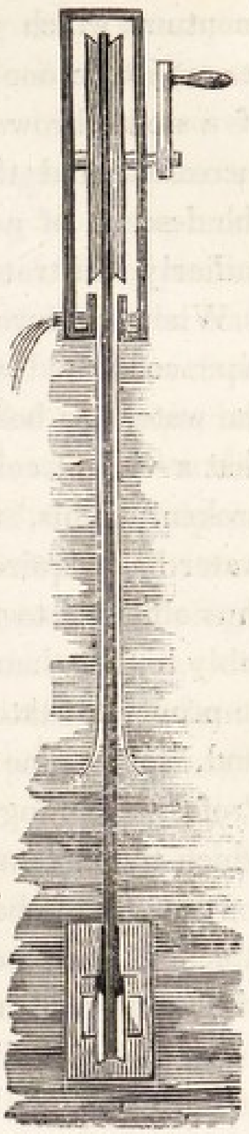
which Dr. Young had erected, being out of repair, he thought it more eligible to substitute for it a common forcing-pump, than to attempt to make any further improvement in it, under circumstances so unfavourable. But if the wheel, with its pipes, were entirely made of wood, it might in many cases succeed better: or the pipes may be made of tinned copper, or even of earthenware, which might be cheaper and lighter than lead.

The centrifugal force, which is an impediment to the operation of Wirtz's machine, has sometimes been employed together with the pressure of the atmosphere, as an immediate agent in raising water, by means of the rotatory-pump. This machine consists of a vertical pipe, or pipes *k k*, caused to revolve round its axis by the handle *h i*, and connected above with the bent pipes *m m*, which are open at their extremities; the whole being furnished with proper valves to prevent the escape of the water when the machine is at rest. As soon as the rotation becomes sufficiently rapid, the centrifugal force of the water in the horizontal pipes causes it to be discharged at the end, its place being supplied by means of the pressure of the atmosphere on the reservoir at *g*, which forces the water to ascend through the vertical pipe. The water thus raised, is received by the trough *e*, and is afterwards allowed to flow off by the spout *n*.



The *rope-pump* of Vera, for raising water to great heights, is more readily constructed than any other hydraulic apparatus of a similar character.

It will be seen that two wheels, or pullies, are in the annexed apparatus connected by an endless rope, and the rope being made to revolve rapidly by the action of a handle at the top, the water adheres to the fibrous parts, and is carried up in a continued stream. The side of the rope connected with the ascending column of water is allowed to pass through a large-sized aperture, whilst the opposite side, on the contrary, is squeezed through a small tube, which retains the water in the reservoir at top, while the rope descends for a new supply. It is probable that the water commonly ascends with about half the velocity of the rope; but the friction required for elevating the quantity raised by such a machine, appears, from calculation, to correspond to a velocity about twice as great as the actual relative velocity. While the water is principally supported by the friction of the rope, its own cohesion is amply sufficient to prevent its wholly falling, or being scattered by any accidental inequality of the motion.



Another diagram may be advantageous for showing the arrangement of the cord with reference to the pullies and reservoir *c*. The endless rope A passes over the friction wheels, or pullies, and ascends through a large tube, as has been already described. A spout D carries off the water to any required distance.

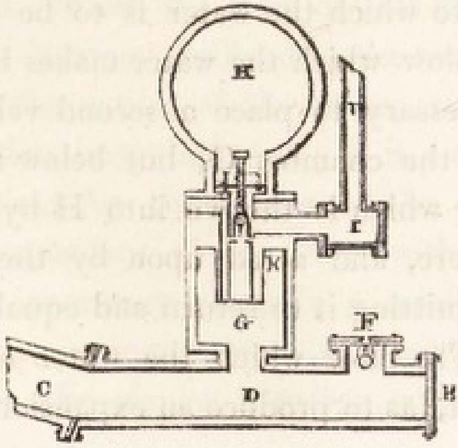
The *hydraulic ram* is another and very useful apparatus for raising water; and its operation depends on the momentum which that or any other fluid may acquire by its motion in one direction. We all know that the velocity of a stone thrown from the top of a building, continually increases; and the same effect invariably takes place in the descent of a fluid.—This, however, may be more familiarly illustrated.

When we turn a stop-cock placed at the bottom of a pipe connected with an elevated cistern, through which the water has been running for a few seconds, it is found that a violent concussion ensues, and the pipe is sometimes broken. This, then, arises from the *momentum* that the water has acquired, and Mongolfier has applied the force thus obtained to the raising of water in a cistern considerably higher than the original reservoir. It may, however, be proper to state that the same thing was effected in England, some time prior to its publication by Mongolfier. Professor Millington thus describes the circumstances under which the instrument was first constructed.

It may have been observed by many, on turning a cock attached to a pipe so circumstanced, that the water flows with great violence; and upon shutting it off suddenly, a concussion is felt, the pipe is shaken, with a noise resembling the fall of a piece of metal within it, and the pipe is not unfrequently burst open near its end. This arises from the new energy which the water has acquired by being put in motion for a short time and then stopped, in consequence of which it makes a considerable mechanical effort against that end of the pipe which opposes its further progress. This effect was experienced in a great degree at an hospital in Bristol, where a plumber was employed to fix a leaden pipe to convey water from the mid-

dle of the building to the kitchen below, and it was found that nearly every time the cock was made use of, the pipe was burst at its lowest end; after making many attempts to remedy this evil, it was at last determined to solder a small pipe immediately behind the cock, which of course was carried to the same perpendicular height as the supplying cistern, to prevent the water running to waste, and now it was found that on shutting the cock the pipe did not burst as before, but a jet of considerable height was forced from the upper end of this new pipe. It therefore became necessary to increase the height of the pipe, to overcome, if possible, this jet, and it was carried to the top of the building, or twice the height of the supplying cistern; where, to the great surprise of those who constructed the work, the jet still made its appearance, though not in such considerable quantities; and a cistern was placed at the top of the house to receive this superfluous water, which was found very convenient, particularly as it was raised without trouble or exertion.

This appears to have been the first water ram known in this country, the circumstance having taken place prior to Mongolfier's contrivance, though he is the first person who organised the machine, and made it completely self-acting, without turning a cock. His mode of construct-



ing the apparatus may easily be understood by referring to the preceding diagram, in which the water descends from a cistern by the pipe C, extending from thirty to forty feet in length. This pipe is laid in a sloping direction, so as to reach the greatest depth D at which the water can run off, which may be from one to six or eight feet below the head. The water would naturally run to waste from the end E; but that is closed by a blank or solid flaunch, and it is only permitted to escape through a round hole in the centre, from whence it would run in an uninterrupted stream. This hole is, however, equipped with a valve within it, as at F, and this valve is so adjusted as to sink by its own weight in the water, while that water is motionless or moving slowly. Now, if we suppose the pipe C D to be supplied with water from the reservoir above, that water will at first pass round the valve, and discharge itself at F; but as soon as it has acquired a small additional force by moving, it will be more than equivalent to the weight of the valve F, and will lift it, by which the passage of the water becomes instantly stopped, and an effort will be made to burst the pipe D: this is prevented by the second orifice over the letter D, communicating with the chamber G and air-vessel H, from whence there is an immediate communication by the pipe I I, with the highest point to which the water is to be raised. As the effect of the blow which the water makes is instantaneous, it becomes necessary to place a second valve between the air-vessel and the chamber G, but below the pipe I I, so that any water which is thrown into H by the effort, may be confined there, and acted upon by the condensed air, instead of permitting it to return and equalize itself in the pipes C D. The blow which the water makes is so sudden and violent, as to produce an expansion in the pipe D

which is as suddenly succeeded by a recontraction and trifling vacuum in D, by the tendency of the water to return upon C when stopped; the effect of this is to bring down the valve F, by which a free passage is once more opened for the water, which again flows and shuts F as before, to produce another blow or pulsation, by which a second quantity of water is thrown up I I. Each repetition of this operation affords a fresh supply of water.

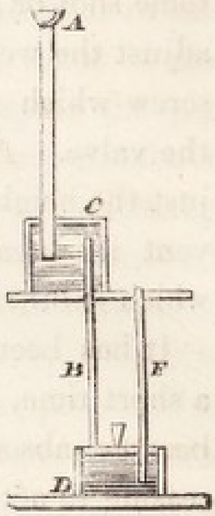
It will be evident that the valves will require some adjustment as to weight. This is effected by making them of hollow brass balls, having a hole on one side, by which some shot or small pieces of metal can be introduced to adjust the weight. The hole is afterwards stopped by a screw which projects and forms a shank or tail to guide the valve. A screw is placed over the upper valve to adjust the height to which the valve should rise, and to prevent its breaking away and getting into the air vessel, which it otherwise might do from the violence of the blow.

It has been found, that after using the water ram for a short time, as it was formerly constructed, the air in H became absorbed and entirely disappeared, and by its ceasing to act as an air vessel, the water would not proceed to any great height up I I. This is obviated in the present case by the chamber G placed between the air vessel and the pipe D. From the form of this chamber, any air which enters it becomes confined in the recess K, and not only equalizes the action of the upper valve, but makes the whole motion instantaneous. K is supplied with air in small machines by the falling of the valve F, which brings a small quantity of air down with it. In larger ones it will be necessary to apply a small snifting valve or spring valve, opening inwards to some part of the outside of G, when the air, as it enters, will rise to the top

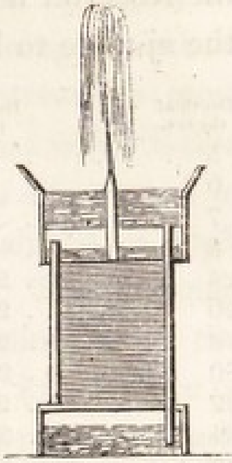
of the chamber K, and as it accumulates, will at length pass into the vessel H, and keep it supplied with air.

Professor Millington says, that in the rams which he had seen, the tube C D has been from half an inch to four inches diameter, and the ascending pipes I I one inch, or rather less: the valve F making from fifty to seventy pulsations in a minute; and the pipe should discharge about half a pint of water at each pulsation, at the height of thirty feet with a six feet head.

The hydraulic apparatus employed at *Schemnitz*, is intended to raise water through the intervention of a column of air. In this apparatus the water, descending through a pipe A into a closed reservoir C full of air, obliges the air to act, by means of a pipe B leading from the upper part of the reservoir or air vessel, on the water in a second reservoir D, at any distance either below or above it, and forces this water to ascend through a third pipe F to any height less than that of the first column. The air vessel is then emptied, and the second reservoir filled, and the whole operation is repeated. The air must, however, acquire a density equivalent to the pressure of the water before it can begin to act; so that if the height of the column were thirty-four feet, it must be reduced to half its dimensions before any water would be raised; and thus half of the force would be lost: in the same manner, if the height were sixty-eight feet, two-thirds of the force would be lost. But where the height is small, the force lost in this manner is not greater than that which is usually spent in overcoming friction and the other imperfections incident to hydraulic machinery; for the quantity



of water actually raised by any machine, is not often greater than half the power which is consumed.



Hero's fountain most probably suggested the construction of the Schemnitz apparatus: the first reservoir of the fountain is lower than the orifice of the jet: a pipe descends from it to the air vessel, which is at some distance below, and the pressure of the air is communicated, by an ascending tube, to a third cavity, containing the water which supplies the jet. The upper reservoir being filled with water, and the lower with air, and water being poured into the pipe at top, the air acts by the ascending tube on the water, and forces it up the central pipe in a continuous stream.

In this, as well as in all other fountains, considerable attention should be paid to the form of the ajutage.

By enlarging the aperture of a jet, the friction against the sides is proportionately diminished; but the thicker the column the greater the resistance of the air. There must, therefore, be some particular diameter for a jet, at which the resistance of the air and the friction will be such, as to produce a maximum effect; this is found to take place when the diameter of the aperture is somewhat less than an inch and a quarter. If the aperture be larger or less than this, the jet will not rise so high. The higher the reservoir, within certain limits, the nearer the summit of the jet approaches to the level of the head of water. Theory, on these subjects, is exceedingly apt to lead to erroneous conclusions, by not comprehending all the modifying circumstances; and the following table will be found valuable, as it has been deduced from experi-

ments to ascertain the height to which jets of water will rise perpendicularly, when the altitudes of the water in the reservoir are from five to one hundred feet, supposing the ajutage to be of the best possible form.

Depth of the res.	Height of the jet.	Depth of the res.	Height of the jet.	Depth of the res.	Height of the jet.
5	4.91	9	8.74	16	15 22
6	5.88	10	9.68	18	17.03
7	6.84	12	11.55	20	18.82
8	7.80	14	13.40	22	20.58
24	22.33	50	43.65	76	62.84
26	24.06	52	45.19	78	64.24
28	25.78	54	46.72	80	65.64
30	27.48	56	48.24	82	67.02
32	29.16	58	49.74	84	68.40
34	30.83	60	51.24	86	69.76
36	32.47	62	52.73	88	71.74
38	34.11	64	54.20	90	72.48
40	35.74	66	55.66	92	73.82
42	37.35	68	57.12	94	75.16
44	38.93	70	58.56	96	76.49
46	40.53	72	60.00	98	77.81
48	42.09	74	61.42	100	79.12

These calculations are only confirmed by experiment in cases when the ajutage through which the fluid runs is particularly constructed; that is, when it is formed by a short tube, of which the sides are so curved that the particles of the fluid may glide along them for some distance, and escape in a direction parallel to the axis of the stream. A short cylindrical pipe is found to answer this purpose in some measure; but the end may be more completely obtained by a tube nearly conical, but with its sides a little convex inwards, so as to imitate the shape which a stream or vein of water spontaneously assumes when it runs through an orifice in a thin plate: for in such cases the stream contracts itself, after it has passed the orifice, for the distance of about half its diameter, so that at this point its thickness is only four-fifths as great as at its passage; and the quantity discharged is only five-eighths

as great as that which the whole orifice would furnish, according to the preceding calculation; instead, therefore, of multiplying the square root of the height by eight, we may employ the multiplier five for determining the actual discharge. But the velocity, where the stream is most contracted, is only one-thirtieth less than that which is due to the whole height; and when the jet is discharged in a direction nearly perpendicular, it rises almost as high as the surface of the fluid in the reservoir. This contraction of the stream, and the consequent diminution of the discharge, is unquestionably owing to the interference of the particles of the fluid coming from the parts on each side of the orifice, with those which are moving directly towards it; and the effect is more perceptible when the orifice is made by a pipe projecting within the reservoir, so that some of the particles approaching it must acquire in their path a motion contrary to that of the stream.

AEROSTATION.

Origin of the Science.—Progress of Aerostation in France.—Rarefied Air Balloon.—Montgolfier.—Messrs. Roberts and Collin.—Pilatre de Rozier.—Andreani.—Blanchard.—Parachute.—Descent of M. Garnerin.—Count Zambecari.—Construction.—Silk.—Varnish.—Valve.—Sadler.—Mechanical Contrivances.—Wings.—Sir G. Cayley.—Professor Danzel.—Present State of Aerostation.—Meteorological Observations.

THE science of aerostation, as connected with hydrostatic equilibrium, belongs almost exclusively to the beginning of the present, or the close of the last century. Mechanical contrivances for the purposes of flying, are, however, of a very early date; and the pigeon of Archytas, or the soaring eagle of the Emperor Charles, may evidently be arranged under inventions of this description.

Bishop Wilkins was an early disciple of this art, and his first step was purely theoretic. He saw that a body lighter than air must rise in it, but he offered no practical suggestion for the purpose. He proposed to exhaust a large copper vessel, without, however, observing that the pressure of the air must crush it inwards, unless the metal were of such a thickness as would make it too heavy for the purpose. Still there was one avenue to the object of pursuit, to which the common and well-known principles of hydrostatics appeared to direct the way, though it had been of all others the most neglected; this was the obvious one, that any body which is specifically, or bulk for bulk, lighter than common air, will rise and swim in it, and sub-

mit to the action of the wind ; therefore, if any body could be found which was in any considerable degree lighter than air, by making it of a sufficient size, a person might attach himself to it, and float along with it. But as air was considered the lightest of all things, there appeared little reason to believe that such a discovery would be made, till, in the year 1766, Cavendish announced to the world, that the gas, now generally called hydrogen, but at that time called inflammable air, was at least seven times lighter than common air. In consequence of this discovery, it occurred to Dr. Black, and he suggested the idea in his lectures, in 1762 or 1763, that if a bladder, sufficiently light and thin, were filled with this air, it would form a mass so much lighter than the same bulk of atmospheric air, that it would float in the latter. He proposed to use the alantois of a calf for this purpose, but other avocations prevented his subsequent attention to this subject. Reflecting on the remarks of Dr. Black, Cavallo, about the commencement of the year 1782, made several experiments to elevate a bag filled with hydrogen gas; he tried bladders, the thinnest and largest that could be procured; but though cleaned with great care, and every superfluous membrane scraped off, they were found somewhat too heavy for the purpose. He also tried bags of the finest China paper, of such a size that, had it been possible to fill them with the gas, their ascension would have been certain; but the experiments failed, the reason of which was, that though common air would not pass through this paper, hydrogen gas passed through it like water through a sieve. In short, he was completely successful only in filling soap-bubbles with the gas, which was easily done by pressing small quantities of gas out of a bladder, while a small pipe from the bladder was immersed in a solution of soap in water ; these bubbles

rapidly ascended in the ambient air, and they may be considered as the first inflammable air-balloons that were ever exhibited.—Cavallo read to the Royal Society the paper in which he gave an account of his experiments, on the 20th of June, 1782.

In the last mentioned year and month, but unknown to the English Philosophers, two brothers, Stephen and Joseph Montgolfier, paper manufacturers at Annonay, about thirty-six miles from Lyons, in France, formed a scheme that led in a short time to the practice of aerostation on a great scale. Taking notice of the ascent of smoke and vapours, it occurred to them, that if a cloud could be inclosed in a bag, a floating vehicle would be immediately formed: their attention was therefore directed to the most feasible method of accomplishing this purpose, or something equivalent to it, and the first experiment was made at Avignon, by Stephen, the eldest of the two brothers, towards the middle of November, 1782. He prepared a bag of fine silk, in the shape of a parallelopipedon; its capacity was about forty cubic feet, and he applied to its aperture burning paper, which rarefied the air, and thus formed in it a kind of cloud; when the bag became inflated, and he beheld with high satisfaction, that it ascended rapidly to the ceiling. Encouraged by this success, he subsequently made several experiments in the open air, in conjunction with his brother, and on the 5th of June, before a large assemblage of people, exhibited the powers of a machine of great magnitude. The capacity of the new aerostat was equal to about 23,430 cubic feet, and when inflated, it measured 117 English feet in circumference. It was formed of linen, lined with paper; its shape was nearly spherical, and when filled with air at half the density of common air, it was estimated to be capable of lifting about 490 pounds besides

its own weight, which, with a wooden frame, sixteen feet in surface, that distended the mouth of it, was equal to 500 pounds more. It was suspended, in a flaccid state, on a pole 35 feet high, straw and chopped wool were burned under the opening at the bottom, and the smoke, as it was then chiefly supposed to be, which entered it, distended it in all its parts, and it ascended with such velocity, that in less than ten minutes it reached the elevation of 6000 feet. A breeze carried it in a horizontal direction to the distance of 7668 feet, and it then fell gently on the ground.

About this time, Joseph Montgolfier visited Paris, and was invited by the Royal Academy of Sciences, to repeat his experiment of Annonay on a larger scale. He constructed with coarse linen and a paper lining, a balloon of a pear shape, and about forty-three feet wide and seventy-five feet high. The smoke, or rather heated air, arising from fifty pounds of dry straw, in small bundles, joined to that of twelve pounds of wool, was found sufficient to fill it, in the space of ten minutes. The bag duly swelled, and made an effort to rise, equivalent to the weight of 500 pounds; but being reserved for exhibition the next day, it was totally destroyed by its exposure, during the night, to incessant and violent rain. It became necessary, therefore, to prepare another balloon; and such was the expedition of the artist, that in five days he got the whole completed. Early on the morning of the 19th of September, it was placed upon an octagon scaffold in front of the palace of Versailles. It had a very showy appearance, being painted with ornaments in oil colours. By ten o'clock, the road from Paris was crowded with carriages of all descriptions.

Every person of any note or fashion hurried from the metropolis to view the experiment; ladies of distinguished rank filled the windows; and the spacious courts and walks,

and even the tops of the houses were covered with impatient spectators. The royal family and their attendants came forth and examined the details of the apparatus. About one o'clock, the discharge of a mortar gave notice that the filling of the balloon was to commence. In eleven minutes, another discharge announced that it was completely inflated; and on the third discharge of the mortar, the cords were cut, and the balloon instantly liberated. After balancing at first in a moment of anxious expectation to the spectators, it rose majestically, in an oblique direction, under the impulse of the wind, till it reached the height of 1500 feet, where it appeared for a while suspended, but in the space of eight minutes it dropped to the ground, at the distance of two miles from the point of its ascent. A sheep, a cock, and a duck, which had been put into the basket, the first animals ever carried up into the air, were found perfectly safe and unhurt by the journey, and the sheep even feeding at perfect ease.

This successful experiment encouraged Montgolfier to prepare, on a more solid construction, another balloon, of a spheroidal form, forty-five feet wide and seventy-five feet high. While it was filling with smoke, Pilatre de Rozier (who afterwards fell a victim to his courage in a subsequent ascent) leaped into the car, and was borne up to the height of 300 feet, where he continued some minutes suspended, the balloon being held down by long cords till it gently descended. The dangers of navigating the aerial element being thus brought to a more correct estimate, it was resolved speedily to attempt the experiment. The badness of the weather, however, at this late season of the year, caused the project to be deferred for several days. At last, on the 21st of November, every thing was ready for the ascent, in the spacious gardens of the chateau of Muette, attached

to the Dauphin's Court. The sky had a lowering aspect, being loaded with heavy clouds, driven about by irregular winds; but the adventurers were not to be easily discouraged. After a first trial, which had nearly proved fatal to them, the balloon was again filled, and Rozier, with the Marquis d'Arlandes, a major of infantry, who had volunteered to accompany him, took their seats in the car, having a store of ballast, and a provision of straw to supply the fire. About two o'clock the machine was launched, and it mounted with a steady and majestic pace. Wonder, mingled with anxiety, was depicted in every countenance; but when, from their lofty station in the sky, the navigators calmly waved their hats, and saluted the spectators below, a general shout of acclamation burst forth on all sides. As they continued to ascend, however, they were no longer discernible by the naked eye. This balloon soared to an elevation of more than 3000 feet, and traversed by a circuitous and irregular course the whole extent of Paris. A curious circumstance occurred during the passage of the floating mass, to the gazers planted on the towers of the metropolitan church of Notre Dame: it chanced to intercept the body of the sun, and thus gave them, for a few seconds, the spectacle of a total eclipse. It has been alleged, that when the balloon had reached so high that the objects on earth were no longer distinguishable, the Marquis d'Arlandes began to think that his curiosity and ambition were sufficiently gratified. He was therefore anxious to descend, and murmured against his companion, who still kept feeding the fire. At last, on hearing some cracks from the top of the balloon, and observing holes burning in the sides, the Marquis became outrageously alarmed at his imminent danger; and applying wet sponges to stop the progress of combustion, he compelled M. Rozier to desist from his officious opera-

tions. As they now descended too fast, however, M. d'Arlandes was not less anxious and diligent in throwing fresh straw upon the fire, in order to gain such an elevation as would clear the different obstacles. The navigators dexterously avoided the lofty buildings of Paris, by supplying fuel as occasion required; and, after a journey of twenty or twenty-five minutes, they safely alighted beyond the Boulevards, having described a track of six miles.

The mania for aerial voyaging soon passed from France to Italy; and the Chevalier Paul Andreani appears to have been the first to construct a large aerostatic machine for this purpose. The balloon was of a spherical form, about sixty-eight feet in diameter, and made of linen, lined with fine paper. In the inside, towards the middle of the apparatus, there was a wooden zone, or hoop: a similar hoop of about fourteen feet in diameter being placed round the lower aperture. On the top of the bag there was a round piece of wood, strengthened with an iron hoop, from which ropes proceeded, and passing down the seams, were fastened to the hoop at the aperture; to which was also attached a series of short wooden arms supporting the brazier or fire-place. Cords proceeding from the same hoop, held a circular basket, which hanging beneath the grate, allowed the aeronauts to supply the fire with fuel without being incommoded by the heat. When the machine was completed, it was conveyed to the Chevalier's country residence at Moncucco, near Milan; and perfectly inflated in about fifteen minutes. This occurred on the 25th of February, 1784, and every thing being in readiness for the intended ascent, the Chevalier, accompanied by his two assistants, entered the car, and immediately ascended with a slow and almost horizontal motion, directing itself towards the adjacent buildings, to avoid which, the fire was encreased, and then

the balloon ascended with the greatest rapidity. After remaining about twenty minutes in the atmosphere, the travellers descended and returned with the apparatus to Moncucco; no part of which received the slightest damage.

The power of a balloon such as we have now described, may be best understood by reference to the following fact: namely, that one degree of heat, according to the scale of Fahrenheit's thermometer, tends to expand the air about one four-hundreth part; and about 400, or rather 435 degrees of heat, will just double the bulk of any given quantity of air. If, therefore, the air inclosed in any kind of covering be heated, and consequently dilated to such a degree, as that the excess of the weight of an equal bulk of common air above the weight of the heated air is greater than the weight of the covering and its appendages, this whole mass will ascend in the atmosphere, till, by the cooling and condensation of the included air, or the diminished density of the surrounding air, it becomes of the same specific gravity with the air in which it floats; and without renewed heat, it will gradually descend.*

We have placed the Montgolfier balloon first in order of arrangement, on account of its great simplicity of construction; but in our historical view of the science of Aerostation, it may be advisable to turn to the progress of discovery in England, where another and more manageable agent was placed at the command of the aerial navigator.

In the year 1776, Mr. Cavendish ascertained that the

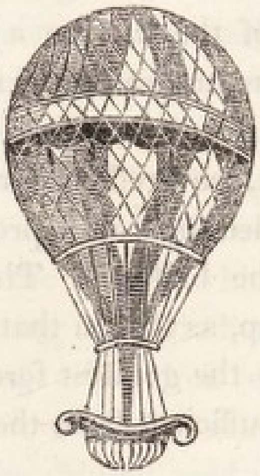
* The buoyant properties of heated air may readily be shown by reference to a very simple experiment. If we roll up a sheet of paper in a conical form, fastening it by its apex to one of the sides of a scale-beam, and balance it by weights attached to the other, the application of a candle beneath the hollow cone will immediately destroy the equilibrium: the flame causing the air to expand, and, as such, rendering the cone lighter than it was in its original state.

specific gravity of hydrogen gas was considerably less than that of atmospheric air; and it occurred to Dr. Black of Edinburgh, that if a bladder, sufficiently light and thin, were filled with this air, it would form a mass lighter than the same bulk of atmospheric air, and rise in it. This thought was suggested in his lectures in 1763; and he proposed, by means of the alantois of a calf, to try the experiment. Other employments, however, prevented the execution of his design. The possibility of constructing a vessel, which, when filled with inflammable air, would ascend in the atmosphere, had occurred also to Mr. Cavallo about the same time; and to him belongs the honour of having first made experiments on this subject. This occurred in the beginning of 1782, of which an account was read to the Royal Society on the 20th of June in that year.

The first experiment with a balloon of this description, was performed in London on the 25th of November, 1783, by Count Zambecarri, an ingenious Italian, to whom we shall presently again allude; with a balloon of oiled silk, ten feet in diameter, and weighing eleven pounds. It was gilt, in order to render it more beautiful and more impermeable to the inflammable air. This balloon having been three-fourths filled with inflammable air, was launched from the Artillery-ground, in the presence of a vast concourse of spectators, at one o'clock in the afternoon; and at half past three was taken up near Petworth, in Sussex, forty-eight miles distant from London; so that it travelled at the rate of near twenty miles an hour. Its descent was occasioned by a rent, which must have been the effect of the rarefaction of the inflammable air, when the balloon ascended to the rarer part of the atmosphere.

The mode of constructing, as well as filling aerostatic machines must now be noticed. Large balloons for inflam-

mable air, such as is shown below, should be made of silk, and coated with varnish, so as to be perfectly air-tight.*



In the upper part of the balloon there is usually placed a

* The varnish for the silk or linen of the inflammable air-balloons should be impermeable to the inflammable gas, pliable, and sufficiently dry to adhere firmly to the stuff. The following varnish has been recommended. To one pint of linseed oil, add two ounces of litharge, two ounces of white vitriol, and two ounces of gum sandarach; boil the whole for about an hour over a slow fire, then let it cool: separate it from the sediment, or strain it through a sieve, and dilute it with a sufficient quantity of spirits of turpentine. But Mr. Cavallo states that the best varnish for an inflammable air-balloon is made with bird-lime. It may be prepared in the following manner:—In order to render linseed oil drying, boil it with two ounces of saccharum saturni and three ounces of litharge, for every pint of oil, till the ingredients are dissolved; then put a pound of bird-lime and half a pint of the drying oil into a pot of iron or copper, holding about a gallon; and let it boil gently over a slow charcoal fire till the bird-lime ceases to elicit sound; then pour upon it two pints and a-half of drying oil, and boil it for about an hour longer, stirring it often with an iron or wooden spatula. As the varnish in boiling swells much, the pot should be removed from the fire, and replaced when the varnish subsides. Whilst it is boiling, it should be occasionally examined, in order to determine whether it has boiled enough. For this purpose, take some of it upon the blade of a large knife, and after rubbing the blade of another knife upon it, separate the knives, and when, on their separation, the var-

valve, opening inwards, and connected by means of a string with the car, so that when the aeronaut wishes to descend, he may readily open the valve and allow the gas to escape. To the lower part of the balloon a pipe is attached, by which an air-tight communication is readily made with the apparatus for generating gas. The car is in most cases made of wicker work, covered with velvet or leather, and painted, and suspended by ropes proceeding from the net which passes over the balloon. The meshes of the net should be small at top, as it is in that situation that the inflammable air exerts the greatest force: but single strings are generally found sufficient from the equator of the balloon to the car.

The machine being constructed, it only remains to fill it with inflammable air (hydrogen gas). The usual method of procuring this gas is by exposing iron or zinc to the action of sulphuric acid, or common oil of vitriol. For this purpose, in the early aerostatic experiments, a number of air-tight casks were disposed in circles of ten or twelve in

nish begins to form threads between the two knives, it has boiled enough. When it is almost cold, add about an equal quantity of spirits of turpentine; mix both well together, and let the mass rest till the next day: then having warmed it a little, strain and bottle it. If is too thick, add more spirits of turpentine. This varnish should be laid upon the stuff when perfectly dry, in a luke-warm state; a thin coat of it upon one side, and about twelve hours after, two other coats should be laid on, one on each side, and in twenty-four hours the silk may be used.

Mr. Blanchard's method of making elastic-gum varnish for the silk of a balloon, was as follows:—Dissolve elastic gum, cut small, in five times its weight of spirits of turpentine, by keeping them some days together; then boil one ounce of this solution in eight ounces of drying linseed oil for a few minutes, and strain it. Use it warm.

In addition to these useful hints as to the mode of silk impervious to the gas, it may be right to add, that an ingenious chemist has lately recommended the use of naptha as a solvent for the cachoutac.

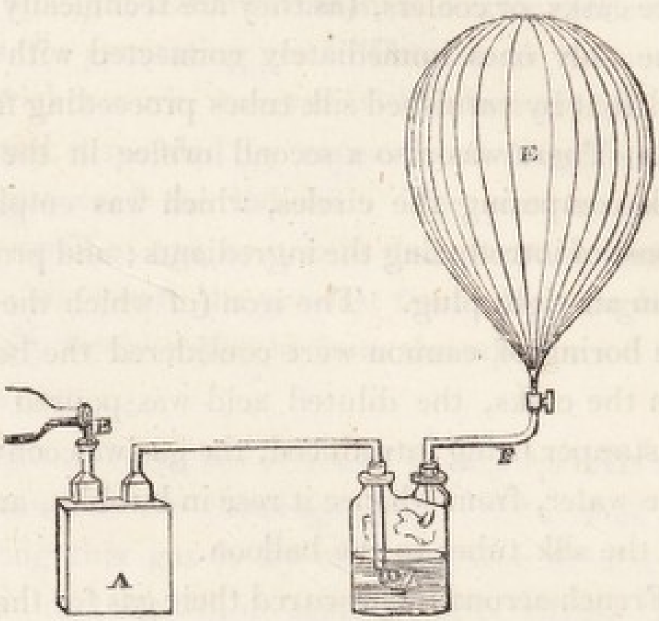
each circle: the casks composing one circle being made to communicate by separate tubes with a centre cask containing water, whose height was such, that the orifice of each tin tube was immersed some inches under the fluid; the centre casks, or coolers, (as they are technically termed,) being the only ones immediately connected with the balloon, and that by varnished silk tubes proceeding from their summits. There was also a second orifice in the head of each cask composing the circles, which was employed for the purpose of introducing the ingredients; and provided also with an air-tight plug. The iron (of which the turnings from the boring of cannon were considered the best) being placed in the casks, the diluted acid was poured upon it, and the stopper being introduced, the gas was conveyed beneath the water, from whence it rose in bubbles, and passed through the silk tubes to the balloon.

The French aeronauts procured their gas for the inflation of their large balloons by another, and more economical process. To effect this desirable object, a quantity of iron wire was put into an iron or earthen tube, which was placed across a small furnace, so that it could be kept at a red heat. One end of the tube being connected with a retort containing water, on distilling which, the vapour from it, in passing over the surface of the ignited iron, is readily decomposed, the iron attracting oxygen, while the hydrogen was made to issue from the tube in a state of comparative purity.

We may now, however, show the mode of filling experimental balloons on a small scale, with the greatest certainty of success.

The aerostat E, in the above diagram, is connected by a pipe F, with the condensing vessel D. The ingredients for making the gas being placed in the leaden or glass box

A. If diluted sulphuric acid be poured on the zinc at A, the gas will be liberated and pass along the horizontal tube to the next vessel, and as it must ascend through the water



at D, the acid vapour is condensed, and hydrogen gas nearly in a state of purity enters the balloon.

The use of carburetted hydrogen gas obtained from the distillation of coal, is an improvement of comparatively modern date. Two or three aeronauts have employed it with the greatest success, though its practical application is certainly due to Mr. Green, one of the most enterprising, though certainly not the most scientific aerial traveller that has appeared during the present century.

Lunardi took an expeditious but careless method to fill his balloon with gas. He had two large casks sunk into the ground for their better security; in which he deposited 2000 pounds of the borings of cannon, divided by layers of straw, to present the largest possible surface. An equal weight of sulphuric acid, or common oil of vitriol, diluted

with six times as much water, was poured upon the iron, and the hydrogen gas thus formed, without being cooled or washed, was immediately introduced into the balloon.

The quantity of hydrogen gas developed during the action of dilute sulphuric acid upon iron, varies not only according to the strength of the acid, but the quantity of the iron employed. Dr. Priestley found that annealed cast iron invariably afforded more inflammable air than iron which had not undergone that process; the difference being nearly one-eighth. Thus iron turnings, as being in some degree annealed, gave considerably more gas than only cast iron, yet less than iron nails perfectly annealed. Mr. Cavendish also obtained from an ounce of zinc, 356 ounce measures of inflammable air; from the same quantity of iron 412 measures; while tin afforded him only half the quantity yielded by iron. Supposing, then, we are about to inflate a balloon of thirty feet diameter, it will require, agreeably to Mr. Cavendish's experiments, about two ounces and a-half of iron for each cubic foot of inflammable air, or 2200 pounds of iron to be dissolved in order to completely fill the machine; and to produce this solution, there will altogether be required an equal weight of concentrated oil of vitriol, and six times this weight of water. But completely filling a balloon before its ascension is useless; because the density of the surrounding medium immediately decreasing, will cause an equally premature expansion of the gas, and require its escape even before it attains 1000 yards in height: the proportional product, therefore, of 2000 pounds of metal will be as much as may with propriety be applied to a machine of thirty feet diameter.

The general elevation to which the balloon will ascend, must be determined by its quantity of ballast, conjoined with the regulation of the safety-valve; but the strain of

the silk case itself would be sufficient to confine the ascent within certain limits, and to procure the stability of the floating mass. Thus, if a balloon fully distended, had yet a slight disposition to rise, the imprisoned gas suffering more and more compression as it gradually ascends, would become proportionally denser, and therefore lose a corresponding part of its previous buoyancy. An equilibrium would hence soon obtain, which must arrest the floating machine at a determinate height in the atmosphere.

It may now be advisable to notice a few of the most remarkable incidents that have occurred in the history of aerostation. Early in the year 1785, Messrs. Blanchard and Jefferies crossed the English channel in an inflammable air balloon constructed by the former gentleman.

The apparatus was conveyed to Dover, and placed at about fourteen feet distance from the perpendicular cliff.* Soon after one o'clock the boat was pushed from *terra firma;* but the weight being too great for the power of the balloon, they rapidly descended. On throwing out some ballast, however, they were soon raised to a considerable altitude, though making but very little way. They had now but thirty pounds of ballast; and at fifty minutes past one the balloon began to descend rapidly, though the aeronauts were but one-third of their journey. The whole of the ballast was then thrown out, and the balloon continuing to descend, a parcel of books, anchors, cords, and other apparatus shared a similar fate. As the balloon approached the sea, Messrs. Blanchard and Jefferies found it necessary to throw away their clothes, and fastening themselves to slings, prepared to cut away the boat as a last resource. Calais was now distinctly seen at a distance of about four miles in the

* The scene chosen for this hazardous enterprize was the identical precipice described by Shakspeare, in his King Lear.

direction of the wind; and the balloon rising quickly, dispelled the fears under which they had previously laboured. At three o'clock they passed over the high grounds between Cape Blanc and Paris, and it is a curious fact that the balloon rose higher at this point than it had done in any other part of their journey. This memorable voyage was concluded in the neighbourhood of Guinnes, the travellers descending in safety in the adjacent forest.

The longest and the most interesting voyage which was performed about this time, was that of Messrs. Roberts and Hullin from Paris. Their balloon was filled with inflammable air. Its diameter was 27¾ feet, and its length 46¾ feet, and it was made to float with its longest part parallel to the horizon, with a boat of nearly seventeen feet long attached to a net that went over it as far as its middle. To the boat were annexed wings or oars, in the form of an umbrella. At twelve o'clock they ascended with 450 pounds of ballast, and after various manœuvres, descended at forty minutes past six o'clock, near Arras, in Artois; having still 200 pounds of their ballast remaining in the boat. Having risen about 1400 feet, they perceived stormy clouds which they endeavoured to avoid; but the current of air was uniform from the height of 600 to 4200 feet. The barometer on the sea-coast was 29.61 inches, and sunk to 23.94 inches. They found that by working with their oars they accelerated their course. In the prosecution of their voyage, which was 150 miles, they heard two claps of thunder; and the cold occasioned by the approach of stormy clouds made the thermometer fall from 77° to 59°, and condensed the inflammable air in the balloon so as to make it descend very low. From some experiments they concluded that they were able by the use of two oars to deviate from the direction of the wind about 22°.

The fate of Pilatre de Rozier has been much and deservedly lamented. He ascended at Boulogne, and was accompanied by the Marquis de Romain. Their machine consisted of a spherical balloon thirty-seven feet in diameter, filled with inflammable air; and under this part of the aerostat was suspended a small Montgolfier balloon, ten feet in diameter, to which the car was attached. This unfortunate experiment was undertaken with a view of discovering a method of raising or lowering aerostatic machines at pleasure, as it was supposed that an increase or diminution of the heat in the fire-balloon would place the buoyant power of the whole apparatus under the control of the aeronaut.

On the 14th of June, 1785, M. Pilatre de Rozier, accompanied by M. Romain, ascended in this complicated machine. They had not been long in the air, when the upper balloon was seen to swell very considerably, and the aeronauts appeared anxious to open the valves, and facilitate their descent by letting the inflammable air escape. The whole machine was shortly after observed to be on fire, at the height of about three-quarters of a mile from the ground, and the silk collapsing, the apparatus descended with such rapidity that both the aeronauts died upon the spot.

Count Zambecarri may be considered as amongst the most unfortunate of the early voyagers. This gentleman, accompanied by Dr. Grassetti, of Rome, and M. Pascal Andreoli, of Ancona, having prepared a large air-balloon, proposed ascending from that city. The filling, however, went on very slowly, and was not completed till midnight. Count Zambecarri and his companions were therefore desirous to put off their ascent till the next day: but the impatience and clamour of the populace obliged them to step into the car and suffer the balloon to ascend. The apparatus rose with the utmost rapidity, and soon reached such a

height, that Count Zambecarri and Dr. Grassetti, benumbed with cold and seized with a nausea, fell into a state of insensibility and deep sleep.

M. Andreoli, who alone retained the use of his senses, was not able to determine the height by his barometer. About half an hour after two in the morning, the balloon began to descend, and M. Andreoli soon observed distinctly the waves of the Adriatic sea dashing against the coast of Romagna. He therefore waked his companions, and endeavoured to kindle a light by a phosphoric match, but without success. At length, however, he obtained a light, and immediately after the balloon fell into the Adriatic, and with such violence as to dash the water several feet above them. The aerial travellers, drenched with sea-water, and benumbed with cold, threw out in great consternation a bag of sand, their instruments, and every thing they had with them in the car. By these means the balloon rose again rapidly: they then passed through three strata of clouds lying over each other; in consequence of which, their clothes were covered with a thick rime; and, on account of the rarity of the air in which they now were, when raised above the clouds, they could scarcely hear each other speak. The moon illuminated the atmosphere under them, and had a blood-red colour. About three o'clock in the morning the balloon again descended, but slowly, and a violent gust of wind at south-west drove it across the Adriatic towards the coast of Istria. The car several times touched the waves; and the travellers were carried in this manner over the surface of the sea for five hours, every moment expecting to be swallowed up by it. At eight o'clock on the following morning they were about twenty Italian miles from the harbour of Veruda, in Istria, when they were fortunately picked up and saved from destruc-

tion by the master of a bark, who accidently discovered them.

In another journey, in which he was accompanied by Dr. Andreoli, after a very successful voyage, he descended in the neighbourhood of Bologna, and having arrived within a short distance of the earth, he made his anchor fast to a tree. The balloon having by this movement acquired an oblique direction, the lamp was overturned, and the spirit of wine it contained fell to the bottom of the car and took fire. The flames soon reached a vessel containing thirty pounds of spirit of wine. The vessel burst, and the flames spread more and more. At length, they extended to the clothes of the aeronauts, and even threatened the netting and the ropes by which the car was suspended. Zambecarri laid hold of a bottle of water and extinguished the fire which had communicated to his clothes. Andreoli, who only thought of escaping, glided down by the anchor-rope to the tree, and fell thence to the ground without sustaining much hurt. The balloon being freed from his weight, rose rapidly with Count Zambecarri, and in a moment disappeared above the clouds. The Count, however, did not lose his presence of mind, but continued to extinguish the fire both in his clothes and in the car.

The balloon was then carried by a strong current of air towards the Adriatic, and at three o'clock the Count perceived the coast of Comachio, but from such an elevation that he could hardly distinguish it. Soon after he fell into the sea at about the distance of twenty-five Italian miles from the coast. The car, which was half burnt, sunk, and count Zambecarri, who held fast by the ropes of the balloon, had the water often up to the neck. Apprehensive that lassitude would oblige him to let go his hold, or that he should be overcome by sleep, he endeavoured to fasten

himself to a rope. By means of a bit of glass he detached one from the balloon, and fastened it round his body, the other end of it being fixed to the machine. In this situation he floated on the water for some hours, the balloon being still inflated.

At length, about six in the evening, he observed seven fishing-boats, the people in four of which, being struck with terror, betook themselves to flight, imagining that they saw some strange kind of sea-monster. The other three approached, and took from the water the unfortunate aeronaut half burnt, after having spent four hours at sea, amidst the most dreadful anguish. The fishermen attempted also to seize the balloon, but, as soon as they had cut the ropes, it rose, and took its course towards the Turkish coast.

M. Gay Lussac furnished the scientific public with the following account of his last aerostatic ascent.

He ascended at ten in the morning, from the Jardin du Conservatoire des Arts et Metiers, which is about twenty toises higher than the level of the sea. His barometer then stood at 28 inches 3.33 lines, and the mercurial centigrade thermometer indicated in the shade, 27.75 degrees. These two instruments varied very little on the earth, or during the course of the ascension, and their changes were observed every hour by M. Bouvard at the Observatory. M. Gay Lussac, in ascending, made a great many observations on the barometer, the thermometer, the hygrometer, and the magnetic needle.

At the height of 3902 metres, or 2002 toises, he found the inclination of the needle the same as at the surface of the earth. The duration of the oscillations of a horizontal needle, made with great care by that able artist Fortin, magnetized by Coulomb, and suspended by a silk thread,

were also the same. M. Gay Lussac never found any sensible difference in their duration. When he reached the height of 6675 metres, or 3425 toises, he opened two glass balloons, which had been exhausted on the earth, and which had preserved their vacuous state. The air entered into them with a hissing noise; and when they were filled he closed them. He continued to rise to the height of 7017 metres, or 3600 toises; his barometer was then 12 inches 1.76 lines, and his thermometer in the shade marked 9½ degrees below the temperature of melting ice. This height, the greatest to which any person ever ascended, surpasses by 600 metres the summit of Chimboraco in Peru, one of the highest mountains on the earth. M. Gay Lussac still, however, saw clouds above him, but which appeared to be at a great elevation. His pulse was accelerated; and the number of pulsations, which at the earth was only 62, increased to 95. His respiration was a little confined; but he thinks he could have risen to the height of 8000 metres without experiencing much inconvenience, had he not been so imprudent as to throw out before, the ballast which would have been necessary to moderate his descent. He therefore descended slowly, and with those precautions which his first ascent had shown to be necessary. At 45 minutes past three he reached the earth, without the slightest accident, six leagues to the north of Rouen, at the small village of Saint Gourgon; the inhabitants of which assembled on seeing his balloon, gave him every assistance, and treated him with the utmost hospitality.

On his return to Paris, his first care was to analyse the air he had collected in his ascent. One of his balloons being opened under water, became half filled with it; which proved that no foreign air had entered it. On comparing the air of this balloon with that collected at the sur-

face of the earth, he ascertained, by several very exact eudiometric processes, that the proportions of oxygen and azote in the two airs were perfectly similar.

This interesting aerial voyage has, therefore, confirmed two important points in natural philosophy; namely, First, That the magnetic force experiences no sensible variation, either in its inclination or its intensity, from the surface of the earth to the greatest heights to which it is possible to ascend. Secondly, That in this interval the constitution of the atmosphere is entirely the same. M. Gay Lussac observed, that the heat decreased nearly in arithmetical progression, in proportion as he rose into the atmosphere, and that each degree of the depression of his centigrade thermometer corresponded to an elevation of about 85 toises 5 feet.

M. Garnerin and another gentleman ascended with an inflammable air, or hydrogen-gas balloon, from Ranelagh Gardens, on the south-west of London; and in exactly three-quarters of an hour reached the neighbourhood of the sea, four miles from Colchester; a distance of about sixty miles; so that they travelled at the astonishing rate of eighty miles an hour. It seems that the balloon had power enough to keep them up four or five hours longer, in which time they might have gone safely to the continent; but prudence induced them to descend when they discovered the sea. The singular experiment of ascending into the atmosphere with a balloon, and descending with a machine called a parachute, was performed by the same ingenious foreigner on the 21st of September, 1802.* He ascended

* It may be proper to state that Blanchard was the first who constructed parachutes, and annexed them to balloons, for the object of effecting his escape in case of accident. During the excursion which he undertook from Lisle, about the end of August, 1785, when this ad_

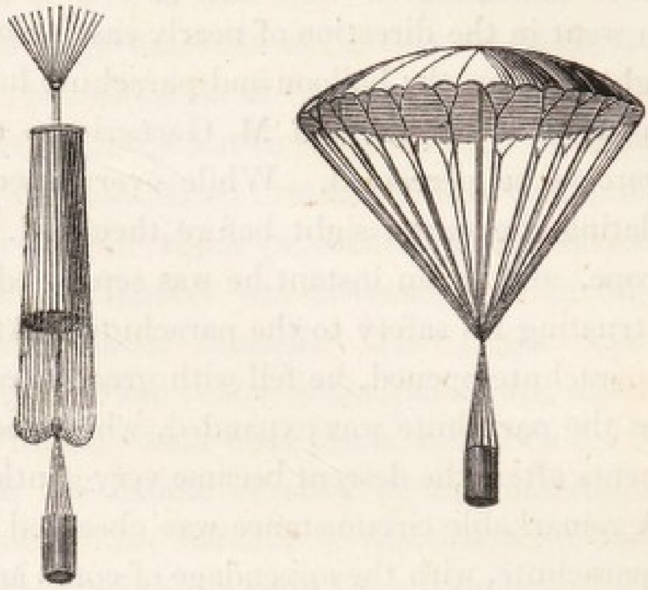
from St. George's parade, London, and descended safely into a field near the Small-pox Hospital, at Pancras. The balloon was filled with hydrogen-gas, and covered with a net, from which ropes proceeded, terminated by a single rope at a few feet below the balloon. To this rope the parachute was fastened in the following manner. It may, however, be proper to state that the parachute itself nearly resembled a large umbrella of canvass, of about thirty feet in diameter, but destitute of the ribs and handle:—several ropes, of about thirty feet in length, which proceeded from the edge of the parachute, terminated in a common joining, from which shorter ropes proceeded, to the extremities of which a circular basket was fastened, and in this basket M. Garnerin placed himself. The single rope passed through a hole in the centre of the parachute, also through certain tin tubes, which were placed one after the other, in the place of the handle or stick of an umbrella, and was lastly fastened to the basket; so that when the balloon was in the air, by cutting the end of the rope next to the basket, the parachute, with the basket, would be separated from the balloon, and, in falling downwards, would be naturally opened by the resistance of the air. The use of the tin tubes was to let the rope slip off with greater certainty, and to prevent its being entangled with any of the other ropes, and also to keep the parachute at a distance from the basket. The balloon began to be filled about two o'clock. There were thirty-six casks, filled with iron filings and dilute sulphuric acid, for the production of the hydrogen gas. These communicated with three other casks, or general receivers, to each of which was fixed a tube that

venturous aeronaut traversed, without halting, a distance not less than three hundred miles, he let down a dog from a vast height in the basket of a parachute, and the poor animal, falling gently through the air, reached the ground unhurt.

emptied itself into the main tube, attached to the balloon. At six, the balloon being quite full of gas, and the parachute, &c. being attached to it, M. Garnerin placed himself in the basket, and ascended majestically, amidst the acclamations of innumerable spectators. The weather was the clearest and pleasantest imaginable; the wind was gentle, and about west by south; in consequence of which, M. Garnerin went in the direction of nearly east by north. In about eight minutes the balloon and parachute had ascended to an immense height, and M. Garnerin in the basket could scarcely be perceived. While every spectator was contemplating the grand sight before them, M. Garnerin cut the rope, and in an instant he was separated from the balloon, trusting his safety to the parachute. At first, before the parachute opened, he fell with great velocity; but as soon as the parachute was expanded, which took place a few moments after, the descent became very gentle and gradual. A remarkable circumstance was observed; namely, that the parachute, with the appendage of cords and basket, soon began to vibrate like the pendulum of a clock; and the vibrations were so great, that more than once the parachute and the basket with M. Garnerin, seemed to be on the same level, or quite horizontal: however, the extent of the vibrations diminished as he descended. On coming to the earth, M. Garnerin experienced some pretty strong shocks, but he soon recovered his spirits, and remained without any material hurt.*

* The terminal velocity of a parachute, or the uniform velocity to which its motion tends, would, according to theory, be equal, if its surface were flat, to the velocity that a heavy body must acquire in falling through the altitude of a column of air incumbent on that surface, and having, under the usual circumstances, the same weight as the whole apparatus. But it may be shown by experiment that a cylinder of air, one foot in diameter and height, weighs only, in ordinary cases, the seventeenth part of a pound avoirdupois. So that, if the square of

The mode of constructing a parachute for experimental purposes, will be best understood by the accompanying diagrams; in which the apparatus is shown both in its open and collapsed state. In the one case, as it ascends with the balloon, and in the other, as it is distended by the air during the passage to the earth.



the diameter of a parachute be divided by 17, the quotient will give the number of pounds equivalent to the weight of an atmospheric column of one foot; and the weight of the apparatus being again divided by this quotient, the result will express the entire altitude of an equiponderant column. Of this altitude, the square root multiplied by 8, will denote the final velocity, or that with which the parachute must strike the ground. Suppose, for example, that the diameter of the parachute were 25 feet, then $25 \times 25 = 625$, and this, divided by 17, gives $36\frac{13}{17}$. Consequently, if the parachute with its load weighed only $36\frac{13}{17}$ pounds, the shock received at the surface of the earth would be precisely the same as that which is felt in dropping from an elevation of one foot. Had the weight of the apparatus, therefore, been four times greater, or $147\frac{1}{17}$ pounds, the shock sustained would be the same as that from a fall of four feet; which is near the limit, perhaps, of what a person can bear without suffering injury from the violence of concussion. The velocity of descent, on this latter supposition, would be sixteen feet each second.

The parachute should be constructed of varnished cambric muslin, or light linen, covered externally with a netting, the meshes of which should converge smaller, as they approach the central portion of the machine; observing also to fix the netting on the surface, by sowing it down upon various parts of the surface. The diameter of the parachute (forming only a small segment of a sphere) when extended, not to exceed twenty feet. The central aperture of the umbrella (to allow the escape of a portion of the air through, as the machine descends) not less than three feet in diameter, and provided with a shutter moving upon a hinge, and opening inwards; furnished also with a cord sliding over a single pulley to shut the aperture, and a second cord to open the valve, (each cord reaching to the car,) thus subjecting the shutter to the will of the aeronaut. By this mechanism, the stupifying vibrations of the car may be moderated, if not wholly prevented, by drawing down the shutter so as to fully expose the aperture, whereby the resistance of the parachute to the atmosphere being lessened, by all this diminution of its opposing surface, the gravitating power of the appended weight (tending to draw the body of the machine continually in the perpendicular) will have proportionally a greater effect: the descent in the interim will be also relatively more rapid; but this may be checked in a moment by closing the orifice, especially when near the surface of the earth.

A strong cord should proceed perpendicularly from the centre of the car, to a point formed by the convergence of a number of cords, proceeding from the second ring of wicker-work, the effect of which would be an immediate extension of the parachute to its full diameter, at the instant of descent, as before adverted to. Also, and lastly, a third hoop of wicker work, of six or eight feet diameter, fixed in the

internal concave of the umbrella, to secure against any accidental collapse of the sides, before the machine has become distended by its pressure on the cylinder of air immediately beneath it.

The attempt made by Mr. Sadler to cross the Irish channel, is well worthy of record. This ingenious aeronaut ascended from Belvidere House, near Dublin, with the wind at south-west, and in thirty-five minutes had sight of the mountains in Wales; he continued in the same direction till near three o'clock, when, being nearly over the Isle of Man, he found himself fast approaching the Welsh coast; and at four o'clock he had a distant view of the Skerry light-house. The wind now shifting, he was again taken off, and lost sight of land; when, after hovering about for a long time, he discovered five vessels beating down channel; and in hopes of their assistance, he determined on descending with all possible expedition, and precipitated himself into the sea. In this most critical situation he had the mortification to find the vessels took no notice of him: obliged, therefore, to reascend, he now threw out a quantity of ballast, and quickly regained his situation in the air, to look out for more friendly aid. It was a length of time before he had the satisfaction of discovering any; and then observed a vessel, which gave him to understand by signal, that she intended to assist him, but could not reach him. Two others also now appeared in sight, and one of them tacking about, hoisted the Manx colours: night now coming on, he was determined to avail himself of their friendly aid, and once more descended into the sea; but here the wind, acting upon the balloon as it lay on the water, drew the car with so much velocity, that the vessel could not overtake it: and, notwithstanding he used his utmost efforts, and, latterly, tied his clothes to the grappling-

iron, and sunk them to keep the car steady; still the balloon was carried away so fast, that he was under the necessity of expelling the gas; upon that escaping, the car actually sunk, and he had now nothing but the net to cling to. His perilous situation, and the fear of getting entangled, deterred the men from coming near him; until, being in danger of drowning, Mr. Sadler begged they would run their bowsprit through the balloon, and expel the remaining gas. Having done this, they threw out a line, which he wound round his arm, and was then dragged a considerable way before they could get him on board, quite exhausted.

The last aerostatic ascent it may be advisable to notice, was performed by a gentleman well known in the scientific world for his attachment to meteorological pursuits.

Captain Beaufoy ascended, in company with Mr. Graham, in the latter gentleman's balloon, on the 17th of June, 1823. The balloon rose about six o'clock; the barometer being then 29.8 inches, the thermometer 66°, and the hygrometer 17° dry. Wind very high from the north.

At eight minutes past six, the barometer was 27.4 inches, or 2257 feet, thermometer 46°, hygrometer 15° dry, when every thing was perfectly distinct, but flat, like a military map; and at twelve minutes past six, barometer 25.5 inches, or 4235 feet, thermometer 45°, the aeronauts passed through some thin mist.

At sixteen minutes past six, the barometer was 23.3 inches, or 6605 feet, thermometer 39°, hygrometer 20° dry, when the machine became enveloped in clouds. On rising above the clouds, a most magnificent sight met the eye—a panorama representing one vast expanse of frozen snow, with enormous masses towering above the rest like mountains, having every summit burnished by the rays of the

sun, which shone most brilliantly from a sky of a deep-blue colour.

At twenty minutes to seven, observes the Captain, the barometer 19.2 inches, or 11,711 feet, thermometer 32°, hygrometer 31° dry, Mr. Graham judged we were as high as we could ascend without throwing out ballast; and, as we were far above every object interesting to the eye, the cord of the valve was slightly pulled, and we commenced an extremely gradual descent. At this elevation, 757 feet higher than Mount Etna, I heard the report of a gun, and could distinguish the metropolis when clouds did not intervene.

At eighteen minutes to seven, the aeronauts had commenced their descent, and the barometer was 19.5 inches, or 11,271 feet, and thermometer 31°; when the descent was so imperceptible, that it could only be ascertained by throwing out small pieces of silver paper.

At nine minutes to seven, the barometer was 22.3 inches, or 7784 feet, thermometer 38°, and hygrometer 23°, when the balloon approached the clouds; which had a most beautiful effect, from the masses of vapour seeming to rise up in eddies to meet the aeronauts.

At seven o'clock, barometer 25 inches, or 4714 feet, the balloon emerged from the clouds, and getting into a new current of air, the apparatus revolved. At three minutes past seven, barometer 26.5 inches, or 3130 feet, every object on the earth became perfectly distinct; and Mr. Graham let down his grappling iron, at the end of a cord 160 yards long.

At seven minutes past seven, barometer 28.3 inches, thermometer 50°, hygrometer 22° dry, the height of houses and trees became apparent; and one minute afterwards, the grapple having caught in the boughs of an oak, brought the car to the ground with considerable violence, and after

rebounding two or three times, the aeronauts stepped out without any difficulty, into a field near Godstone.

Captain Beaufoy found, with one exception, that the air continued to get drier as they ascended into the higher regions of the atmosphere.*

The balloon was 63 feet high, by $37\frac{1}{2}$ in diameter, and was capable of holding 46,388 feet of gas; and as each cubical foot of common air equals $1\frac{1}{5}$ oz. the whole weighed 3479 lbs. But the inflammable air used, was $2\frac{1}{2}$ lighter than common air; therefore,

$\frac{2}{5}$ of 3479=1392 lbs. weight of gas.
630 lbs. weight of silk, car, aeronauts, &c.

2022 lbs. total weight suspended.

which, deducted from 3479 lbs. gives 1457 lbs. for the power of rising.

The best mode of conducting balloons, when constructed, filled, and actually ascending in the atmosphere, is an ob-

* From the meteorological facts furnished in the preceding ascent, we pass to those registered by Mr. Forster of Tottenham. Mr. Forster says, that he had long suspected, from the direction of the flying clouds, that the currents of air which occupied the higher regions of the atmosphere came down afterwards, and blew over the earth's surface in the same direction as they had previously blown above. To ascertain this fact, he adds, "I observed attentively the various directions of small air-balloons, made and sent up by my brother. Out of more than twenty experiments, I have selected the following as confirming this fact:—they were made in different years, and in different times of the year.

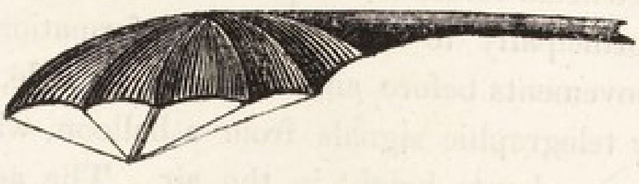
"In October 1809, a gas-balloon, three feet seven inches in diameter, on ascending, first moved with an E. wind; at the height of (about) 500 feet, it got into a N.N.W. current; and lastly, at a much greater altitude, got into a strong gale from S.W., which carried it into Cambridgeshire. The successive changes of the wind next the earth, as indicated by the weather-cocks, were E., N.N.W., and S.W.

ject of great importance in the practice of aerostation. The method generally used for elevating or lowering the balloons with rarefied air, has been the increase or diminution of the fire; and this is entirely at the command of the aeronaut, as long as he has any fuel in the gallery. The inflammable air-balloons, on the contrary, have been generally raised or lowered by diminishing the weight in the boat, or by letting out some of the gas through the valve; but the alternate escape of the air in descending, and discharge of the ballast for ascending, will by degrees render the machine incapable of floating; for in the air it is impossible to supply the loss of ballast, and very difficult to supply that of inflammable air. These balloons will also rise or fall by means of the rarefaction or condensation of the inclosed air, occasioned by heat and cold. It has been proposed to aid a balloon in its alternate motion of ascent and descent, by annexing to it a vessel of common air, which might be condensed by lowering the machine, and rarefied again by expelling part of it, for raising the machine. But a vessel adapted to this purpose, must be very strong, and, after all, the assistance afforded by it would not be very considerable. M. Meunier, in order to attain this end, proposed to inclose one balloon filled with common air, in another filled with inflammable air: as the balloon ascends, the inflammable air is dilated, and of course compresses the internal balloon containing common air, and by diminishing its quantity, lessens its weight. Others have proposed to annex a small machine with rarefied air to an inflammable air-balloon by ropes, at such a distance that the fire of the former might not affect the inflammable air of the latter: the whole apparatus, thus combined, of balloons formed on the two principles of heated and inflammable air, might be raised or lowered by merely increasing or diminishing the fire in the

lower balloon. The latter plan, however, as in the case of Pilatre de Rozier's aerostat, was found to be too complicated for practice.

The most obvious method of producing a lateral motion is by taking advantage of the winds. These are: occasional winds; trade winds between the tropics; the land and sea breezes, which, in warm climates set from and towards the shore by day and night alternately; the superior currents of air, which often proceed in a direction contrary to those below; and the breezes which commonly follow the direction of every river. To these aids we may also add the remarkable phænomenon observed by all aerial navigators: viz. that the balloon sinks lower than usual when over water, and that it has a tendency to keep the direction of a river. This circumstance may partly be attributed to the wind following the current, but principally to the specific gravity of air, impregnated with aqueous vapour, being diminished, and the tendency of the machine to the point of least gravity.

If wings or oars be used for the purpose of directing a balloon, they should be as large and light as possible; and they may be made of silk stretched between metal wires or tubes. If they are flat, they must be turned edgeways when they are moved in the direction of the balloon's course, and flat, in the opposite direction. One of the wings used by Mr. Blanchard, is represented in the accom-



panying diagram, and an examination of its construction will show that it would readily give way to the resisting

media in one direction, while in the other, it would meet with a considerable degree of resistance.

But, to whatever degree of perfection aerial navigation may attain, the limits to which a traveller might soar, will for ever be confined to but a small distance, even supposing that man could exist in any station of the aerial regions, however elevated. The density of the atmosphere decreasing in a geometrical proportion, it will be found that, if a sphere of sheet copper, of half a pound to the square foot, were constructed of equal diameter with our earth, and totally exhausted of its inclosed air, such a globe would attain its equilibrium at 70,047,346 miles distant from the surface of the earth; nor would it attain a greater elevation, although its power of ascension at the instant of departure would be equal to 2,871,691,637,967,270,771,712 pounds.

Almost the only purpose connected with the active business of life, to which balloons have hitherto been applied with success, had for its object that of military reconnoissance. In the early part of the French revolutionary war, when ingenuity and science were so eagerly called into active service, a balloon, prepared under the direction of the Aerostatic Institute in the Polytechnic School, and intrusted to the command of two or three experienced officers, was distributed to each of the republican armies. The decisive victory which General Jourdan gained, in June 1794, over the Austrian forces in the plains of Fleurus, has been ascribed principally to the accurate information of the enemy's movements before and during the battle, communicated by telegraphic signals from a balloon, which was sent up to a moderate height in the air. The aeronauts, at the head of whom was the celebrated Guyton Morveau, mounted twice in the course of that day, and continued about four hours each time, hovering in the rear of the army

at an altitude of 1300 feet. In the second ascent, the enterprise being discovered by the enemy, a battery was opened against them; but they soon gained an elevation above the reach of the cannon.

From a careful examination of the above facts, it will be sufficiently evident that no human force will enable the aeronaut to direct the course of his machine in opposition to that of the wind; his balloon passing at nearly the same rate as the element that supports it. Still, however, it should be added, that the advantages which are likely to result to the science of meteorology from the use of this convenient vehicle for the conveyance of self-registering instruments in the higher regions of the air, more than compensates for the labour that has been expended on the cultivation of this science.

ACOUSTICS.

Nature of Sound.—Mode of Propagation.—Conducting Power of Bodies.—Experiments by Wheatstone.—Velocity of Transmission.—Reflection of Sound.—Speaking and Hearing Trumpets.—Echo.—Organs of Voice and Hearing.—Construction of Musical Instruments.—Organ Pipe.—Vibration of Strings and Plates.

The science of *Acoustics* is now become of considerable importance as a branch of natural philosophy. In nearly all the general treatises hitherto published, we find the phenomena of sound comprised in a few brief pages attached to the pneumatical division: and in public lectures, with the exception of those by Dr. Young, but little has been done for the experimental illustration of acoustics, beyond the ringing of a bell beneath the receiver of an air-pump, or the blowing of a speaking trumpet, to show the new direction that may thus be given to the aerial pulses.

Sounds of all kinds are usually conveyed to the auditory nerve through the medium of the air, so that when an elastic body is struck, that body, or some part of it, is made to vibrate, or strike against the air. This is sufficiently evident in the vibration of a string in a violin or harpsichord; for we may perceive by the eye, or feel by the hand, the trembling of the strings, when, by striking, they are made to sound. If a bell be struck by a clapper on the inside, the bell is made to vibrate. The base of the bell is a circle; but it has been found that, by striking any part of this circle on the inside, that part flies out, so that the diameter which passes through this part of the base will be

longer than the other diameter. The base, by the stroke, is changed into an ellipse, or oval, whose longer axis passes through the part against which the clapper is struck. The elasticity of the bell restores the figure of the base, and makes that part which was forced out of its place return back to its former situation, from which the same principle throws it out again; so that the circular figure of the bell will be again changed to an ellipse, only now the shorter axis will pass through the part which was first struck. The same stroke which makes the bell vibrate occasions the sound, and as the vibrations decay, the sound grows weaker. We may be convinced by our senses, that the parts of the bell are in a vibratory motion while it sounds. If we lay the hand gently on it, we shall easily feel this tremulous motion, and even be able to stop it: or if small pieces of paper be put upon the bell, its vibrations will put them in motion.

These vibrations in the sounding body will cause undulations or waves in the air; and, as the motions of one fluid may often be illustrated by those of another, the invisible motions of the air have been properly enough compared to the visible waves of water produced by sudden collision with a stone, or any other missile. These waves spread themselves in all directions in concentric circles, whose common centre is the spot where the stone fell, and when they strike against a bank or other obstacle they return in the contrary direction to the place from whence they proceed. Sound, in like manner, expands in every direction, and the extent of its progress is in proportion to the impulse on the sonorous body.*

* When a gun is discharged, a great quantity of gas is liberated by the firing of the gunpowder, which being violently propelled from the piece, condenses the air that encompasses the space where the expan-

Such is the yielding nature of fluids, that when other waves are generated near the first waves, and others again near these, they will perform their vibrations among each other without any very material interruption; those that are coming back will pass by those that are going forwards, or even through them: for instance, if we throw a stone into a pond, and immediately after that, another, and then a third, we shall perceive that their respective circles will proceed in succession, and strike the banks in regular order.

Newton was the first who attempted to demonstrate that the waves or pulses of the air are propagated in all directions round a sounding body; and that during their progress and regress, they are twice accelerated, and twice retarded, according to the law of a pendulum vibrating in a cycloid. These propositions are the foundation of almost all our reasoning concerning sound. When sonorous bodies are struck, they, by their vibration, excite waves in the air, and some parts of these waves entering the ear, produce in us that sensation which we call sound. How these pulsations act upon the auditory nerve, to produce sound, we know not, as we see no necessary connexion between the pulses and the sensation, nor the least resemblance between them; but we can trace their progress to a certain extent in the mechanism of hearing.

Strictly speaking, sonorous bodies are those whose sounds are distinct, of some duration, and which may be compared with each other, such as those of a bell, or a musical string, and not such as give a confused noise, like that

sion happens; for, whatever is driven out from the space where the expansion is made will be forcibly driven into that which is around it.

This condensation forms the first pulse: and as this, by its elasticity, expands again, pulses of the same sort will be produced and propagated in every direction.

made by a stone falling on the pavement. To be sonorous, a body must be elastic, so that the tremors exerted by it in the air may be continued for some time: it must be a body whose parts are capable of a vibratory motion when forcibly struck.

All hard bodies, when struck, return more or less of sound; but those which are destitute of elasticity give no repetition of the sound; the noise is at once produced and dies: while other bodies, which are more elastic and capable of vibration, repeat the sounds produced several times successively. These last are said to have a tone; the others are not allowed to have any. If we wish to give non-elastic bodies a tone, it will be necessary to make them continue their sound, by repeating our blows quickly upon them. This will effectually give them a tone; and an unmusical instrument has often by this means a fine effect in concerts. The effects of a drum depend upon this principle. Gold, silver, copper, and iron, which are elastic metals, are sonorous; but lead, which possesses scarcely any elasticity, produces little or no tone. Tin, which in itself has very little more sound than lead, highly improves the tone of copper when mixed with it.*

Let us now suppose that the sonorous body is a bell. We may conceive this bell to be formed of an infinitude of rings placed one above another from the base to the highest point: at the moment of the percussion, each ring is compressed so as to assume an oval shape, whose greater axis is perpendicular to the direction in which the stroke is made.

* Bell-metal is formed of ten parts of copper, and one of tin. Each of these is ductile when separate, though tin is only so in a small degree; yet they form, when united, a substance almost as brittle as glass, and highly elastic. So curious is the power of tin in this respect, that even the vapour of it, when in fusion, will give brittleness to gold and silver, the most ductile of all metals.

The return of each ring to its first figure is succeeded by a new change of figure producing an oval, posited with its axes contrarywise to the former; and the two changes succeed one another thus, till the sound as well as the motion dies away. The vibrations of the particles which compose each annulus, excite here also, in the neighbouring air, a small agitation which communicates itself from one particle to another, till the limit is attained where the sound ceases to be heard; and nearly the same may be said, duly regarding analogy, of all bodies shaken by means of percussion.

With respect to the degree to which the sound yielded by the bell corresponds, we must readily conceive that the rings situated nearer the base, having a greater circumference, tend to perform their vibrations more slowly, while the rings nearer the summit, whose circumferences are smaller, tend to produce vibrations oftener. Here, therefore, there will be established, nearly as in the compound pendulum, a compensation, in virtue of which, the vibrations become all reduced to an equal duration, which is a kind of medium between that which took place for the inferior rings, and that which measured the motion of the upper rings, if the former and the latter had been insulated.

The academicians del Cimento inclosed an organ-pipe, with bellows worked by a spring, in the receiver of an air-pump and of a condenser, and they found that, as long as the sound was audible, its pitch remained unchanged. Papin screwed a whistle on the orifice which admits the air into the receiver of the air-pump; and Dr. Young fixed an organ-pipe in the same manner: and the result agreed with the experiment of the academicians.

Chladni and Jacquin, of Vienna, made about ten years ago, some experiments with a view to determine the sono-

rous properties of different gases; the results of which, being curious, may be stated here. By causing a small tin pipe, brought into contact with a cock in the neck of a bell-glass, to be blown by gas contained in a bladder, applied to the external aperture of the cock, these philosophers observed, that the sound was a semi-tone lower with azotic and oxygen gas than with atmospheric air; a third lower with carbonic acid gas; and nearly the same with nitrous gas; but with oxygen gas, from nine to eleven tones higher than the air that surrounds us. A mixture of azote and oxygen, in the same proportions as in the atmospheric air, gave the same tone as the latter; but when the mixture of these gases was not uniform, the sounds were totally discordant. The experiments of Chladni and Jacquin were very different from those of Priestley and Perolle, on sound in different kinds of gases. The experiments of the last-mentioned philosophers related only to the intensity with which the vibrations of another elastic body (of a bell struck by a hammer) are conducted through these gases. Perolle contradicts Priestley's assertion, that the power of conducting is as the densities; but to this rule Priestley himself makes an exception, in regard to oxygen gas, which appears to be a stronger conductor: azotic gas was examined by neither of these philosophers. In hydrogen gas they both found the conducting power very weak, which is no doubt owing to its little density. In oxygen gas they found the sound somewhat stronger than in common air; in the nitrous gas, Perolle found it also somewhat stronger. In carbonic acid gas, Priestley found the sound stronger, but Perolle weaker, duller, and somewhat lower than in common air; which last circumstance may be considered as agreeable to truth, because the vibrations of a sounding body must be more retarded the denser the surrounding fluid is, or according to its pressure on that body.

Sir Isaac Newton's propositions respecting the velocity of the propagation of sound, were the beginning of all the more accurate investigations relating to acoustics. But that distinguished mathematician formed his calculations on data that were subsequently proved to be erroneous, and it may in the present case be advisable to confine ourselves to an experimental view of the subject, merely prefacing our remarks by a brief notice of the early experimentalists, from which it will be seen that the rate at which sound traverses, has been estimated differently by different persons, whose experiments have been performed under a variety of circumstances.

	Feet per second.
By Sir Isaac Newton, at the rate of . .	968
By Mr. Robarts, at	1300
By the Hon. Mr. Boyle, at	1200
By Mr. Walker, at	1338
By Mersennus, at	1474
By the Florentine Academicians, at .	1148
By the French Academicians	1172
By Flamstead, Halley, and Derham, at .	1142

The velocity of sound was determined with considerable accuracy, and on a great scale, by Cassini and Maraldi, while employed in conducting the trigonometrical survey of France. During the winter of the years 1738 and 1739, these astronomers repeatedly discharged, at night, when the air was calm, and the temperature uniform, a small piece of ordnance, from their station on Mont-Martre, above Paris, and measured the time that elapsed between the flash and the report, as observed from their signal-tower at Mont L'hery, at the distance of about eighteen miles. The mean, of numerous trials, gave 1130 feet for the velocity of the transmission of sound.

About the same time, Condamine, who was sent with the other academicians to ascertain the length of a degree in Peru, took an opportunity of likewise measuring the celerity of sound. He found this was 1175 feet on the sultry plain of Cayenne, and only 1120 feet on the frozen heights of Quito. It was obvious, therefore, that the rarefaction of the air in those lofty regions had but in a very small degree affected the result. Compared with what had been observed in France, the velocity of the aerial pulses was somewhat diminished at Quito, by the prevailing cold, but was, on the other hand, considerably augmented by the excessive heat and moisture which oppress Cayenne.*

Dr. Moll's experiments, which were made with the greatest accuracy in Holland, in the year 1823, are of considerable importance. He ascertained that when sound was transmitted by a clear atmosphere, unaccompanied by the retarding accelerating effects of wind, it travelled at the rate of about 1,116 English feet per second.

A very valuable and elaborate series of experiments on

* The distance at which sounds may be heard, is much greater than is generally imagined. Dr. Derham informs us, on the authority of S. Averrani, that at the siege of Messina, the report of the guns was heard at Augusta and Syracuse, almost 100 Italian miles distant; and he also states, that in the naval engagement between the English and Dutch, which took place in 1672, the report of their guns was heard upwards of 200 miles off. Humboldt mentions the reports of volcanoes in South America, heard at the distance of 300 miles; and Dr. Thomson states, on the authority of a friend, that the loud explosions which took place from the volcano in St. Vincent's, were heard distinctly at Demerara: now this is a distance which must considerably exceed 300 miles. On the other hand, again, sound is enfeebled and dissipated sooner in alpine regions: thus, the traveller, roving at some height above a valley, descries, with uncommon clearness, perhaps a huntsman on the brow of the opposite mountain, and while he watches every flash, yet can he scarcely hear the report of the fowling-piece.

the velocity of sound, has been made at Madras, by Mr. Goldingham. The following table contains the substance of these experiments; and it is curious to remark, how the velocity gradually increases towards the middle of the year, and again gradually diminishes. Mr. Goldingham conceives that this regularity would be still greater, with the mean of several years observations.

Months.	Barometer, in inches.	Thermometer, Fahr.	Hygrometer dry.	Velocity of a sound in a second in ft
January . .	30.124	79.05	6. 2	1101
February . .	30.126	78.84	14.70	1117
March. . .	30.072	82.30	15.22	1139
April . . .	30.031	85.79	17.23	1145
May . . .	29.892	88.11	19.92	1151
June . . .	29.907	87.10	24.77	1157
July . . .	29.914	86.65	27.85	1164
August . .	29.931	85.02	21.54	1163
September .	29.963	84.49	18.97	1152
October . .	30.058	84.33	18.23	1128
November .	30.125	81.35	8.18	1101
December .	30.087	79.37	1.43	1099

Mr. Goldingham concludes, that for each degree of the thermometer, 1.2 feet may be allowed in the velocity of sound for a second; for each degree of the hygrometer 1.4 feet; and for one-tenth of an inch of the barometer 9.2 feet. He concludes that 10 feet per second is the difference of the velocity of sound between a calm and in a moderate breeze, and $21\frac{1}{4}$ feet in a second, or 1275 in a minute, is the difference when the wind is in the direction of the motion of sound, or opposed to it.

The effects of sound are considerably increased during the night; and this was remarked by the ancients. Humboldt was particularly struck with this fact, when he heard the noise of the great cataracts of the Orinoco; which he

describes as three times greater in the night than in the day; though during the former time, the humming of insects, and the sound of the breeze is scarcely heard. M. Humboldt attempts to account for this singular phenomenon by the following hypothesis: he supposes that the vibrations of sound are materially retarded by partial undulations in the atmosphere, arising from the sun's heat—so that the waves of sound are divided and redivided, whenever the density of the medium through which they are propelled, is sufficiently altered to form an *acoustic mirage*.

It is well known that solid bodies, in general, are good conductors of sound: thus, any agitation communicated to one end of a beam is readily conveyed to the ear applied to the other end of it. The motion of a troop of cavalry is said to be perceived at a greater distance by listening with the head in contact with the ground, than by attending to the sound conveyed through the air; and we may frequently observe that some parts of the furniture of a house are a little agitated by the approach of a waggon, before we hear the noise which it immediately occasions. The velocity with which impulses are transmitted by solids, is in general considerably greater than that with which they are conveyed by the air: M. Wunsch has ascertained this by direct observations on a series of deal rods closely united together, which appeared to transmit a sound instantaneously, while a sensible interval was required for its passing through the air. It appears from experiments on the flexure of solid bodies of all kinds, that their elasticity, compared with their density, is much greater than that of the air: thus, the height of the modulus of elasticity of fir-wood is found, by means of such experiments, to be about 9,500,000, whence the velocity of an impulse conveyed through it must be 17,400 feet, or more than three miles in

a second. It is obvious, therefore, that in all common experiments, such a transmission must appear perfectly instantaneous. There are various methods of ascertaining this velocity from the sounds produced under different circumstances by the substances to be examined, and Professor Chladni has in this manner compared the properties of a variety of natural and artificial productions.

It does not appear that any direct experiments have been made on the velocity with which an impulse is transmitted through a liquid, although it is well known that liquids are capable of conveying sound without difficulty; Professor Robison informs us, for example, that he heard the sound of a bell, transmitted by water, at the distance of 1200 feet. It is, however, says Dr. Young, easy to calculate the velocity with which sound must be propagated in any liquid of which the compressibility has been measured. Mr. Canton has ascertained that the velocity of water is about 22,000 times as great as that of air; it is, therefore, measured by the height of a column which is in the same proportion to 34 feet, that is 750 thousand feet, and the velocity corresponding to half this height is 4,900 feet in a second. In mercury, also, it appears from Mr. Canton's experiments, that the velocity must be nearly the same as in water; in spirit of wine a little smaller.

It seems probable, from various analogies, that ice has nearly the same faculty of transmission as water itself. If a heavy blow be struck against any part of the frozen surface of a large pool or lake, a person standing at a wide distance from the spot will feel, under foot, a very sensible tremor, at some considerable time before the noise conveyed through the atmosphere has reached his ear. It is asserted, that the savage tribes who rove on the icy steppes of Tartary, can readily distinguish, from afar, the approach

of cavalry, by applying their head close to the frozen surface of the ground.

The rate with which the tremor of sound is transmitted through cast-iron, has been ascertained, from actual experiment, by M. Biot. This philosopher availed himself of the opportunity of the laying of a series of iron pipes, to convey water to Paris; these pipes were about eight feet each in length, connected together with small leaden rings. A bell being suspended within the cavity, at one end of the train of pipes, on striking the clapper at the same instant against the side of the bell, and against the internal surface of the pipe, two distinct sounds were successively heard by an observer stationed at the other extremity. With a train of iron pipes of 2550 feet, or nearly half a mile in length, the interval between the two sounds was found, from a mean of two hundred trials, to be 2.79 seconds. But the transmission of sound through the internal column of air, would have taken 2.5 seconds: which leaves 59 for the rapidity of the tremor conducted through the cast-iron. From other more direct trials, it was concluded that the exact interval of time, during which the sound performed its passage through the substance of the train of pipes, amounted only to 26.100th parts of a second; being ten or twelve times less than the ordinary transmission through the atmosphere.

It is well known that the intensity of sound is diminished by the rarefaction of the medium in which it is produced. We might, therefore, expect the sound excited in hydrogen gas would be more feeble than what it is, under similar circumstances, produced in atmospheric air of a similar specific gravity; but the difference is actually much greater.

A small piece of clock-work, by which a bell is struck every half-minute, being placed within the receiver of an

air pump, the machine was put in motion, and after the air had been rarefied 100 times, hydrogen gas was introduced; but the sound, so far from being augmented, was, at least, as feeble as in atmospheric air of that extreme rarity, and decidedly much feebler than when formed in air of its own density, or rarefied ten times.

The most remarkable fact is, that the admixture of hydrogen gas with atmospheric air has a predominant influence in blunting or stifling sound. If one-half of the volume of atmospheric air be extracted, and hydrogen gas be admitted to fill the vacant space, the sound will then become scarcely audible.

But the rate of the transmission of sound is found to vary in different gases, after the inverse subduplicate ratio of their densities : thus, through carbonic gas, the communication of the tremor would be about one-third slower than ordinary ; but, through the hydrogen gas, which is twelve times more elastic than common air, the flight would very nearly exceed three and a-half times the usual rapidity. An admixture of this gas with the atmosphere would, therefore, greatly accelerate the transmission of sound.

It may be worth while observing, that Mr. Cooper has ascertained, that if hydrogen gas be breathed for a few moments, it has the curious effect of changing the voice. The effect is observed on the person speaking, immediately after leaving the vessel of hydrogen, but it soon goes off. No instance has yet occurred in which this effect on the voice has not been produced by the hydrogen.

Pipes may readily be employed for the conveyance of sound, which operate by confining the pulsations to one particular path, and there was an amusing experiment exhibited at Mr. Merlin's museum, which may be thus illustrated.

Let two heads of plaster of Paris be placed on pedestals, on opposite sides of a room; a tin tube, of an inch in diameter, must pass from the ear of one head through the pedestal under the floor, and go up to the mouth of the other. When a person speaks low into the ear of one bust, the sound is reverberated through the tube, and is heard distinctly by any one who puts his ear to the mouth of the other. If there be two tubes, one going to the ear, and the other to the mouth of each head, two persons may converse together by applying their mouth and ear reciprocally to the mouth and ear of the busts: while other people, standing in the middle of the room, between the heads, will not hear any part of the conversation.

By a reference to the preceding facts, it will be evident that there is scarcely any body that does not possess the power of conducting sound by the vibration of its particles, and our space will only permit of a brief notice of the experiments by Mr. Wheatstone, tending to illustrate the phenomena of polarization.

"I connected," says he, "a tuning-fork with one extremity of a straight conducting rod, the other end of which communicated with a sounding-board: on causing the tuning-fork to sound, the vibrations were powerfully transmitted, but in gradually bending the rod, the sound progressively decreased, and was scarcely perceptible when the angle was a right one. As the angle was made more acute, the phenomena were produced in an inverted order; the intensity gradually increased as it had before diminished: and when the two parts were nearly parallel, it became as powerful as in the rectilineal transmission. By multiplying the right angles in a rod, the transmission of the vibration may be completely stopped."

In these experiments, the axis of the oscillations of the

tuning-fork should be perpendicular to the plane of the moveable angles; for, if they are parallel, they will still be transmitted. Mr. Wheatstone gives the following explanation to prove this:—"I placed a tuning-fork perpendicularly on the side of a rectilineal rod. The vibrations were therefore communicated at right angles; when the axis of oscillations of the fork coincided with the rod, the intensity of the transmitted vibrations was at its maximum. In proportion as the axis deviated from parallelism, the intensity diminished; and when it became perpendicular, the intensity was a minimum." The phenomena of polarization may be observed in many chorded instruments. The chords of the harp are attached to a conductor which has the same direction as the sounding-board; if any chord be altered from its quiescent position, so that its axis of oscillation shall be parallel with the bridge or conductor, its tone will be full; but if the oscillations be excited, so that their axes shall be at right angles with the conductor, the tone will be feeble.

Echoes are produced by the air which has been put in motion, striking against a wall, hill, or any other prominent body, by which its vibrations are disturbed. But though several persons in different situations, will hear the echo, or repetition of the same sound, yet, in a particular direction, the echo may be heard much better than in any other direction. Now, if two straight lines be drawn from the centre, or middle of the reflecting surface, one to the place from which the original sound proceeds, and the other in the above-mentioned best direction, those two lines will be found to make equal lengths with, or to be equally inclined to, that surface. Hence, it appears, that, in the reflection of sound, the angle of incidence is equal to the angle of reflection. Therefore, if a person wishes to hear the

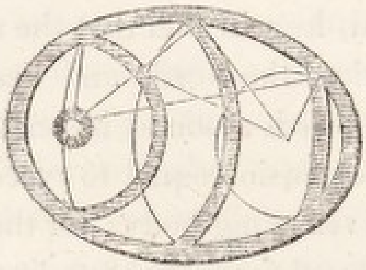
echo of his own voice in the best manner possible, he must stand in a direction perpendicular to the reflecting surface. And this shows, that though sound proceeds from an original sounding body, or from a reflecting surface, in every direction, yet a greater quantity of it proceeds in some particular direction than in any other, which is probably owing to the original impulse being given to the air more forcibly in one direction than in any other, as also to the want of perfect freedom in the motion of the aerial fluid.

If a person standing before a high wall, or bank, at a certain distance, and uttering a word, hears a repetition of that word, or sound, he will find that the time which elapses between his uttering the word, and hearing the echo, is equal to that time which a sound is known to employ, in going through an extension equal to twice the distance between him and the reflecting body; for the vibratory motion of the air must proceed from the sounding person to the reflecting surface, and back again from the latter to the former. But the same original sound, and the repetition of it, viz. the echo, may be heard by other persons situated at different distances, both from the original sounding place, and from the reflecting body. The effect, however, will not be exactly alike: viz. those who are nearer to the reflecting body, will hear the echo sooner than other persons; those who are far off, will hear it later: and a situation is easily found, from which they will hear both the original sound and the echo at the same time; in which case they will perceive, as it were, one sound, but louder than they would without the echo.*

* Addison, and other travellers into Italy, mention an extraordinary echo in that country, at the Simonetta Palace, near Milan. It will return the sound of a pistol fifty-six times, even though the air be very foggy.

If in an elliptical chamber, a sounding body be placed in one of the foci, or concave extremities, the sound will be heard much louder by a person situated in the other focus, than in any other part of the chamber. In this case, the effect is so powerful, that even when the middle part of the chamber is wanting, so that the two narrow elliptical shells only exist, the sound produced in one focus will be heard by a person situated in the other focus: but hardly at all by those who stand in the intermediate space.

The way in which the sound is reflected, will be understood by a reference to the lines in the accompanying diagram.

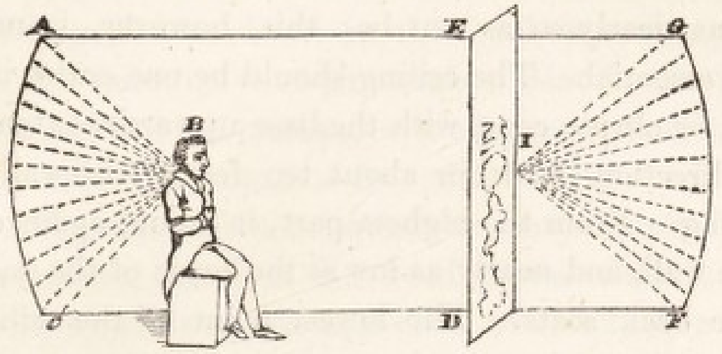


An umbrella, held in a proper position over the head, may serve to collect the force of a distant sound by reflection, in the manner of a hearing trumpet; but its substance is too slight to reflect any sound very perfectly, unless the sound fall on it in a very oblique direction.

A very pleasing experiment may be performed with the following apparatus, which tends to illustrate what has already been stated. Place a concave mirror A *c*, of two feet in diameter, in a perpendicular direction, and at the distance of about five or six feet from a partition D E, in which there is an opening equal in size to the mirror, against this opening must be placed a picture painted in

The echo is heard behind the house, which has two wings; the pistol is discharged from a window in one of those wings; the sound is returned from a dead wall in the other wing, and is heard from a window in the back-front.

water-colours, on a thin cloth, that the sound may easily pass through it. Behind the partition, at the distance of a few feet, place another mirror F G, of the same size as the first, and directly opposite to it. At the point B, is placed



the figure of a man seated on a pedestal, with his ear exactly in the focus of the first mirror; his lower jaw must be made to open by a wire, and shut by a spring; the wire must pass through the figure, and under the floor, to come up behind the partition. Let a person, properly instructed, be placed behind the partition, near the mirror; any one may whisper into the ear of the image with the certainty of being answered. The deception is managed by giving a signal to the person behind the partition, who, by placing his ear to the focus I, of the mirror F G, will hear distinctly what the other said, and moving the jaws of the statue, by the concealed wire, will return the answer directly, which will be heard distinctly by the first speaker.

In many cases, the reflection of sound becomes extremely inconvenient, by the new direction that is given to the voice in large rooms, and a variety of architectural arrangements have been employed to remedy this effect; but there is another circumstance connected with the transmission of sound in an apartment, which should not escape our attention: namely, that the aerial pulses are facilitated or

retarded in their progress by the artificial currents that arise from the process of ventilation.

The methods by which it is proposed by Mr. Matthews to counteract this acoustical defect, are as follows: where there is room, a circle should be preferred, or at least a form as nearly so as can be; this, however, is not positively essential. The ceiling should be one entire inverted dome, or obtuse cone, with the base upwards, extending in that direction to within about ten feet of the walls of the building. From the highest part, it should again descend to the wall, and nearly as low as the heads of the occupants of the back seats. The lowest point of the ceiling, if a circle, to be in the centre, not more than fifteen or sixteen feet from the ground. The station of the speaker should be under the lowest point of the cone, with a hollow sounding-board about a foot above his head, and so constructed as to convey a clear sound behind him. A constant breeze of air will be made to pour forth in every direction, from holes in its sides, until it reaches the highest part of the ceiling. From thence, it cannot return; but will be drawn off by means of ventilators that will not admit cold air: but will leave the vacuous space to be supplied from the sounding-board only. In courts of justice, and other places where the voice will have occasionally to proceed from different parts of the building, it can be made to proceed from the place where a person is speaking; and the moment he has done, to proceed from an opposite place in which another person also speaks, by opening and shutting dampers provided for this purpose. This air in winter can be heated to the degree required. Thus, the sound, instead of having occasion to cross the ascending evaporation, and be opposed to the current of air, which now rushes forward to supply its place, will pass along with

the current, and a moderately low-toned voice will be distinctly heard in every part of a large room.

The *human voice* depends principally on the vibrations of the membranes of the glottis, excited by a current of air, which they alternately interrupt and suffer to pass; the sounds being also modified in their subsequent progress through the mouth. The parts subservient to the formation of sound are, the trachea, or wind-pipe, through which the air passes and repasses into the lungs; and which serves, as it were, for a bellows; the larynx, which is a short cylindrical canal, at the head of the trachea; and the glottis, which is a little oval cleft, or chink, over which the epiglottis inclines backwards, as it ascends from its origin at the upper part of the thyroid cartilage. Within the glottis are extended its ligaments, contiguous to each other before, when they are inserted into the thyroid cartilage, and capable of diverging considerably behind, whenever the aretynoid cartilages separate. These ligaments, as they vary their tension, in consequence of the motions of the aretynoid cartilages, are susceptible of vibrations of various frequency, and, as they vibrate, produce a continuous sound. Properly speaking, there are two ligaments on each side: but this mode of operation is not fully understood; probably one pair only performs the vibrations, and the other assists, by means of the little cavity interposed, in enabling the air to act readily on them, and in communicating the vibrations again to the ear.

From what we have seen, it will be evident that the mechanism of *speech* properly forms a part of the science of acoustics, though it is not easy to understand why, in a structure which consists chiefly of ligaments, so great a variety of tones can be produced. It may appear still more difficult to explain why the ligaments of the

glottis should sometimes move more quickly, so as to produce acute tones; and at other times more slowly, so as to sound graver ones. Observation, however, has afforded us some clue to the solution of this mystery. It may be seen that the larynx is movable, and it is found to rise in acute tones, and to descend in grave ones: hence, those whose voices are naturally too grave, conquer the defect by raising the larynx. In producing musical sounds after ten tones, we commence a new octave. Some men, however, can produce twelve; very fine singers exceed sixteen, descending equally far below the gravest tone. To produce this variation of four octaves, the ascent and descent must be very considerable, amounting to an inch in each direction, or two in the whole.

Those animals only that possess lungs possess a *larynx*, and hence none but the three first classes in the Linnean system, consisting of mammals, birds, and amphibials. Even among these, however, some genera or species are entirely dumb; as the myrmecophaga or ant-eater, the manis or pangolin, and the cetaceous tribes, together with the tortoise, lizards, and serpents: while others lose their voice in particular regions; as the dog is said to do in some parts of America, and quails and frogs in various districts of Siberia.

The larynx of the bird class is of a very peculiar form, and admirably adapted to that sweet and varied music with which we are so often delighted in the woodlands. In reality, the whole extent of the trachea or windpipe in birds may be regarded as one vocal apparatus; for the larynx is divided into two sections, or may rather, perhaps, be considered as two distinct organs; the more complicated, or that in which the parts are more numerous and elaborate, being placed at the bottom of the trachea, where it divides into two branches, one for each of the lungs; and the sim-

pler, or that in which the parts are fewer, and consist of those not included in the former, occupying its usual situation at the upper end of the trachea, which, however, is without an epiglottis; the food and other substances being incapable of entering the aperture of the glottis from another contrivance. The lungs, trachea, and larynx of birds, therefore, may be regarded as forming a complete natural bagpipe, in which the lungs constitute the pouch and supply the wind; the trachea itself the pipe; the inferior glottis the reed, or mouth-piece, which produces the middle sound; and the superior glottis the finger-holes, which modify the simple sound into an infinite variety of distinct notes, and at the same time give them utterance.

The mechanism of *hearing* is simple in its arrangement, and beautifully adapted to the purposes of life.

Adapted in an eminent degree to the purposes it is designed to execute, the ear offers an inviting subject to such as are disposed to investigate the minute mechanism of an organ, which contributes remarkably to some of our most exquisite and refined enjoyments. Whoever has witnessed and attentively observed the distressing effects arising from a loss, or diminution of its sensibility, will readily acknowledge that such deprivation throws us at a distance from our fellow-creatures, and, in the present state of society, renders us more solitary beings than the loss of sight itself. Though the rapid glance of the eye, the immense distance to which it enables us to carry our perceptions, and the extended circle it embraces, have given rise to some of our most pleasurable and magnificent sensations; though it has brought us acquainted with objects which seemed ever placed far beyond our reach; still the more humble sense which we are now considering, the more confined dominion of the ear, has contributed most efficiently to the every-day

happiness of life. It enables us to hold communication with our fellow-creatures; to improve and exalt our understandings by the mutual interchange of ideas; and thus to increase the circle, not only of our physical, but of our moral relations. The charms of eloquence, the pleasure resulting from the concord of sweet sounds, inexplicable perhaps as it remains, are other sources of intellectual enjoyment, which contribute to place this sense among the most delightful as well as the most important we possess. Whatever, therefore, by explaining its structure, or examining its functions, can lead us to improve its natural, or restore its disordered sensibility, cannot be a subject of trivial moment. Our more immediate object is to consider the human ear, observing only, that the structure of the organ, being suited to one great end, is in all cases fundamentally the same; its different forms and varieties depending on the peculiar economy and abode of each individual creature.

The organ of hearing, in its simplest form, consists of the expansion of a nerve, gifted with its peculiar sensitive qualities, over the surface of a delicate membrane. In man and the more perfect animals, there is an additional apparatus connected with this, the design of which is supposed to be that of collecting and modifying those pulses of sound, which are finally to be impressed on the nervous pulp. In man this apparatus consists of a piece of cartilage, seated externally to the head, which contracts into a funnel leading to the internal parts. The bottom of this tube is truncated obliquely, and its aperture closed by a firm membrane stretched across it, which separates this external part of the ear from the succeeding, or middle portion of the organ. Beyond, or on the opposite side of this membrane, we meet with a small cavity, hollowed out in bone, which has been termed the barrel of the tympanum. Of the several openings into it, there is one more particu-

larly demanding our attention here. It is the internal aperture of a tube, the other extremity of which opens at the posterior part of the nose, behind and above the palate. By means of this communication, the external air is admitted into this barrel, and equipoises the weight of the atmosphere on the other side of the membrane. Across the cavity there is extended, though by no means in a straight line, a series of little bones, the exterior one of which is attached to the membrane we have just mentioned, the most internal of the set being firmly connected with another membrane, which, in conjunction with it, shuts up the entrance to a still more deepened cavity, called the labyrinth of the ear. This last hollow, excavated as it were in the solid bone, consists of a middle portion of irregular figure, and of different channels, which proceed from it in various directions, and, finally, return, with the exception of one only, to the same chamber. All these passages are lined by a membrane, on which the sentient extremity of the auditory nerve is expanded in different shapes; from these it is collected into one trunk, and goes on to join a particular part of the brain, and thus completes the communication between the external agent and the sensorium.

The anatomy of the external ear may, however, be best understood by referring to the illustrative diagram on the next page.

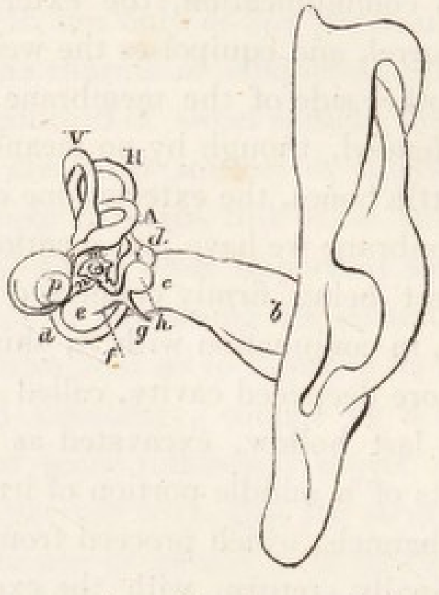
The meatus externus is seen detached from the bone at *b*. The oblique direction of its internal end is shown at *d e*, the membrana tympani stretched on its bony ring, and bulging inwards.

f g h, the malleus: *f*, the handle or process attached to the membrana tympani; *g*, the long process; *h*, the head.

i k, the incus: *i*, the short leg or process; *k*, the long process.

m, the stapes.

V H A *m n p*, the labyrinth: *n p*, the cochlea; *n*, its beginning, its termination at *p*; this is followed by the vestibule; V, the bony case of the anterior, or smaller of

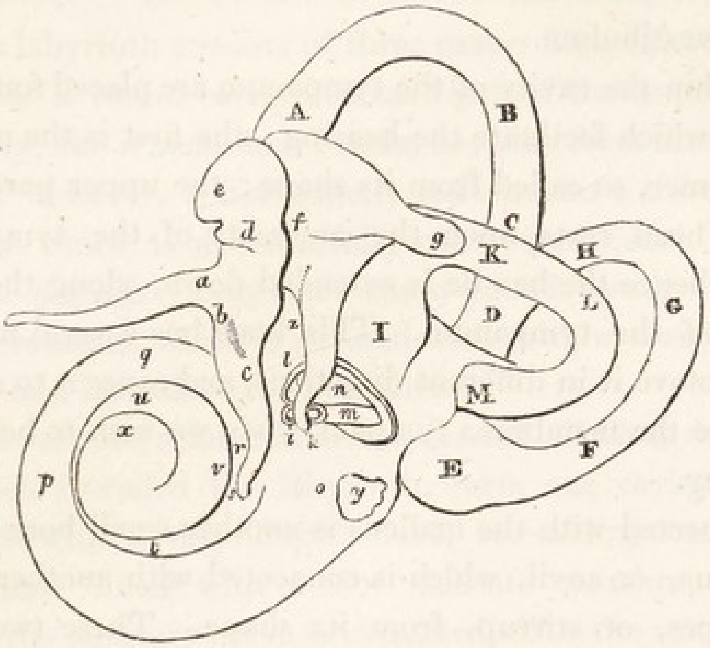


the semicircular canals; H, the posterior, or largest semicircular canal; A, the outer, or smallest canal.

The external part of the ear is differently formed in different animals; and admirably suited to their various situations and habits. In man, it is close to the head, but so formed as to collect the various pulses with great accuracy; in other animals it is more simple, where less accuracy is required, but it is in general much larger, having the appearance of an oblong funnel; and this gives them a greater delicacy of hearing, which was necessary for them.

Dr. Savart considers the external ear as an important auxiliary to the tympanum, capable also of entering into vibration by communication, and having for its principal function to present always to the air (by the various directions and inclinations of its surfaces to one another) a certain number of parts, upon which the undulations of the air shall fall perpendicularly. The little muscles which are inserted in it, he thinks, contribute by their action to increase its tension and render it more elastic.

The following anatomical view of the principal parts of the ear, taken collectively, will tend to facilitate our acquaintance with its arrangement.



The letters *a* to *e*, form the malleus; *a* being the long process; *b*, the shorter process; *c*, the handle, or process attached to the membrana tympani; *d*, the neck; and *e*, the head of the malleus.

f, the body of the incus; *g*, the short leg; then follows the long leg, or process; *i*, the small epiphysis of this leg, articulated with the stapes.

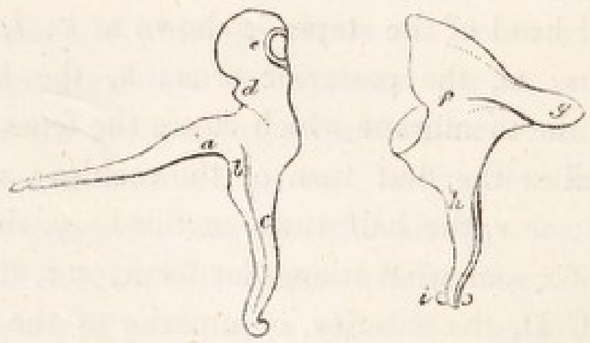
The small head of the stapes is shown at *k*; *l*, being the anterior crus; *m*, the posterior crus; *n*, the basis, connected with the membrane which closes the fenestra ovalis. *o* to *r*, describes the first turn of the cochlea; *s t u v*, the second turn; *w x*, the half turn, or third: *y*, the foramen rotundum, of a somewhat triangular form; *z z*, the vestibulum; A B C D, the anterior, or superior of the semicircular canals. A, the ampulla, or sinus ellipticus; B C, its curvature; and D, its junction with the inferior, or posterior canal. E F G H, the inferior canal: E, its ampulla,

F G H, its peculiar curve, and the connection of the united canal D, with the exterior semicircular canal. I K L M, the exterior canal: I, the ampulla, or sinus infundibulformis; K L, the direction of its curve; M, its termination in the vestibulum.

Within the cavity of the tympanum are placed four small bones, which facilitate the hearing: the first is the malleus, or hammer, so called from its shape: the upper part of its round head rests upon the concavity of the tympanum, from whence the handle is extended down, along the membrane of the tympanum. This bone has several muscles, which move it in different directions, and cause it to stretch, or brace the membrana tympani, when we wish to hear with accuracy.

Connected with the malleus is another small bone called the incus, or anvil, which is connected with another called the stapes, or stirrup, from its shape. These two bones are connected by a small oval-shaped bone called os orbiculare, placed between them: the whole forming a little chain of bones.

The malleus and incus being the principal agents in the operation of hearing, are represented on a large scale in the diagram beneath; the same letters of reference being still employed.



The stapes, or stirrup, has its end of an oval form, which fits a small hole called fenestra ovalis, in that part of the ear called the labyrinth, or innermost chamber of the ear.

The labyrinth consists of three parts: first, the vestibule, which is a round cavity in a hard part of the os petrosum; secondly, the semicircular canals, so called form their shape, which, however, is not exactly semicircular; thirdly, the cochlea, which is a beautifully convoluted canal, like the shell of a snail. This part has a round cavity called fenestra rotunda, which is covered with a thin elastic membrane, and looks into the tympanum.

The vestible, semicircular canals, and cochlea, the whole of which is called the labyrinth, form one cavity, which is filled with a very limpid fluid, resembling water, and the whole lined with a fine delicate membrane, upon which the auditory nerve is expanded, like the retina upon the vitreous humour of the eye. This beautiful apparatus was only lately discovered by an Italian physician, Scarpa. The auditory nerve is a portion of the seventh pair, which is called the portio mollis, or soft portion.

There is one part of the ear still to be described; namely, the Eustachian tube, so called from Eustachius, the anatomist, who first described it.

This tube opens by a wide elliptical aperture into the tympanum behind the membrane; the other end, which gradually grows wider, opens into the cavity of the mouth. By this canal the inspired air enters the tympanum to be changed and renewed; it likewise serves some important purpose in hearing, with the nature of which we are yet unacquainted. It is certain that we can hear through this passage, for if a watch be put into the mouth, and the ears stopped, its ticking may be

distinctly heard; and in several instances of deafness this tube has been found completely blocked up.*

We have now to notice the labours of M. Savart, who has paid considerable attention to the anatomy and uses of the tympanum.

By a series of experiments, which, fortunately for the cause of humanity, have not been verified in this country, he ascertained that the membrane of the tympanum exactly resembled in its effects the vibrations of a drum, or plate.

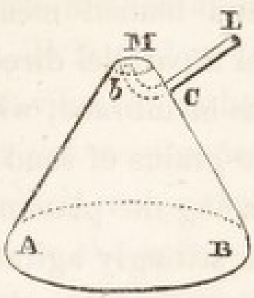
That the membrane of the tympanum may justly be compared with an ordinary membrane acted upon by communicated vibrations. This was proved, by submitting the real ear to the following experiment:—after having removed the temporal bone, he made with the saw a section parallel to the external surface of the membrane, so as to lay it open, and to be enabled to cover it with sand: the sand was observed to be slightly put in motion, when a vibrating plate was brought parallel with the membrane, and very near its surface; but it was impossible, from its limited extent, and particularly on account of its form, to prove the existence of any nodal line. The existence of

* Though the use of the Eustachian tube has been doubted, as conveying sound by the mouth, yet a simple experiment will convince us, that it has some influence in this respect; thus, if a deaf person is to converse with another, and a wire or other medium of communication is made to pass to the mouth of each, by placing its extremity between the teeth, the deaf person will hear the conversation better than without this assistance, which certainly proves that part of the vibrations of sound is carried along the wire into the mouth, and applied to the ear through the Eustachian tube in the throat; while a part also reaches the ear externally, and is collected in the auricle in the usual manner. We have seen people quite deaf to outward sounds, enjoy a concert on the piano-forte, by means of a long narrow bar of wood placed on the instrument, the opposite end being grasped between the teeth.

the motions were rendered much more evident, by substituting for the human tympanum the drum of a calf's ear.

He observed also, that when the internal muscle of the malleus acted, and, consequently, that when the membrane was tightened, it was more difficult to produce evident motions in the grains of sand; so that the uses of this little muscle appear, like those of the iris, to consist in preserving the organ from impressions too intense, which, under certain circumstances, it might otherwise receive.

To imitate this mechanism, he proposes a conical tube of pasteboard A B, the summit of which is truncated, and fur-



nished with a small membrane M, which may be tended at pleasure by means of a little bent lever L *b*, passing through the side of the tube, having its bearing at C, and touching the internal surface of the membrane. When the membrane which is substituted for that of the tympanum is covered with sand, he found that it became more difficult to excite appreciable motions, when it is more tended; and, on the contrary, when it was left to itself, its motions became so strong that the sand was greatly agitated.

The membrane of the tympanum may, therefore, be considered as a body put in motion by the air, and performing always a number of vibrations equal to that of the body which has produced the oscillations in the air; but, besides, as the direction of the molecular motions of the mem-

branes, and generally of all bodies, continually vary with the direction of the vibrations of the body directly put in motion, it may be presumed that it is by this means that we are able to judge of the direction of the sound, when it arrives without having been reflected.

The following experiment shows, that if the auditory passage, the concha, and the bell of the ear, serve to render the aerial oscillations more intense, they also are of use to reciprocate the vibrations of the air, and to transmit them to the membrane of the tympanum, with the same degree of force, whatever may be their direction. A very wide conical tube was formed of thin pasteboard, and to its smaller end a thin and tended membrane was firmly fastened: on bringing in a parallel direction to the upper and external surface of this membrane, when covered with sand, a vibrating plate, the grains of sand were but slightly put in motion; but on placing the plate near the large orifice of the tube, they became strongly agitated. Another conical tube was opposed by its summit to the preceding, but without touching the membrane, and afterwards the plate was put in vibration at the larger orifice of each of the tubes: it was observed that the communicated motions were incomparably more energetic when the aerial undulations arrived through the tube which was in immediate contact with the membrane, than when they arrived through that which did not touch it.

Another experiment shows the important influence which the malleus, fastened upon the internal surface of the membrane of the tympanum, exercises upon the nature of its motions. If a small wooden rod, reduced at its edges, be fixed on a stretched membrane, so that it may extend itself from the centre to the circumference, or even beyond, the figures produced by the membrane will be mo-

dified by the presence of the little rod, and the latter will be caused to vibrate so strongly, that very distinct nodal lines will be produced in it, even when its dimensions are rather considerable.

It appears then from this, that the malleus fulfils at the same time two distinct functions: first, it modifies, by means of its muscles, the tension of the membrane, in order to preserve the organ from over-intense impressions, and to dispose it conveniently to receive the weakest impressions; and secondly, it reciprocates the motions of the membrane, and communicates them to other parts. Since this bone is in immediate contact with the incus, and the incus communicates with the lenticular bone, and, by its means, with the stapes, it is evident that the membrane of the tympanum cannot vibrate, without producing corresponding oscillations in the membranes of the fenestra ovalis. The mechanism which causes the tension of the latter membrane, and preserves the soft parts contained in the labyrinth from intense impressions, may be illustrated by an experiment. Had the membranes which close the entrances of the labyrinth been in immediate contact with the atmospheric air, their elastic state would have been continually influenced by the changes of temperature of that fluid. It may, therefore, be presumed, that the use of the membrane of the tympanum is to prevent the direct contact of the atmospheric air, and that the case of the drum and the mustoid cells form a kind of receptacle, in which the air, already warmed, coming from the mouth through the Eustachian tube, acquires the constant temperature of the body, in order to establish, before the apertures of the labyrinth, an atmosphere, the properties of which are invariable: so that it is probable that the great temporal artery, separated from the case of the drum only

by a very thin bony partition, is of some importance in the mechanism of audition.

In *deafness*, the auditory nerve first fails to detect the soft distinctions of sound; vibrations must be stronger and stronger, to convey through the medium of a thickened tympanum, impressions to the brain. But while the faculty of hearing declines, the nerves may be occasionally so much excited, that they will detect sounds with their wonted acuteness. A very striking instance of this is apparent in the case of a gentleman, so deaf that he could only hear the voice when raised to its highest pitch, and yet, when riding in a carriage rattling along the streets, he could hear common conversation without difficulty. It would, by this, appear, that the powers of hearing, although impaired, yet being greatly excited by this discordant din, and the tympanum or drum of the ear placed in more than ordinary tension, the sense was partially restored.

Dr. Wollaston has lately discovered the very singular fact, that there are many persons who never felt any defect in their hearing, and who yet cannot hear certain sounds, which others perceive distinctly.

It is well known, that persons affected with slight deafness, hear sharp sounds much better than those which are grave and low. They distinguish the voices of women and children, from their acuteness, much better than the lower tones of men's voices. This fact is acted upon practically, as it may be remarked, that those accustomed to speak to deaf people use a shriller tone of voice, rather than merely a louder tone than common.

This partial deafness may be artificially produced, by shutting the mouth and nose, and exhausting the air in the Eustachian tube, by a forcible attempt to take breath by

expanding the chest. When this is carefully done, so that the exhaustion of the air behind the drum of the ear is as complete as possible, the external air is felt strongly, and even painfully, pressing on the drum; and the ear becomes insensible to low sounds, though shrill sounds are as readily perceived as before.

After the ear is brought into this state, it will remain so for some time, without continuing the painful effort to take breath, and even without stopping the breath; for, by suddenly discontinuing the effort, the end of the tube will close like a valve, and prevent the air from getting into the drum. The act of swallowing will open the closed tube, and restore the ear to its wonted feeling.

When the ear is thus exhausted, if we attempt to listen to the sound of a carriage passing in the street, the rumbling noise cannot be heard, though the rattle of a chain or loose screw remains as easily heard as before. At a concert the experiment has a singular effect: as none of the sharper sounds are lost, and the great mass of the louder sounds are suppressed, the shriller ones are consequently so much the more distinctly heard, even to the rattling of the keys of a bad instrument, or the scraping of catgut unskilfully touched.

On examining the external ear in *quadrupeds*, it is found to resemble the oblique section of a cone, from near the apex to the base. Hares, and other animals exposed to danger, and liable to be attacked by men, or beasts of prey, have large ears, and they are particularly directed backwards; while their eyes at the same time, full and prominent, warn them of any danger in front. Rapacious animals, on the contrary, have their ears placed directly forwards, as is observable in the lion, the tiger, the cat, and others.

All animals, as far as we know, possess the sense of hearing: it was formerly doubted with respect to fishes. The organ of hearing in fishes, was first discovered by the late Mr. John Hunter; and is prosecuted at a considerable length, in his work on the Organ of Hearing in Fishes, by the late professor Monro, of Edinburgh. Thus the modern researches and discoveries in comparative anatomy, have sufficiently established their possession of this sense, as well as the other classes.

In cray-fish, and the sepiæ, the organ is most simple, consisting of a small cavity or vestibule, and a single membranous tube. The spinous fishes, in addition to the hollow of the vestibule, and membranous bag containing the lappilli, are provided with semi-circular canals; whilst, in the oseous fishes, the whole organ is enclosed by bone. To the labyrinth of the serpent tribe, which is very similar to the internal ear of the cartilaginous fishes, there is added an officulum, closing the fenestra ovalis. In one of this order, and in almost all the four-footed reptiles, the membrana tympani is furnished with this officulum.

In prosecuting our inquiries farther, the ear has been discovered in insects; it lies at the root of their antennæ, or feelers, and can be distinctly seen in the lobster, and some others of the larger kind.

In the sea-tortoise, the frog, and other amphibious animals, its structure is peculiar, by there being no external meatus, but an expanded Eustachian tube, at the back part of the roof of the mouth, near where the under and upper jaws articulate. This tube has a winding course behind the upper jaw, and leads to a large cavity, resembling the cavity of the human tympanum, covered by the skin of the temple and a tough substance. The latter then passes into the bottom of the tympanum, and next into a smaller cavity filled with a watery humour, and last it opens into a

third cavity, having three semicircular canals, and a sac containing a soft cetaceous substance, on the membrane of which are distributed the nerves. Thus, making a comparison of it with the human ear, the tough substance, or cartilaginous body supplies the small bones of our ear, and the membrane to which it is connected is analogous to the membrane of the foramen ovale. The sac, and semicircular canals and nerves, exactly resemble the human labyrinth, or internal ear.

The mode of constructing a *trumpet* for the purpose of conveying sounds to a distance, was well known to the ancients. Its invention is, however, usually ascribed to Sir Samuel Morland, who called it the *tuba Stentorophonica*. An account of this instrument was published at London in 1671; in which the author relates several of his early experiments; the result of which was, that a speaking-trumpet constructed by him, five feet six inches long, twenty-one inches diameter at the greater end, and two inches at the smaller, being tried at Deal castle, was heard at the distance of three miles, the wind blowing from the shore.

Kircher, in his "Phonurgia Nova," published in 1673, says, that "the tromba, published last year in England, he invented twenty-four years before, and published in his Misurgia:" he adds, that "Jac. Albanus Ghibbisius, and Fr. Eschinardus ascribe it to him; and that G. Scottus testifies of him, that he had such an instrument in his chamber in the Roman College, with which he could call to, and receive answers, from the porter."*

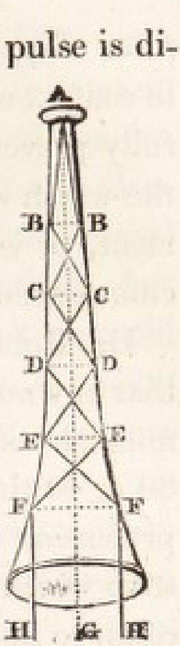
* When we consider how famed Alexander the Great's tube was, with which he used to address his army, and which might be distinctly heard a hundred stadia, or furlongs, it is somewhat strange that the moderns should pretend to the invention; the Stentorophonic horn, or tube of Alexander, of which there is a figure preserved in the Vatican, being almost the same with that now in use.

In a speaking trumpet, the sound in one direction is usually supposed to be increased, rather by the reflection of the sound than by its greater intensity in one direction; and, as the real action of the instrument, or the true motion of the air through it, is not generally understood, different persons, according to their particular conceptions of the case, have recommended peculiar shapes for the construction of such trumpets: some suggest a conical shape; others, that which is formed by the rotation of certain curves round their axis; others, again, have recommended an enlargement or two of the cavity in the length of the trumpet; but that which has been most commonly recommended as the best figure for such a trumpet, is generated by the rotation of a parabola about a line parallel to the axis.

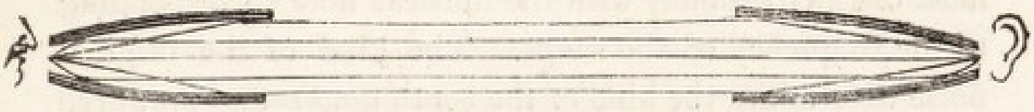
The true physical explication of the speaking-trumpet appears to have been first given by Professor Leslie. "In the case of articulate sounds, (says he,) the confining of the air does not affect the pitch of voice, but it augments the degree of intonation. The lateral flow being checked, that fugacious medium receives a more condensed and vigorous impulsion. As the breath then escapes more slowly from the mouth, it waits and bears a fuller stroke from the organs of speech. But the speaking-trumpet is only an extension of the same principle; its performance does certainly not depend upon any supposed repercussion of sound; repeated echoes might divide, but could not augment the quantity of impulse. In reality, however, neither the shape of the instrument, nor the kind of material of which it is made, seems to be of much consequence. Nor can we admit, that the speaking-trumpet possesses any peculiar power of collecting sound in one direction, for it is audible distinctly on all sides.

To put the construction of this instrument in the plainest and simplest point of view, we have only to suppose the lips

to be enclosed at A, and, as such, that the aerial pulse is directed parallel to the axis of the tube. If this system of enclosure was not resorted to, the air would expand itself in every direction, instead of being propelled in the required line; but the instant the wave spreads, it is received by the reflecting surface B, from whence it impinges at C, and from thence, by repeated reflection, to D E and F. The direction it has now required, will be indicated by the lines F H, which are parallel to the axis of the tube, so that by this method a concentration of sound takes place, which could not be effected by any other means.



The *ear-trumpet* differs but little from the acoustical apparatus just described, as a reference to the accompanying diagram, in which two trumpets are seen placed opposite to each other will readily show. In the one case, the lines show the way in which the aerial pulses are propelled from the lips in any required direction; while, in the other, they are collected and received by the organs of hearing.



Mr. Gough has tried several experiments on ear-trumpets, which are very deserving of notice: the first experiments were made with a view to determine the degree in which hearing was assisted, by the vibrations excited in the metallic shell of the trumpet, and conveyed by it to the orifice of the auditory duct. The result of these experiments was, that absolute contact of the thing producing the sound, with the apparatus for the ear, was necessary, in order that the latter should produce its effects. The ticking of a watch, the scratching of a pin, or even that of a twisted

piece of paper, was conveyed well by the instrument, when in contact with it, (every other avenue for sound being carefully prevented,) but the sound was no longer heard when the watch was moved the smallest distance from the instrument, or when the other noises were made in similar circumstances.

Dr. Robison found, by the most distinct experiments, that any noise whatever, will have the effect of producing a musical note if repeated with due frequency, not less than 30 or 40 times in a second. Nothing surely can have less pretension to the name of a musical sound than the solitary snap which a quill makes when drawn from one tooth of a comb to another: but when the quill is held to the teeth of the wheel, whirling at such a rate that 720 teeth pass under it in a second, the sound of *g in alt.* is heard most distinctly; and if the rate of the wheel's motion be varied in any proportion, the noise made by the quill is mixed, in the most distinct manner, with the musical note corresponding to the frequency of the snaps. The kind of the original noise determines the kind of the continuous sound produced by it, making it harsh and unpleasant, or smooth and harmonious, according as the original noise is abrupt or gradual: but even the most abrupt noise produces a tolerably smooth sound when sufficiently frequent. Nothing can be more abrupt than the snap just now mentioned; yet the *g* produced by it has the smoothness of a bird's chirrup. An experiment was made by Dr. R. which was less promising for a musical note than any other that could have been well conceived. A stop-cock was so constructed, that it opened and shut the passage through a pipe 720 times in a second. This apparatus was fitted to the pipe of a conduit leading from the bellows to the wind-chest of an organ. The air was simply allowed to pass gently along this pipe by the

opening of the cock. When this was repeated 720 times in a second, the sound *g in alt.* was most smoothly uttered, equal in sweetness to a clear female voice. When the frequency was reduced to 360, the sound was that of a clear but rather harsh man's voice. The cock was now altered in such a manner that it never shut the hole entirely, but left about one-third of it open. When this was repeated 720 times in a second, the sound was uncommonly smooth and sweet. When reduced to 360, the sound was more mellow than any man's voice at the same pitch.

An instrument called the *Sirene*, has been proposed by Baron Cogniard de la Tour. It is evidently constructed on the same principles as Dr. Robison's apparatus. It consists of a circular copper box, four inches in diameter: the upper surface is pierced with 100 oblique apertures, each a quarter of a line in width, and two lines long, arranged in a circle round the axis. In the centre of this surface is an axle, on which a circular plate turns by a current of air, or by means of a simple mechanism. This plate has also 100 apertures, corresponding to those in the surface of the box below it, having the same obliquity, but in the opposite direction. The obliquity of these apertures is not necessary to the production of the sounds, but serves to give motion to the circular plate, by the impulse it receives from the currents of air which issue from the apertures in the box. The wind of a pair of bellows being conveyed to the box by means of a tube, the circular plate is set in motion, and the apertures in the surface of the box are alternately open and shut to the passage of the air, by which means a regular series of blows is given to the external air, and a sound analogous to that of the human voice is produced, becoming more or less acute according to the greater or less velocity of the plate. When water, in place of air, is made to pass

through the apertures, sounds are equally produced, even when it is entirely plunged in the fluid, and the same number of concussions produces the same sound as in the air.

Wind-instruments generally produce their effect by the vibrations of a column of air confined at one end, and either open or shut at the other. These vibrations are determined mainly by the length of the sounding column. Yet, interior and subordinate vibrations are found to co-exist with the fundamental one. The whole column spontaneously divides itself into portions equal to the half, the third, or the fourth of its longitudinal extent.

In mixed wind-instruments, the vibrations or alterations of solid bodies are made to co-operate with the vibrations of a given portion of air. Thus, in the trumpet, and in horns of various kinds, the force of inflation, and, perhaps, the degree of tension of the lips, determines the number of parts into which the tube is divided, and the harmony which is produced. In the serpent, the lips co-operate with a tube, of which the effective length may be varied by opening or shutting holes: and the instrument which has been called an organized trumpet, appears to act in a similar manner. The trombone has a tube which slides in and out at pleasure, and changes the actual length of the whole instrument. The hautboy and clarinet have mouth-pieces of different forms, made of reeds or canes; and the reed-pipes of an organ, of various constructions, are furnished with an elastic plate of metal, which vibrates in unison with the column of air that they contain. An organ generally consists of a number of different series of such pipes, so arranged that, by means of registers, the air proceeding from the bellows may be admitted to supply each series, or excluded from it at pleasure, and a valve is opened when the proper key is touched, which causes all the

pipes belonging to the note, in those series of which the registers are open, to sound at once.

The longitudinal vibrations of a column of air, contained within a tube open at both ends, are powerfully excited, and very loud and clear tones produced, by the inflammation of a streamlet of *hydrogen gas*. This curious experiment was made first in Germany, and appears, indeed, to have been scarcely known, or at least noticed, in other countries. Yet it is most easily performed, and will be considered amusing, if not instructive. A phial, being partly filled with dilute sulphuric acid, a few bits of zinc are dropped into the liquid. As the decomposition of the water embodied with the acid now proceeds, the hydrogen gas, thus generated, flows regularly from the aperture. The gas being first ignited, and a glass tube passed over the exit-pipe, the burning speck at its point instantly shoots into an elongated flame, and creates a continued sharp and brilliant musical sound. This effect is not owing to any vibrations of the tube itself, for it is no wise altered by tying a handkerchief tightly about the glass, or even by substituting a cylinder of paper. The tremor excited in the column of air, is, therefore, the sole cause of the incessant tone, which only varies by a change in the place of the flame, or a partial obstruction applied at the end of the tube. The exciting force must necessarily act by starts, and not uniformly. The length of the flame might seem to prove, that the hydrogen gas is not consumed or converted into aqueous vapour as fast as it issues from the aperture. A jet of it catches fire instantaneously, but is immediately followed by another; the succession of inflamed portions being so rapid as entirely to escape the keenness of sight. The column of air contained within the tube, would thus be agitated by a series of incessant strokes, or sudden expansions,

and there can be little doubt but that a very curious instrument, possessing great power in a small space, might thus be constructed.

It may now be advisable to examine the vibrations of a sounding string. A musical string or chord, is supposed to be perfectly flexible and of uniform thickness, to be stretched between two fixed points by a force incomparably greater than its own weight, and to vibrate in a single plane, through a minute space on each side of its natural position. Its motions may then be traced through all their stages, by comparing the chord to a portion of an elastic medium of the same length, contained between two bodies capable of reflecting any impulse at each end; for example, to a portion of air situated between two walls, or inclosed in a pipe stopped at both ends: for the vibration of such a medium will be performed in the time occupied by any impulse in travelling through twice its length; and the vibration of the chord will be performed in the same time, supposing the height or depth of the medium equal to the length of a portion of the chord, of which the weight is equivalent to the force applied to stretch it, and which may be called with propriety the modulus of the tension. If the chord be at first bent into a figure of any kind, and then set at liberty, the place of any part of it, at every subsequent time, will be such, that it will always be in a right line between two points moving along the figure each way, with the appropriate velocity; but, in order to pursue this determination, we must repeat the figure of the chord on each side of the fixed points, in an inverted position, changing the ends as well as the sides. Hence it appears, that, at the end of a single vibration, the whole chord will assume a similar figure on the opposite side of its natural place, but in an inverted position; and after a complete or

double vibration, it will return precisely to the form which it had in the beginning. The truth of this result is easily shown by inflecting any long chord near one of its ends, having first drawn a line under its natural position, and it will then be evident that the chord returns, in each vibration, nearly to the point of inflection, and passes at that end, but to a much shorter distance, on the opposite side of the line, while at the other end its excursions are greatest on the opposite side of the line.

The shapes which the same string assumes in its vibrations, after having been struck with different methods, may, in a great measure, be perceived. "Take," says Dr. Young, "one of the lowest strings of a square pianoforte, round which a fine silvered wire is wound in a spiral form; contract the light of a window, so that, when the eye is placed in a proper position, the image of the light may appear small, bright, and well designed, on each of the convolutions of the wire: let the chord be now made to vibrate, and the luminous point will delineate its path, like a burning coal whirled round; and will present to the eye a line of light, which, by the assistance of a microscope, may be very accurately observed."

Mr. Hawkins has furnished us with a very beautiful experiment tending to illustrate the harmonic division of a string, when its vibrations are checked at any particular part. Mr. H.'s apparatus consisted merely of a brass wire 15 or 16 feet long, spirally curled through its whole length, and stretched over two bridges near its two ends, against the wainscot of the room, on which was a scale, dividing the space between the bridges into aliquot parts, as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, &c. through its whole length. The string, thus prepared, was laid hold of by the thumb and finger in the middle, and drawn about two inches out of its quiescent

position, and let go; then the tip of the finger or the feather of a quill being dexterously applied, to check the extreme vibrations opposite to any one of the aliquot divisions, the string began immediately to vibrate in so many separate parts, without destroying the total vibration, which still continued, and supported its subordinate vibrations for a minute or more, in a manner highly gratifying to the eye, as the vibrations were slow enough to be readily counted and compared with each other.

Having thus far examined the form assumed by the string, it may be advisable to direct our attention to the acoustical effect. Let us suppose two strings formed of the same matter, of the same thickness, and equal in their tension, but unequal in their length, it will be found by experiment,

1st. That if the shortest is equal to half the longest, the sound which it will produce must be an octave above the sound produced by the longest.

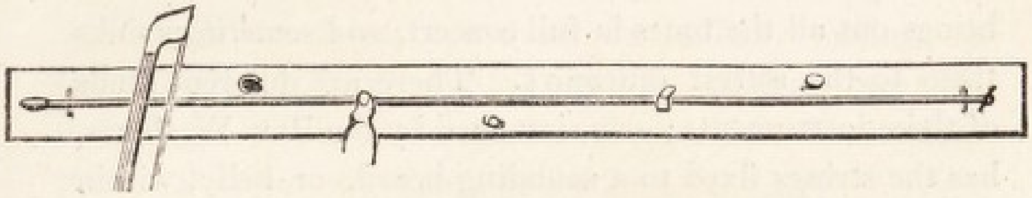
2dly. That if the shortest constitutes a third part of the longest, the sound which it produces must be a twelfth above the sound produced by the longest.

3dly. That if it constitutes the fifth part, its sound will be a seventeenth above.

If two strings, the length of one of which is an aliquot part of the other, be of equal thickness, and equally stretched, any vibrations given to the shorter string will communicate themselves to the corresponding parts of the lower string placed near it. If the vibrating shorter string be an acuter octave, the other will vibrate by its half lengths only: if the string which communicates the motion be an acuter double octave, or a fourth of the length of the other, the longer string will vibrate only by the fourths of its lengths from one end to the other. Thus, if one

string were four feet long, and the other one foot, on striking the latter with a quill the vibrations will be communicated to the former, so that it will only vibrate in foot lengths throughout. This may be made evident by hanging little paper bridges at every foot length of the longer string; for, on the vibrations being communicated to it, the papers hanging at the middle of each foot in length will be thrown off, while those that hang at the end of each foot will remain unmoved upon the string; whence it is inferred that the vibrations are made about those points as so many fixed points, the intermediate spaces having each its separate vibration.

This is experimentally demonstrated by Dr. Young with the assistance of a diagram.

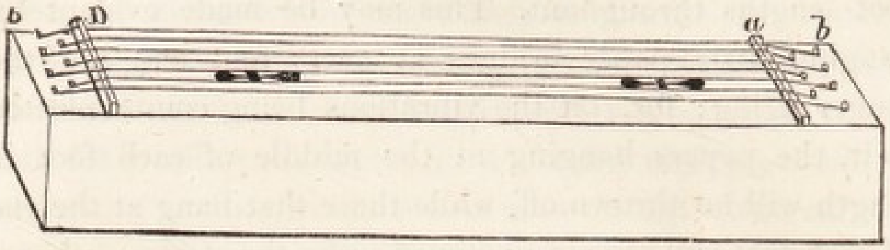


Thus, a string impelled by the bow of a violin, and lightly touched at the same time at a point one-third of its length from the end, the small pieces of paper fly off from the middle of the vibrating portions, while the piece situated at the remaining point of division retains its situation.

The *Æolian-harp* furnishes a very pleasing illustration of the mechanical operation of air on vibrating strings.

On the next page is a representation of this simple instrument, which was invented by Kircher. The Æolian harp consists of a long narrow box of very thin deal, about five or six inches broad, and two inches deep, with a circle in the middle of the upper side, of an inch and a half in diameter, in which is drilled small holes. On this side, seven, ten, or more strings of very fine gut, are stretched over bridges

at each end, like the bridge of a fiddle, and screwed up or relaxed with screw-pins. The strings are all tuned to one and the same note, and the instrument is placed in some



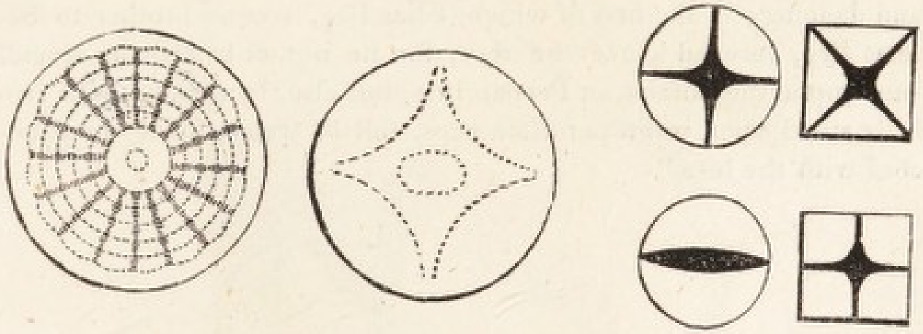
current of air, where the wind can pass over its strings with freedom. A window, of which the width is exactly equal to the length of the harp, with the sash just raised to give the air admission, is a proper situation. When the air blows upon these strings with different degrees of force, it will excite different tones of sound; sometimes the blast brings out all the tones in full concert, and sometimes sinks them to the softest murmurs. There are different kinds of these instruments; one, invented by the Rev. W. Jones, has the strings fixed to a sounding-board, or belly, within a wooden case, and the wind is admitted to them through an horizontal aperture. In this form, the instrument is portable, and may be used in the open air. The tension of the strings must not be great, as the air, if gentle, has not sufficient power to make them vibrate; and if it blow fresh, the instrument does not sing, but screams.

Musical instruments which produce sounds by means of vibrations depending on the elasticity of solid bodies, are less frequently employed than those we have already examined. Such is the stacada*, a series of cylinders of glass,

* In making the stacada or instrument of bars, it is of considerable importance that the precise point of support should be discovered; and this may be effectually accomplished by strewing sand on the surface of the bar, and the part of the vibrating rod on which the sand remains at rest may be considered as the proper point of support.

or of metal, struck either immediately with hammers, or by means of keys; the tuning fork, the gong, the cymbal, and the bell.

The vibrations of plates differ from those of rods, in the same manner as the vibrations of membranes differ from those of chords; the vibrations which cause the plate to bend in different directions being combined with each other and sometimes occasioning singular modifications. These vibrations may be traced through wonderful varieties by Professor Chladni's method of strewing dry sand on the plates, which, when they are caused to vibrate by the operation of a bow, is collected into such lines as indicate those parts which remain, either perfectly or very nearly, at rest during the vibrations. Dr. Hooke had employed a similar method for showing the nature of the vibrations of a bell; and it has sometimes been usual, in military mining, to strew sand on a drum, and to judge, by the form in which it arranges itself, of the quarter from which the tremors produced by countermining proceed.



A sufficient illustration of the more simple figures formed by plates covered with sand, will be found in the above sketch, which exhibits a view of the variable forms which result from both square and circular plates.

Nearly similar figures will result from the vibration of water or any other fluid in a glass, and the tone that is thus

elicited differs very materially from that of any other sounding body we have yet noticed.

The *finger harmonica* was originally proposed by Dr. Franklin, and it consisted of a series of glass basins, attached to a spindle, and made to revolve by means of a pedal. If, during their revolution, a moistened finger be applied to the edge of the glass, the most beautiful tones are elicited, and a series may be so arranged as to form the most delicate harmony. A nearly similar instrument is now constructed by Mr. Tate, under the title of *Celestina;* and the above ingenious mechanic brings them exactly into tune, by the simple process of grinding from the under surface of the glass, instead of changing the note by the introduction of water.*

* It is a curious circumstance that this mode of tuning glasses was resorted to in the East at a very early period, as appears from the following extract, from an account of an Embassy from the Duke of Holstein to the Sophi of Persia, in 1637.

"While we were busy in eating plentifully of the delicious fruits and preserves that were brought in, we were also diverted with music and dancing; in the first of which, Elias Beg, second brother to Seferas Beg, excelled above the rest; for he not only gave us several tunes upon the tamora, or Persian lute, but also, by striking with two little sticks upon seven porcelain cups, full of water, made them accord with the lute."

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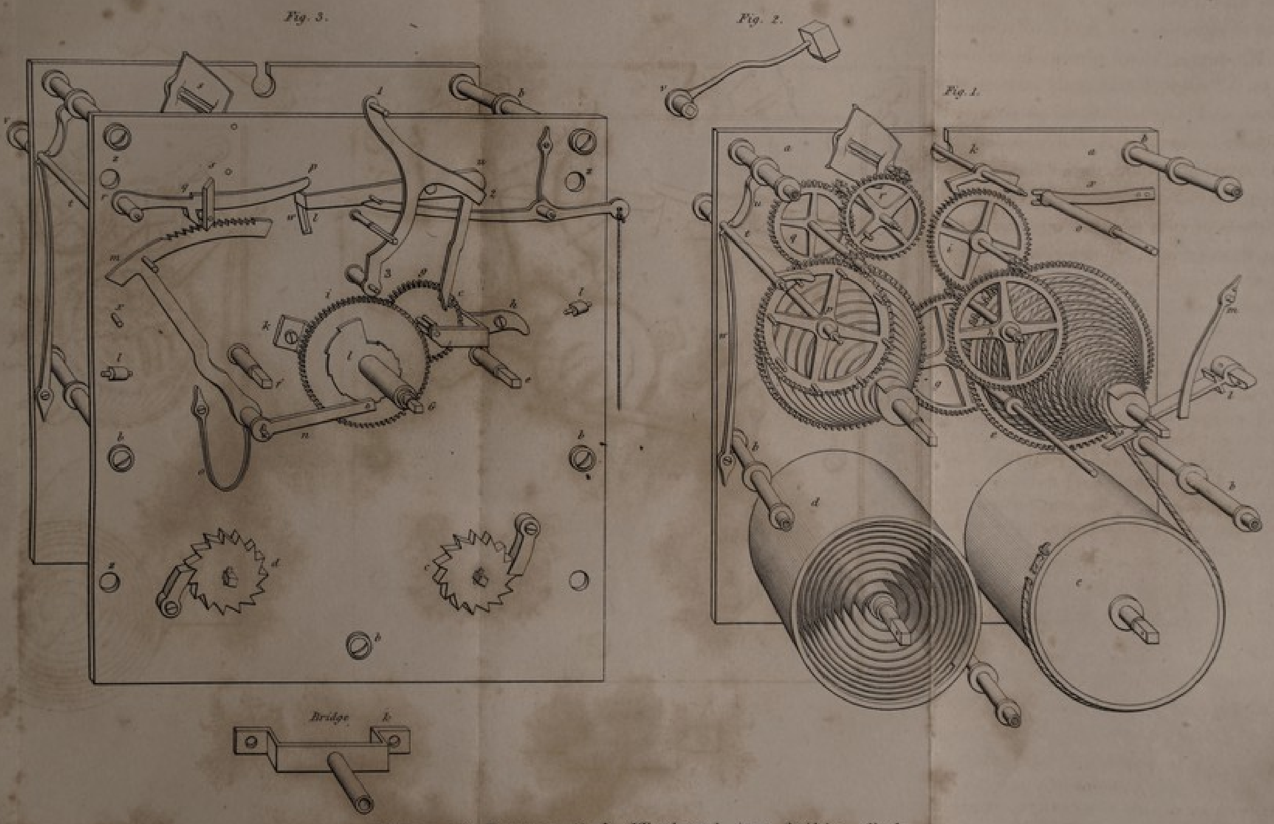

Interior and Exterior of the Wheel-work in a Striking Clock.

G. Gladwin sculp.

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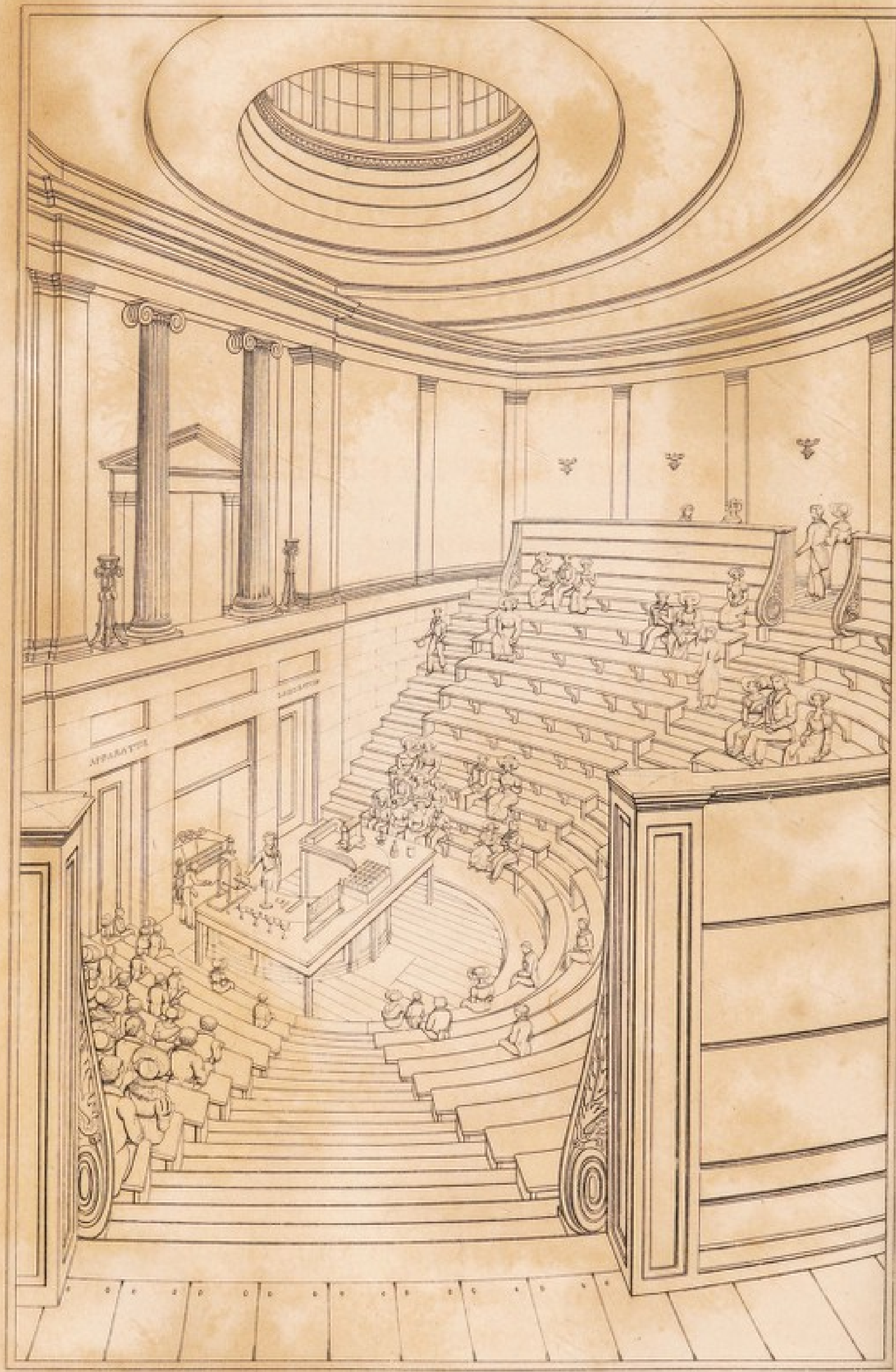

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INTERIOR OF THE THEATRE OF
THE LONDON INSTITUTION.

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NATURE OF LIGHT, AND CONSTRUCTION OF OPTICAL MACHINES.

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As all the phenomena which offer themselves to our observation in this science, owe their origin to the direct agency, or presence of light: it may be advisable, in the first place, to examine some of its more important properties; and then show the application of those data to the construction of optical machines.

There are two theories, or rather, hypotheses, that have been adopted to explain the action of light, with reference

to its transmission. The one supposes the rays to consist of small particles, and, as such, material; while the other presumes the existence of a fluid pervading all space, which, by its vibratory motion, enables us to see luminous bodies. According to the latter hypothesis, light may be considered as analogous to sound, which is known to depend entirely on the pulsations of the air and other sonorous bodies transmitting a vibratory motion to the organs of hearing.

A very striking circumstance respecting the propagation of light, is the uniformity of its velocity in the same medium. According to the projectile hypothesis, the force employed in the free emission of light must be about a million million times as great as the force of gravity at the earth's surface; and it must either act with equal intensity on all the particles of light, or must impel some of them through a greater space than others, if its action be less powerful, since the velocity is the same in all cases: for example, if the projectile force is weaker with respect to red light than with respect to violet light, it must continue its action on the red rays to a greater distance than on the violet rays. There is no instance in nature, besides, of a simple projectile moving with a velocity uniform in all cases, whatever may be its cause; and it is extremely difficult to imagine that so immense a force of repulsion can reside in all substances capable of becoming luminous, so that the light of decaying wood, or of two pebbles rubbed together, may be projected precisely with the same velocity, as the light emitted by iron burning in oxygen-gas, or by the reservoir of liquid fire on the surface of the sun. Another cause would also naturally interfere with the uniformity of the velocity of light, if it consisted merely in the motion of projected corpuscles of matter: M. Laplace has

calculated, that if any of the stars were 250 times as great in diameter as the sun, their attraction would be so strong as to destroy the whole momentum of the corpuscles of light proceeding from it, and to render the star invisible at a great distance; and, although there is no reason to imagine that any of the stars are actually of this magnitude, yet some of them are probably many times greater than our sun, and therefore large enough to produce such a retardation in the motion of its light, as would materially alter its effects.

If, however, we adopt the opinion, that the particles of light are material, and that they are continually passing from the various luminous bodies that surround us, it may be inquired why they do not interfere with each other in such a manner as to confound all distinct perception of objects, if not quite destroy the sense of seeing? Their velocity, however, enables us to answer these questions, by convincing us that they may be separated at least a thousand miles, and yet be perfectly efficient to the purposes of vision. It is an undoubted fact, that the effect of light upon the eye is not instantaneous, but that the impression remains after the light has been withdrawn. Of this, any one may satisfy himself, by shutting his eye, after having looked for some time on a candle, a star, or any other luminous object, when a faint momentary picture of the object will remain. The same thing may be proved by whirling round a stick, the extremity of which is on fire; if the motion be quick enough, the perception of a complete circle of flame will be impressed on the eye. The actual duration, for a certain time, of the impression of light being thus proved, let it be supposed to continue distinct only for the 150th part of a second; then, if one lucid point of the sun's surface emit 150 particles of light in a

second, these will be amply sufficient to afford light to the eye without any intermission; and yet the particles emitted will be more than 1000 miles apart.

It has been ascertained by the astronomical observations of Roemer and of Bradley, that each ray of light emitted by the sun, arrives at the earth in eight minutes and one-eighth, when the earth is at its mean distance of about ninety-five millions of miles. Roemer deduced this velocity from observations on the eclipses of the satellites of Jupiter; and Bradley confirmed it by his discovery of the cause of the apparent aberration of the fixed stars.

But we have other proofs not less decisive than this, of the extreme minuteness of the particles of light, when we observe with what facility they penetrate the hardest bodies, as glass, crystal, precious stones, and even the diamond itself, through all which they find an easy passage, or those bodies could not be transparent. When a candle is lighted, if there is no obstacle to obstruct its rays, it will fill a space of two miles round with luminous particles in an instant of time, and before the least sensible part of the substance is lost by the luminous body. Nay, how small must the particles of light be, when they pass without removing the minutest particles of microscopic dust that lay in their way, and even these minute particles are rendered visible, by reflecting back the particles of light that strike against them.

Some bodies intercept light, or are opaque; others allow its transmission, and as such, are transparent; and there are gradations from perfect opacity to nearly perfect transparency. It is probable, that opacity results from the attraction of the substance for light, and not from its density: for it can scarcely be supposed that the particles of bodies should not be far enough distant to allow of the passage of light. Newton supposes the particles of transpa-

rent bodies to be of uniform density and arrangement, and attracting the ray of light equally in every direction, they suffer it to pass through them without obstruction; whereas, in opaque bodies, the particles are either of unequal density, or irregularly arranged, and the light being unequally attracted, cannot therefore penetrate the body.

Experience has long ago established the fact, that vegetables become destitute of smell and colour, and lose much of their combustibility, by growing in the dark. In Dr. Black's Lectures, we find an illustration of this circumstance in an account given by the celebrated Dr. Robinson, of Edinburgh. In the drain of a coal-work under ground, he accidentally laid his hand upon a very luxuriant plant, with large indented foliage, and perfectly white. He had not seen any thing like it, nor could any one inform him what it was. He had the plant brought into the open air in the light. In a little time the leaves withered, and soon after new leaves began to spring up, of a green colour, and of a different shape from that of the old ones. On rubbing one of the leaves between his fingers, he found that it had the smell of common tansy, and ultimately it proved to be that plant, which had been so changed by growing in the dark. Indeed, it was recollected that some soil had been taken into the drain from a neighbouring garden, some time before it was found so altered.

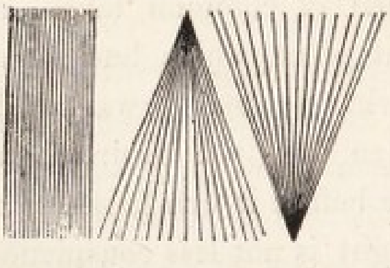
This effect of light is not less conspicuous in the growth of celery. By covering it with earth, the light is shut out, which would very soon turn it green, and make its flavour so strong as to render it unfit to be eaten, at the same time that it would render it more fibrous and tenacious.

The parts of fish also, which are exposed to the light, such as the back, or fins, are uniformly coloured; but the belly, which is deprived of it, is white in nearly all of

them; while birds that inhabit tropical countries have much brighter plumage than those of the North; and this is also the case with every species of insect.

Light is found to produce various chemical changes upon bodies. When the oxyd of silver is precipitated from nitric acid by muriatic acid, the insoluble muriate is at first white, and if kept in the dark at the common temperature, would doubtless remain so for an indefinite length of time. If, however, it be exposed to the light for a little time, it begins to assume a purple colour, and ultimately becomes black. This effect takes place more rapidly according to the intensity of the light. Hence, it has been proposed to measure the intensity of light by the time of its changing. An instrument has been invented for this purpose by Mr. Leslie.

It has been shown that rays of light diverge in every direction from the various luminous or radiant bodies that surround us. A pencil of rays emitted from a point are seen at one extremity of the subjoined diagram.



A series of parallel rays are placed at the opposite extremity, while the central rays are convergent; an effect which is easily produced by optical machines.

When a ray of light falls upon any polished surface, a portion is reflected; and the more obliquely it falls upon the surface of the body, the greater in general is the reflected portion. To ascertain the amount of divergence

from the reflecting plane, it may be taken as an axiom, that the angle of reflection is invariably as the angle of incidence, and upon this circumstance all the properties of plane mirrors depend.*

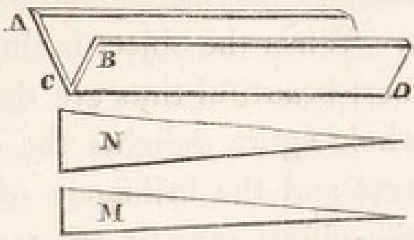
The effect of combining two or more plain mirrors, so as to produce a multiplication of images, was known at a very early period, and described by writers on optics. Baptista Porta, in his "Magia Naturalis," gives an account of the construction of an instrument, which he calls a *polyphaton*, in which two rectangular specula are united by two of their sides, so that they may be opened or shut like a book, and the angles varied; and also of a polygonal speculum, consisting of several mirrors arranged in a polygon, for multiplying in different directions the images of objects. Kircher, also, in his "Ars Magna Lucis et Umbra," describes as an invention of his own, the former of these constructions, and distinctly traces the relation between the angle of inclination of the mirrors, and the number of images formed. The very same contrivance was afterwards adopted by Bradley, for the purpose of assisting in the designing of garden plots and fortifications; and he states that, "from the most trifling designs, we may, by this means, produce some thousands of good draughts." But the particular application of this principle, in the case where the two reflectors are inclined to one another at a small angle, so as to form a series of symmetrical images distinctly visible only in a particular position of the eye, was a discovery reserved for Dr. Brewster. The first idea of this remarkable property occurred to him in the course of some

* By the *angle of incidence*, is meant the angle made by a ray of light, with a perpendicular to the reflecting surface, at the point where the ray falls; and by the *angle of reflection*, the angle which the ray makes with the same perpendicular on the other side.

experiments in which he was engaged on the polarization of light, during the year 1814. But the only circumstance which at that time attracted his attention, was the circular arrangement of the images of a candle round the centre, and the multiplication of the sectors formed by the extremities of the plates of glass, between which the light had undergone several successive reflections. In repeating, at a subsequent period, some experiments of M. Biot, on the action of homogeneous fluids upon polarized light, and in extending them to other fluids which he had not tried, Dr. Brewster happened to place them in a triangular trough, formed of two plates of glass, cemented together by two of their sides, so as to form an acute angle. The ends being closed up with pieces of plate glass, cemented to the other plates, the trough was fixed horizontally, for the reception of the fluids. The eye being necessarily placed without the trough, and at one end, some of the cement, which had been pressed through between the plates, at the object end of the trough, appeared to be arranged in a remarkably regular and symmetrical manner. Pursuing the hint thus obtained, and investigating the subject optically, he discovered the leading principles of the caleidoscope, in as far as the inclination of the reflectors, the position of the object, and that of the eye, were concerned.

This instrument, in its most common form, consists of two reflecting surfaces, inclined to each other at any angle, but more properly at an angle which is an aliquot part of 360°. The reflecting surfaces may be two plates of glass, plain or quicksilvered, or two metallic surfaces, or the two inner surfaces of a solid prism of glass, or rock crystal, from which the light suffers total reflection. The plates should vary in length according to the focal distance of the eye; five, six, seven, eight, nine, and ten inches will in ge-

neral be most convenient; or they may be made only one, two, three, or four inches long, provided distinct vision is obtained at one end, by placing at the other end an eye-glass, whose focal length is equal to the length of the reflecting planes. The inclination of the reflectors that is in general most pleasing, is 18°, 20°, or 22½°, or the 20th, 18th, and 16th part of a circle, but the planes may be set at any required angle, either by a metallic, a paper, or cloth joint, or any other simple contrivance. When the two planes are put together, with their straitest and smoothest edges in contact, they will have the form shown in the diagram A B C D, where A B C is the aperture, or angle

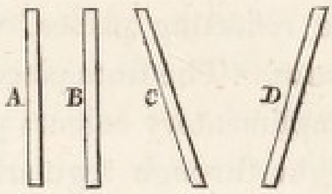


formed by the plates. In this figure the plates are rectangular; but it may often be more convenient to give them the triangular form, shown at M or N. When the instrument is thus constructed, it may be either covered up with paper or leather, or placed in a cylindrical or any other tube, so that the aperture A B C may be left completely open, and also a small aperture at the angular point D. If the eye is now placed at D, and looks through the aperture A B C, it will perceive a brilliant circle of light, divided into as many sectors as the number of times that the angle of the reflectors is contained in 360°. If this angle is 18°, the number of sectors will be 20°; and, whatever be the form of the aperture A B C, the luminous space seen through the instrument will be a figure produced by the

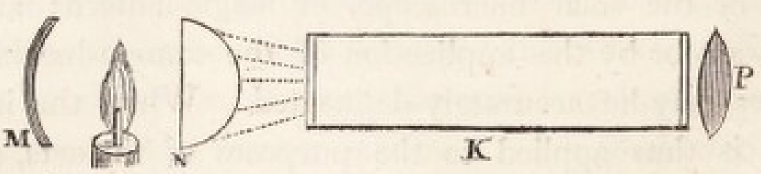
arrangement of twenty of these apertures round C, as a centre, in consequence of the successive reflections between the polished surfaces. Hence it follows, that if any object, however ugly or irregular in itself, is placed before the aperture A B C, the part of it that can be seen through the aperture will be seen through every sector, and every image of the object will coalesce into a form mathematically symmetrical, and highly pleasing to the eye. If the object be put in motion, the combination of images will likewise be put in motion, and new forms, perfectly different, but equally symmetrical, will successively present themselves, sometimes vanishing in the centre, sometimes emerging from it, and sometimes playing around in double and opposite oscillations. When the object is tinged with different colours, the most beautiful tints are developed in succession, and the whole figure delights the eye by the perfection of its forms and the brilliancy of its colouring. The motion of the object may be effected either by the hand, or by a simple piece of mechanism; or the same effect may be produced by the motion of the instrument over the object, or round its own axis. In the form of the caleidoscope now described, the object should be held close to the aperture A B C, and the eye should be placed as nearly as possible in the line C D; for the figure loses its symmetry in proportion as the object recedes from A B C, and as the eye rises above D. The instrument is therefore limited, in its present form, to the use of objects which can be held close to the aperture. In order to remove the limitation, the tube which contains the reflectors should slide in another tube, of nearly the same length, and having a convex lens at its farther extremity; the focal length of the lens should be always less than its greatest distance from the aperture A B C. In general, it should be about

one-third or one-fourth of that distance, but it will be advisable to have two or even three lenses of different focal lengths, to fit into the end of the outer tube, and to be used as circumstances may require, or a variation of focal length may be produced by the separation or approach of two lenses. When the instrument is thus fitted up, it may be applied to objects at all distances; and these objects, whose images are formed in an inverted position at the aperture A B C, may be introduced into the symmetrical picture in the very same manner as if they were brought close to the instrument. Hence we can introduce trees, flowers, statues, and living animals; and any object which is too large to be comprehended by the aperture A B C, may be removed to such a distance that its image is sufficiently reduced. The caleidoscope is also constructed with three or more reflecting planes, which may be arranged in various ways. The tints placed before the aperture may be the complimentary colours produced by transmitting polarized light through regularly crystallized bodies, or pieces of glass that have received the polarizing structure. The partial polarization of the light, by successive reflections, occasions a partial analysis of the transmitted light; but in order to develope the tints with brilliancy, the analysis of the light must precede its admission into the aperture. Instead of looking through the extremity D of the tube, the effects which have been described may be exhibited to many persons at once, upon the principle of the solar microscope, or magic-lantern; and, in this way, or by the application of the camera-lucida, the figures may be accurately delineated. When the instrument is thus applied to the purposes of the arts, an infinity of patterns is created, and the artist can select such as he considers most suitable to his work. When a know-

ledge of the nature and powers of the instrument has been acquired, by a little practice he will be able to give any character to the pattern that he chooses, and he may even create a series of different patterns, all rising out of one another, and returning, by similar gradations, to the first pattern of the series. In all these cases, the pattern is perfectly symmetrical round a centre, or all the images of the aperture A B C are exactly alike: but this symmetry may be altered; for, after the pattern is drawn, it may be reduced into a square, a triangular, an elliptical, or any other form that he pleases. The instrument will give annular patterns, by keeping the reflectors separate, as at C D; and it will give rectilineal ones, by placing the reflectors parallel to each other, as in A B.



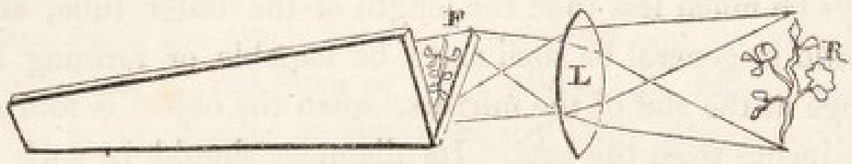
The exhibition of the effects of the caleidoscope to a number of spectators at the same time, by throwing the images on a wall, after the manner of the magic-lantern, or solar microscope, might be easily accomplished, if sufficient light could be procured for the illumination of the objects. The form of an instrument for this purpose, is represented in the accompanying figure, where a powerful



flame or lamp is employed: the light from which being

augmented by the reflector M, and concentrated by the very convex lens N, upon the transparent objects at the end of the caleidoscope K, is formed into an image on the opposite wall by refraction through the lens P, the focal distance of which is somewhat shorter than the length of the tube. The brilliant light produced during the combustion carried on by means of a stream of oxygen gas, is peculiarly fitted for the exhibition of these effects.

Dr. Brewster has furnished us with a very pleasing variety of this instrument in the *telescopic caleidoscope*. It consists in substituting the images of distant objects for the small transparent bodies usually employed, which is effected by placing a convex lens at a certain distance from the tube. The arrangement of the apparatus will readily be understood, as the theory of its construction has already been described.



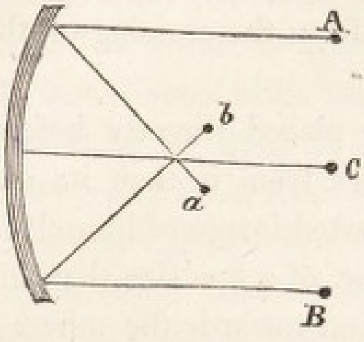
The lens L forms an image of the object R at F, which image is multiplied by the reflecting powers of the instrument, and forms a symmetric spectrum, precisely in the same way as if a real object of that size had occupied its place. The lens may be fitted to the end of a separate tube, external to that of the instrument, and capable of being drawn out upon it to the proper distance, which is known by observing when the spectrum appears perfectly symmetrical. The instrument in this form has been called the *telescopic* or *compound caleidoscope;* and is applicable to distant objects of every description, and equally so to those in motion as those at rest. All their movements are represented with singular effect in the spec-

trum. A blazing fire viewed by it, gives the appearance of beautiful fire-works, at one time rushing with great rapidity towards the centre, and at another, issuing from it towards the circumference, or darting in splendid starriform corruscations over the field of vision. These varieties in the spectrum are occasioned both by turning the instrument round its axis, and by moving it forwards in any direction. The compound caleidoscope has thus a much more extended range than the simple kind; and it has this further advantage, that it admits of the symmetry of the spectrum being rendered perfectly correct, since the images may be brought exactly to the ends of the mirrors; a condition which never can be completely obtained, when the objects are confined in a glass case, as they must then always be separated from the mirrors, by at least the thickness of the glass. The focal length of the lens should always be much less than the length of the outer tube, and should in general be such as to be capable of forming an image at the end of the mirrors, when the object is four or five inches from the lens. Its diameter should be such as that, when it is at its greatest distance from the mirrors, it shall still occupy the whole of the field of view which is seen by direct vision; or, in other words, that the eye shall not see any part of its edge.

The effects which result from the falling of parallel rays of light on a concave mirror, will be easily understood by reference to the opposite figure.

The ray A, on striking against the glass, is reflected back towards *a*; while B, is similarly reflected towards *b*. The ray C, on the contrary, returns back precisely in the same direction as it had previously descended. In the above figure, we have only represented three rays, but it will be obvious, that rays of light will fall on every part of

the polished surface, and, as such, form a distinat picture of the image to be reflected. The rays are also inverted,



as will be seen by reference to the change that occurs in the position of the letters.

There are, however, other phenomena connected with the operation of concave mirrors. By them, convergent rays are rendered more convergent; their effect, therefore, is to magnify. This effect, however, will only take place when the eye is between the mirror and its principal focus, that is, the focus or point where rays falling parallel or perpendicular on the glass, will unite after reflection; the point where the rays of the sun, which are always considered as parallel, will unite and burn, for a concave mirror acts as a burning glass. By the ordinary law of reflection, the principal focus of a concave mirror is at one-half of the diameter of that sphere, of which the concave surface is a section, which is therefore sometimes called the centre of concavity.* At this point, the rays reflected from

* To find the focal distance of a concave mirror, place it so that its axis may be directed to the centre of the sun. Find the burning point, or receive the image upon a white piece of paper, and the distance thus found, between the paper and the centre of the speculum, is the focal length. Or, cover the mirror with paper, in which make two or more holes, and observe where the beams of light reflected from these holes unite, and this will be the focal distance.

the mirror are converged and cross; and if the spectator's eye is beyond this point or focus, he will not see the image behind the mirror, but before it, a shadowy form suspended in the air, but from the crossing of the rays it appears inverted.

If a person be placed directly before a large concave mirror, but further from it than its centre of concavity, he will see an inverted image of himself in the air, between him and the mirror, of a less size than his own person. If he hold out his hand towards the mirror, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk when his hand is in the centre of concavity; and he will imagine he may shake hands with his image. If he reach his hand further, the hand of the image will pass by his hand, and come between it and his body; and if he move his hand towards either side, the hand of the image will move towards the other; so that whatever way the object moves, the image will move the contrary way. A by-stander will see nothing of the image, because none of the reflected rays that form it enter his eyes. From this remarkable property of a concave mirror to form an image in the air, mirrors of this sort are used to produce a variety of singular appearances, to amuse the curious, or to impose upon the ignorant and superstitious. A few of these experiments may be noticed.—If a fire be made in a large room, and a smooth mahogany table be placed at a considerable distance near the wall, before a large concave mirror, so situated that the light of the fire may be reflected from the mirror to its focus upon the table, and a person stand by the table, he will see nothing upon it but a long beam of light; but if he advance towards the fire, not directly between the fire and the mirror, he will see an

image of the fire upon the table, large and erect. If another person, who knows nothing of the experiment beforehand, should chance to enter the room, and look from the fire towards the table, he would be startled at the appearance; for the table would seem to be on fire. In this experiment, there should be no light in the room but what proceeds from the fire; and the mirror ought to be at least fifteen inches in diameter. If the fire used in the last experiment be extinguished, or covered by a screen, and a large candle be placed in a similar position, a person standing by the candle, will see the appearance of a star, or rather planet, upon the table, as brilliant as Venus or Jupiter in a cloudless sky; and if a slender wax-taper be then placed near the candle, a satellite to the planet will appear on the table; and on moving the taper round the candle, the mimic satellite will go round the planet. Another experiment may be adduced:—take a glass bottle, partly fill it with water, and cork it in the common manner: place this bottle opposite a concave mirror, and beyond its centre of concavity, that it may appear reversed; let the spectator retire to a still greater distance than the bottle, which he will then see in the air inverted, and the water, which is actually in the lower part of the bottle, will in the image appear uppermost. Invert the bottle whilst before the mirror, and in the image the water will appear in the lower part of the bottle; when it is in this inverted state, uncork the bottle, and whilst the water is running out, the image will appear to be filling; but as soon as the bottle is empty, the illusion ceases. As the image formed by a concave mirror may be thrown through a hole into an adjoining room, where a spectator will in certain situations perceive the image of any object the concealed manager

may choose, it is evident how much the credulous may be imposed upon.*

From what we have seen of the optical effects of a bent glass, it will be evident that an object of a certain size, placed either perpendicularly or obliquely before a convex mirror, will necessarily appear curved or bent, because the different points of the object are not at equal distances from the surface of the mirror. All these effects will be very apparent from inspecting one of the small glass globes, lined with common amalgam used for making looking-glasses; which are sometimes suspended in old-fashioned apartments. In these, the company seated in the room, or round the table, are represented by very minute images, which appear not at a certain distance behind, as in plain looking-glasses, but very near the surface of the mirror, and always in some degree curved or distorted.

Mirrors are sometimes constructed for optical purposes, which combine the effects of plain and spherical glasses. The properties of cylindrical mirrors are such that the dimension of objects, corresponding lengthwise to the mirror, are not much changed; but those corresponding breadthwise, have their figure altered, and their dimensions lessened, the further they are from the mirror, whence arises a very great distortion. 2. If the plane of the reflection cut the cylindrical mirror through the axis, the reflection is

A few years back, a person derived considerable emolument from exhibiting in the metropolis some optical deceptions of this kind with concave mirrors. A ghastly apparition was sometimes made to meet the uninitiated spectator, and from its shadowy appearance, was viewed as something superhuman. At other times, a hand was held out in the air with every possible mark of friendship, but when he approached to unite it with his own, a drawn sword was instantly presented to his breast. A nosegay, or a piece of fruit was offered, but when the spectator attempted to seize it, a death's head appeared.

performed in the same manner as in a plane mirror; and if parallel to the base, the reflection is the same as in a spherical mirror; if it cut it obliquely, the reflection is the same as in an elliptic mirror. Hence, as the plane of reflection never passes through the axis of the mirror, except when the eye and the object are in the same place; nor parallel to the base, except when the radiant point and the eye are at the same height; the reflection is therefore usually the same as in an elliptic one. If a hollow cylindric mirror be directly opposed to the sun, instead of a focus of a point, the rays will be reflected into a lucid line parallel to its axis, at the distance of about one-fourth of its diameter. Conical mirrors produce a still more extraordinary distortion of the figures seen in them, than cylindrical ones, from the breadth of the image being gradually reduced as it approaches the apex, where it becomes a mere point.

The effect of a cylindrical mirror in diminishing the breadth of objects facing it, being the same as that of a convex mirror of the same radius, and the effect of the conical mirror, at any given height, being regulated by the same principle, it becomes easy to draw anamorphoses for a cylindrical or conical mirror of any size. The pictures called by this name, and which are sold with mixed mirrors by the opticians, appear very much distorted, but when placed before the mixed mirror for which they are intended, their images are well calculated for ordinary vision.

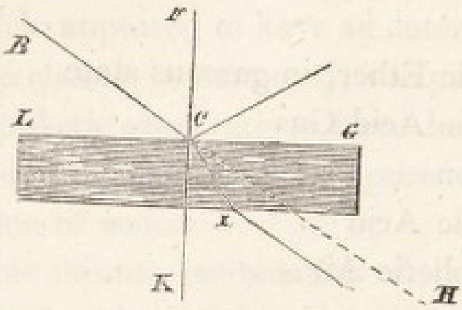
We must not omit to notice some burning mirrors, which were celebrated on account of their size and extraordinary effects. One of these optical machines was the work of Stettala, a canon of Milan; it was parabolic, and, acting as a burning glass, inflamed wood at the distance of fifteen or sixteen paces. Vilette, an artist and optician of Lyons, constructed three, about the year 1670; one of which was

presented to the king of Persia; the second was purchased by the king of Denmark; and the third by the king of France. The one last mentioned was thirty inches in diameter, and of about three feet focus. The rays of the sun were collected by it into the space of about one inch. It immediately set fire to the greenest wood: it fused silver and copper in a few seconds; and in one minute vitrified brick and flint earth. A mirror superior even to these was constructed by Baron Von Tchivnhausen, about 1687; it consisted of a metal plate, twice as thick as the blade of a common knife; it was five feet three inches in breadth, and its focal distance was three feet six inches; it produced the following effects: wood, exposed to its focus, immediately took fire; copper and silver passed into fusion in a few minutes, and slate was transformed into a kind of black glass, which, when laid hold of with a pair of pincers, could be drawn out into filaments. Pumice stone and fragments of crucibles, which had withstood the most violent furnaces, were also vitrified.*

Besides the properties of light to be reflected and transmitted, there are some curious phenomena, arising from the attraction of light. When a ray of light enters any transparent medium, in a direction perpendicular to its surface, the ray will maintain its course in the same direc-

* Burning-mirrors may be constructed of various other materials as well as metal; and when formed of wood and leaf gold, nothing is necessary but to turn a piece of exceedingly dry and very hard wood into the form of the segment of a concave sphere; to cover it in an uniform manner with a mixture of pitch and wax, and then apply bits of gold-leaf, about three or four inches in breadth. Instead of gold leaf, small plane mirrors might be adapted to the concavity, and the effect would be little inferior to that of a mirror made entirely of metal. Father John mentions a mirror made of pasteboard, covered on the inside with straw cemented to it, which was so powerful as to fuse all metals.

tion; but if the ray of light make any angle less than a right angle with the surface of the medium, it will not continue in the same direction, but will be drawn towards a straight line, perpendicular to the same surface, and passing through the medium at the point where the oblique ray enters. The angle which the incident ray makes with the perpendicular, is called the angle of incidence; and the angle which the ray makes with the same perpendicular, after it enters the medium, is called the angle of refraction. In all the degrees of obliquity at which a ray enters any medium, the sine of the angle of incidence has the same ratio to the sine of the angle of refraction.



The ray, in the first instance, descends from B to C, and enters the flat plate of glass, which, giving a new direction, causes it to approach the perpendicular. The original angular path, however, is again resumed on arriving at I, though it will be obvious, that if the glass had not intervened, it would have continued in the direction of B H. If we suppose another ray to fall perpendicularly on a similar plane of glass, as F K on L G, that ray will continue its course without being bent out of its ordinary direction.*

* This principle will explain several of the common phenomena of nature. Mr. Walker observes, that " many a schoolboy has lost his life, by supposing the bottom of a clear river to be within his depth,

Bodies differ very materially in their refractive power, and we may here introduce a table, forming a sufficiently numerous series for illustrating their properties in this respect: the connexion between their combustibility and refractive power will be apparent.

Hydrogen	6.61436
Diamond	3.1961
Olive Oil	2.7684
Alcohol	2.2223
Ammonia	2.16851
Carburetted Hydrogen . .	2.09270
Gum Arabic	1.8826
Water	1 7225
Muriatic Ether, in gaseous state	1.71344
Muriatic Acid Gas . . .	1.19625
Nitrogen	1.03408
Carbonic Acid	1.00476
Atmospheric Air	1.00000
Oxygen	0.86161

as (when he stands on the bank) the bottom will appear one-fourth nearer the surface than it really is." The skilful marksman who shoots a fish in the water with a bullet, takes his aim considerably below the fish as it appears, because it appears much nearer the top of the water than it really is. As the refraction in all cases must depend on the obliquity of the ray, that part of any body which is most immersed, will seem to be most materially altered by the refraction. When, however, the object extends to no great depth in the water, the figure is not materially distorted; but if the object is of a considerable size, or extends to a great depth, those rays which proceed from the more distant extremities come in a more oblique direction on their emergence into the air, and, consequently, they suffer a greater refraction than the rest. Thus, a straight leaden pipe appears near the bottom of a deep water to be curved, and a flat bason seems deeper in the middle than near the sides.

The refraction of light may be thus illustrated, without the aid of

By a reference to the preceding table, it will be found that inflammable bodies refract light much more than those that are not inflammable. Sir Isaac Newton divided transparent bodies into two classes, each of which had the power of refracting light. The first consisted of the inflammable, in which it was much more than according to the ratio of their density.

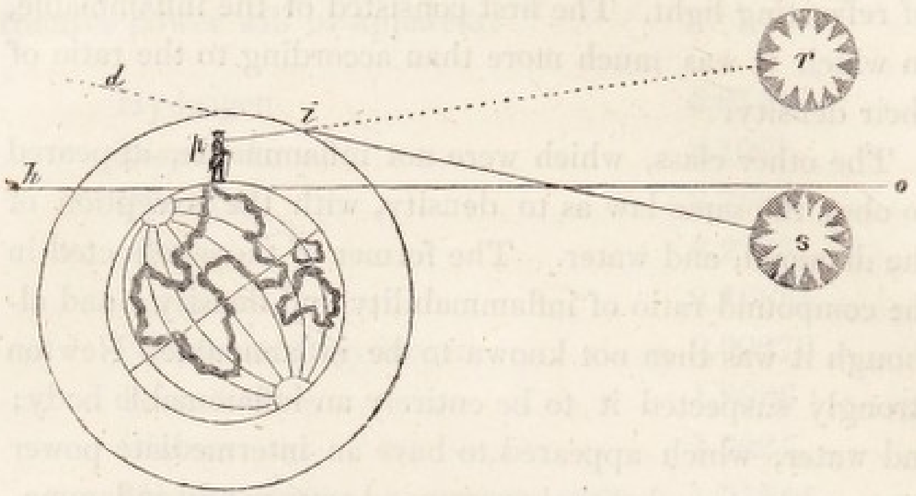
The other class, which were not inflammable, appeared to obey the same law as to density, with the exception of the diamond, and water. The former of these refracted in the compound ratio of inflammability and density; and although it was then not known to be inflammable, Newton strongly suspected it to be entirely an inflammable body; and water, which appeared to have an intermediate power between the two classes, he supposed, was partly inflammable. These prophetic observations have been verified, in the discovery of the diamond being pure carbon, and in the decomposition of water.

Prior to a more minute examination of the nature of atmospheric refraction, it may be advisable to illustrate its effects by a simple figure.

The central circle, representing the earth, is surrounded by a boundary line of air. A person placed at *p*, is viewing the sun, or any other heavenly body at *r*, although it is not really above the plane of the horizon *h o*. This ap-

apparatus. Take an empty bason into a dark room, make a small hole in the window shutter, so that a ray of light may proceed to the bottom at a given point: mark the spot: then, without disturbing the bason, pour water into it, and the ray, instead of proceeding to the point marked, will be bent out of its first direction, and be found at another point nearer the side. In repeating the experiment, if a piece of looking-glass be laid at the bottom of the bason, the light will be reflected from it, and will be observed to suffer the same kind and degree of refraction in going out, as in coming in, only in a contrary direction.

parently paradoxical phenomenon is the result of refraction, for the rays of light are bent out of their course on entering our atmosphere, and, as such, change the apparent position of the body.



The quantity of terrestrial refraction was estimated by Dr. Maskelyne at one-tenth of the distance of the object observed, expressed in degrees of a great circle. Henec, if the distance be 10,000 fathoms, its tenth part, 1000 fathoms, is the 60th part of a degree, or one minute, which, therefore, is the refraction in altitude of the object at that distance. But Le Gendre was induced, by a variety of experiments, to allow only one-fourteenth part of the distance for the refraction in the altitude; so that in the distance of 10,000 fathoms, the 14th part of which is 714 fathoms, he allows only 44″ of terrestrial refraction, so many being contained in 714 fathoms. Again, Delambre makes the quantity of terrestrial refraction to be one-seventh part of the arc of distance. And the English measurers, from many very exact observations, determine the quantity of the medium refraction to be a twelfth part of the said distance. The mean of all these is about .085 of the intercepted arc, which is probably not very far from

the truth: this quantity, however, it must be observed, is found to vary very considerably with the different states of the weather and atmosphere, from one-seventh to one-eighteenth of the contained arc.

Picard found by meridian altitudes of the sun, in 1669, that it was greater in winter than in summer. He found, also, that it was less by day than by night. In the observations given at the end of his journey to Uraniburg, to settle the latitude of that place, and its difference of longitude from Paris, for the purpose of comparing the observations of Tycho Brahe with those made at the Royal Observatory at Paris, he found the horizontal refraction for the first limb of the sun that made its appearance above the horizon there 33′.2″, and for the second 32′.37″. So that in the small interval of time that the sun was in rising, the refraction was diminished twenty-five seconds by the warmth arising from the sun's presence.

It was soon found that the refraction near the pole must be greater than in our climate, the degree of cold being more intense. It was also found to be less in the torrid zone, where the heat is greater than in Europe. Bouguer made a variety of observations at Peru, the result of which he has given us. In 1740, he came down into an island situated in the river of Emeralds, called Isle of Inca, where he determined the refraction from 1_{o} to 7° of altitude; and the table which he afterwards computed, shows the refraction to be about one-seventh less than in Europe. The horizontal refraction he found to be 27′; but at 6° of altitude it is 7′.4″; and at 45°, it is 44″. Bouguer then gives a table for Quito, which is more elevated above the level of the sea. M. le Gentil found it greater at Pondicherry in India, although in the torrid zone.

The most singular of all the phenomena of refraction is,

perhaps, the property of some natural substances, which have a double effect on the light transmitted through them; as if two mediums of different densities freely pervaded each other, the one only acting on some of the rays of light, the other on the remaining portion. These substances are usually crystallized stones, and their refractions have sometimes no further peculiarity; but the rhomboidal crystals of calcareous spar, commonly called *Iceland crystal*, possess the remarkable property of separating such pencils of light, as fall perpendicularly on them, into two parts, one of them only being transmitted in the usual manner, the other being deflected towards the greater angle of the crystal. It appears from the experiments of Huygens, confirmed and extended by Dr. Wollaston, that the medium which causes the unusual refraction, has a different refractive power, according to the direction in which the light passes through it; and that if an oblate or flattened spheroid be described within a circle, its axis being in the middle of one of the obtuse solid angles, and its principal diameters in the proportion of 9 to 10, the refractive power, with respect to light passing in any direction, will always be inversely as the diameter of the spheroid which is parallel to it; and where it is greatest, will be equal to that of the medium which produces the usual refraction, of which the index is *. A ray of light falling perpendicularly on any surface of the spar, its point of incidence being considered as the centre of the spheroid, will meet the surface of the

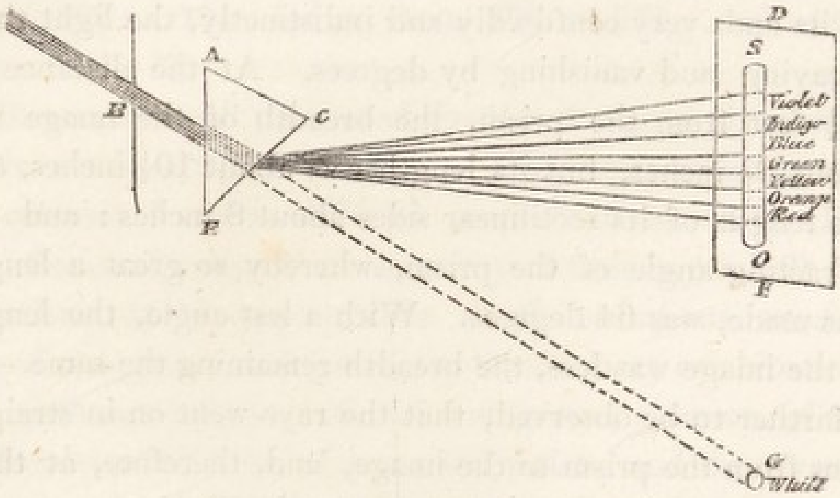
* The means of ascertaining the double refraction of substances are very simple; the following is quoted by M. Soret: "Two plates of tourmaline, cut parallel to the axis of the crystal, and placed crossways, so as to absorb all the light from the apparatus: the substance to be examined is to be placed within the plates; if it is doubly refractive, the light re-appears through the tourmalines; if not, all remains dark."

spheroid at the point where it is parallel to that of the spar; and a ray incident on the same surface in any other direction, will preserve a relation to the perpendicular ray, which is nearly the same as in ordinary refraction.

These phenomena will, however, be more fully examined under the article polarization.

We have hitherto considered the rays of light as perfectly homogeneous; but Newton discovered at a very early period of his investigations, that what we call white light, is, in reality, a compound of various-coloured rays differing in their refractive power. To experimentally illustrate this fact, it is only necessary to throw the ordinary sunbeam on a glass prism, and it will be found, that, instead of proceeding in its ordinary course, the ray will be decomposed, and show a coloured spectrum.

Newton thus describes his mode of performing this experiment, with reference to an engraved figure.



" In a very dark chamber, at a round hole B, about one-third of an inch broad, made in the shut of a window, I placed a glass prism A C E, whereby the beam of the sun's light B G, which came in at that hole, might be refracted

upwards, towards the opposite wall of the chamber, and there form a coloured image of the sun, represented at S O. The axis of the prism (that is, the line passing through the middle of the prism, from one end of it to the other end, parallel to the edge of the refracting angle,) was in this, and the following experiments, perpendicular to the incident rays. About this axis I turned the prism slowly, and saw the refracted light on the wall, or coloured image of the sun, first to descend, and then to ascend. Between the descent and ascent, when the image seemed stationary, I stopped the prism and fixed it in that posture.

"Then I let the refracted light fall perpendicularly upon a sheet of white paper D F, placed at the opposite wall of the chamber, and observed the figure and dimensions of the solar image S O, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel sides, and two semicircular ends. On its sides it was bounded pretty distinctly; but on its ends very confusedly and indistinctly, the light there decaying and vanishing by degrees. At the distance of $18\frac{1}{2}$ feet from the prism, the breadth of the image was about $2\frac{1}{8}$ inches, but its length was about $10\frac{1}{4}$ inches, and the length of its rectilinear sides about 8 inches; and the refracting angle of the prism, whereby so great a length was made, was 64 degrees. With a less angle, the length of the image was less, the breadth remaining the same. It is farther to be observed, that the rays went on in straight lines from the prism to the image, and, therefore, at their going out of the prism, had all that inclination to one another, from which the length of the image proceeded. This image S O was coloured, and the more eminent colours red, orange, yellow, green, blue, indigo, violet, together

with all their intermediate degrees, in a continual succession, perpetually varying."

The philosopher continued his experiments; and by making the rays thus decompounded pass through a second prism, he states, though erroneously, that they did not admit of farther decomposition, and that objects placed in the rays producing one colour, always appeared to be of that colour. He then examined the ratio between the sines of incidence and refraction of these decompounded rays, and found that each of the seven primary colour-making rays, as they may be called, had certain limits within which they were confined. Thus, let the sine of incidence in glass be divided into fifty equal parts; the sine of refraction into air of the least and most refrangible rays, will contain respectively 77 and 78 such parts. The sines of refraction of all the degrees of red will have the intermediate degrees of magnitude, from 77 to $77\frac{1}{3}$; orange from $77\frac{1}{3}$ to $77\frac{1}{2}$; yellow from $77\frac{1}{5}$ to $77\frac{1}{3}$; green from $77\frac{1}{3}$ to $77\frac{1}{2}$; blue from $77\frac{2}{3}$ to $77\frac{1}{2}$; indigo from $77\frac{2}{3}$ to $77\frac{7}{9}$; and violet from $77\frac{1}{2}$ to 78.

From this small number of simple sensations, then, with their combinations, we obtain seven primitive distinctions of colours: but the different proportions in which they may be combined, afford a variety of tints beyond all calculation. If we suppose three simple sensations, consisting of red, green, and violet, the three binary combinations are yellow, consisting of red and green; crimson, of red and violet; and blue, of green and violet; and the seventh in order, is white light, composed by all the three united. But the blue thus produced, by combining the whole of the green and violet rays, is not the blue of the spectrum, for four parts of green and one of violet make a blue, differing

very little from green; while the blue of the spectrum appears to contain as much violet as green: and it is for this reason that red and blue usually make a purple, deriving its hue from the predominance of the violet.

The scientific world is indebted to Mr. Kent for a very curious series of experiments, tending to illustrate the analysis of white light. They go to prove that the solar beam may be reduced into three primary colours. Mr. Kent thus describes his experiments.

I threw the colours of the prism on a screen, eleven feet distant, and having placed the lens between them, and only two inches from the prism, I found the prismatic colours magnified, and in the same order, to the extent of two feet six inches in width, and one foot three inches in depth. In this case, the sun's rays were admitted through a Venetian blind; but when admitted through a hole in a shutter, of five inches by four, the dimension was only two feet by nine inches.

Having placed the lens at the focal distance of two feet three inches from the prism, the figure of the prism was clearly defined, without exhibiting any prismatic colours whatever on the screen.

I placed the lens three feet from the prism, which produced only the figure of the prism, having the violet ray at the bottom, and the yellow above.

When the lens was five feet from the prism, the figure of it was distinctly seen with the prismatic colours reversed.

I placed the lens behind the prism, and threw the sun's rays on it at its focal distance, two feet three inches, when the prismatic colours were increased, both in brilliancy and magnitude, considerably more than in the first experiment.

I put the lens within the focal distance of the screen, when a small figure of the prism was seen very bright, but without any prismatic colour.

Having placed the lens as in the second experiment, when no prismatic rays were produced, but a perfect spectrum of the prism in a strong white light; I then placed another prism in the focus of the lens, and to my surprise it produced three colours only: viz. yellow of a greenish tint, red, and deep violet. Wishing to ascertain if those three colours were neutral, I tried them with a third prism, and found not the slightest alteration; and having placed a card so as to receive them, I found, on giving it a whirling motion, that the colours were entirely lost.*

If by means of two prisms, a small piece of paper be illuminated, the one half with red, and the other half with violet light, and an observer view the same through another prism, the paper will, by the different refrangibility of the rays, appear divided into two. For the violet half being seen by a more refrangible light, will appear to be carried farther from its true place than the red, and will, therefore, seem to be separated from it. The same is likewise true of colours which arise from the separation of light, which is made by bodies on which it falls, and which we are apt to call natural colours; for if a paper be painted, the one half with a lively red, and the other half with an indigo, and it be placed in the sun's light, it will in the same manner appear divided, if viewed through a prism.

From what has been stated, the principal phenomena of colours may, without much difficulty, be explained. If all

* Mr. Kent says, that the prism he used in his experiments, was five inches long, and the side planes one inch broad; the lens being six inches in diameter, with a focus of two feet three inches.

the different-coloured rays which the prism affords are re-united in the focus of a convex lens, the produce will be white; yet these same rays, which, taken together, form white, give, after the point of their re-union, that is, beyond the point where they cross each other, the same colours as those which departed from the prism, but in a reversed order, by the crossing of the rays; the reason of which is clear; for the ray being white before it was divided by the prism, must necessarily become so by the re-union of its parts, which the difference of refrangibility had separated, and this re-union cannot in any manner tend to alter or destroy the nature of the colours; it follows, then, that they must appear again beyond the point of crossing. A similar effect will be produced if the dispersed rays are received from the prism upon a concave reflector. In the focus of the reflector, they will unite and form a white or colourless image of the sun. But it is curious to remark, that if any one of the colours is stopped in its progress to the reflector by the interposition of a wire, or any other slender opake body, then the image in the focus will be an imperfect white, or a mixed colour. Beyond the focus, the rays separate again, as in the case of their passing through a convex lens, and form the coloured spectrum; only the order of the colours, from the crossing of the rays, is inverted.

Having thus, by analysis, shown that white light may be decomposed, or reduced to what may at present be considered as its primary elements, it may now be advisable to show how its re-union may be effected, and we shall thus synthetically illustrate its nature. This is usually accomplished by whirling colours in the proportions already described, painted on a small disc of card, by means of a pin thrust through the centre. The same effect may, however, be more readily produced by painting on the surface of a

board, the various tints being exactly neutralised by actual experiment, and attaching the screen to the axis of a whirling table. If this plan be resorted to, the most vivid tints may be blended, and a perfectly white ground produced.*

It was originally remarked by Newton, and the fact has since been confirmed by the experiments of Dr. Herschel, that the different-coloured rays have not the same illuminating power. The violet rays appear to have the least luminous effect: the indigo more; and the effect increases in the order of the colours, the green being very great; between the green and the yellow the greatest of all; the yellow the same as the green, but the red less than the yellow.

When the solar rays are passed through a convex lens, or reflected from a concave, a very intense heat is produced by the concentration of the rays. Count Rumford has shown, that when the rays of the sun are made to pass through a certain aperture, and fall upon any substance to be heated, while the same area of light is made to pass through a lens, in the focus of which the same quantity of matter is to be heated, they become heated in the same time to the same degree. Nothing is better known, in short, than that the rays of the sun are capable of exciting sensible heat. Newton, and the philosophers of his age, accounted for heat by the motion excited in the parts of the body by the agitating power of the absorbed light. Melville supposed that the heat was expelled from the terrestrial matter by the light. At present, it is generally admitted, on the strength of some valuable experiments to which we have

* If the whole spectrum be divided into 360 equal parts, the red will occupy 45 of them, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80.

already alluded, that the rays of light and caloric are separately emitted from the sun, the luminous rays producing light, and the caloric, heat.

Sir William Herschel introduced a beam of light into a dark room, which was decomposed by a prism, and then exposed a very sensible thermometer to all the rays, in succession, and observed the heights to which it rose in a given time. He thus determined, that the heating power of the red, to that of the green rays, was $2\frac{3}{4}$ to 1; and $3\frac{1}{2}$ to 1, in red to violet.

On repeating these experiments, he found that the greatest quantity of calorific rays were even beyond the coloured spectrum at about half an inch from the commencement of the red rays. At a greater distance from this point, it began to diminish, but was very perceptible even at the distance of $1\frac{1}{2}$ inch.

It will appear, from what has been stated, that these calorific rays are less refrangible than the rays of light; hence the calorific focus will fall beyond that of the luminous. Dr. Herschel made an experiment to verify this inference, but did not come at any thing conclusive. He afterwards made experiments to collect these invisible calorific rays, and caused them to act independently of the light; by which he concludes, that they are sufficient to account for all the effects produced by the solar rays in exciting heat; that they are capable of passing through glass, and of being refracted and reflected, after they have been finally detached from the solar beam.

Dr. Morichini appears to have been the first person to point out the connection between *light and magnetism*. To experimentally illustrate this important fact, he employed a prism, and caused the decomposed rays to fall on a series of small needles, and the needle intersected by the violet ray was soon found to acquire permanent polarity. It has

since been ascertained, that this property is not peculiar to the violet ray, but extends, though in a less degree, through several other rays in the series.

The phenomena arising from *atmospheric refraction* may be best understood by an examination of the apparent alteration in the colours of the heavens.

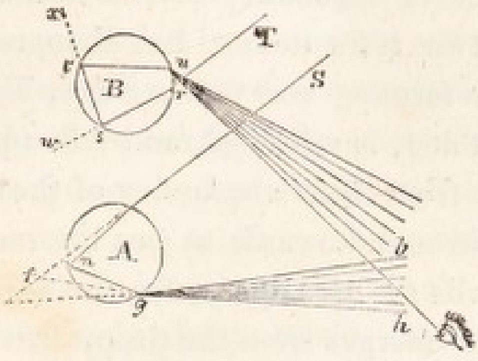
If the light of the setting-sun, by passing through a long tract of air, be divested of a portion of its rays, the remainder which is transmitted, will illuminate the western clouds with an orange colour, and as the sun sets more and more, a greater number are reflected, while the clouds grow more deeply red, till at length the entire disappearance of the sun leaves them of a leaden hue.

When a direct spectrum is thrown on colours darker than itself, it mixes with them; as the yellow spectrum of the setting sun, thrown on the green grass, becomes a greener yellow. But when a direct spectrum is thrown on colours brighter than itself, it becomes instantly changed into the reverse spectrum, which mixes with those brighter colours. So the yellow spectrum of the setting sun thrown on the luminous sky, becomes blue, and changes with the colour or brightness of the clouds on which it appears. But the reverse spectrum mixes with every kind of colour on which it is thrown, whether brighter than itself, or not: thus, the reverse spectrum, obtained by viewing a piece of yellow silk, when thrown on white paper, was a lucid blue-green; when thrown on black Turkey leather, becomes a deep violet: and the spectrum of blue silk, thrown on white paper, was a light yellow; on black silk, was an obscure orange; and the blue spectrum obtained from orange-coloured silk, thrown on yellow, became a green.

Of the natural phenomena produced occasionally by the separation of the primary colours, the *rainbow* is one of the

most beautiful. This meteor, which in poetical language is called the *iris*, never makes its appearance, except when the spectator is situated between the sun and a shower of rain; and that this conclusion is just, any one may satisfy himself by the following experiment: fill a hollow glass globe with water, and suspend it in the sun, in such a manner that it may be raised or lowered at pleasure; at a certain height above the eye of the spectator, who looks at it with his back to the sun, the globe will appear to be red; let it then be slowly lowered, and it will appear to be orange, and afterwards, in succession, as it descends, it will appear yellow, green, blue, indigo, and violet. Hence the same drop of rain, which must be considered as a little globe, supplies all the seven colours to the eye. There are sometimes two rainbows seen at the same time, one within the other, and, what may seem remarkable, the order of the colours of the exterior bow is the reverse of that of the interior one. When two bows are seen, the exterior one is comparatively faint, and it is, therefore, sometimes called the false or secondary bow; while the greater distinctness of the interior one has obtained for it the appellation of the primary bow. To trace the progress of a ray of light through a drop of rain in each of these bows, will explain the cause of their differing in brightness. In the true or primary bow, the rays of light arrive at the spectator's eye after two refractions and one reflection.*

* The rainbow was one of those phenomena which astonished and perplexed the ancients; and, after many absurd and unsuccessful conjectures, their best philosophers, Pliny and Plutarch, relinquished the enquiry as one which was above the reach of human investigation. In the year 1611, Antonio de Dominis made a considerable advance, however, towards the theory of the rainbow, by suspending a glass globe in the sun's light, when he found that, while he stood with his back to the sun, the colours of the rainbow were reflected to his eye



Thus, let A, in the above diagram, be a drop of rain, and S a ray from the sun falling on the upper part of the drop. It will suffer a refraction, and instead of going forward in a right line, it will be bent to *n*; at *n*, part of it will emerge, but the remainder will be reflected to *g*; at *g* it will be again refracted on passing into the air towards the eye at *h*; being thus twice refracted and once reflected, the ray is separated into its primitive colours; the red part, which is least thrown out of its course, makes an angle, at its emergence, with the incident solar ray of forty degrees two minutes, as S *f h*; and the violet, being the most easily thrown out of its course, makes with the solar light an angle of forty degrees seventeen minutes. The different colours, therefore, at the distance of the spectator, are considerably separated, and affect the eye in succession with the seven colours; but the succession is so quick, and so many drops fall through the same circuit in the same time, that the mind loses the idea of succession, and the bow seems permanent as long as the shower continues in a proper direction for the eye.

in succession by the globe, as it was moved higher or lower. He was, however, unable to account for the production of the different colours, as the experiments with the prism had not yet been made, and it was reserved for Newton to perfect the discovery.

The exterior or secondary bow is formed by two reflections and two refractions. Let B represent one of the drops of rain forming this bow; a ray, T, from the sun, falling upon it at *r*, is refracted, and falls upon the back of the drop at *s*; from the transparency of the drop, a portion of it passes through towards *w*, but the remainder of it is reflected towards *t*; here again, for the same reason as before, part of it emerges from the drop, in the direction *x*, but the portion still left is reflected to *u*, where it is refracted towards the spectator, with the red rays uppermost. The great quantity of light lost at each reflection, is the cause of the indistinctness of this bow, and therefore we cannot be surprised that we rarely, if ever, see bows formed by a still greater number of reflections within the drops; for though they may exist, they are too faint to be seen. The secondary bow cannot be seen when the elevation of the sun is above fifty-four degrees seven minutes, and it is broader than the interior bow, because the rays are more dispersed before they reach the eye.

Very beautiful effects resulting from the decomposition of white light are visible on the surface of the feathers of birds, and are also exhibited on the surface of mother-of-pearl, and may readily be imitated on steel, and most transparent bodies. Dr. Brewster, while pursuing a series of experimental investigations on this subject, found, by the aid of the microscope, that they arose from grooves in the striated surface; that they were produced when the flat surface was unpolished, and that they could be communicated to wax, gum-arabic, tinfoil, the fusible metal, and even to lead, by hard pressure, or the blow of a hammer. He determined also, that the mottled colours upon all bodies with an imperfect polish, and the scratches or grooves upon polished metals, could be communicated to wax and other sub-

stances. The same structure which gives these communicable colours, he succeeded in producing artificially on the surface of calves-feet-jelly, that had been boiled a considerable time; and he discovered, with a powerful microscope, the same minute grooves which exist in mother-of-pearl, and they were so near one another, that some thousands of them must have been contained in a single inch. These grooves were completely visible to the unassisted eye, but they gave in a very distinct manner the colours of mother-of-pearl.

Mr. Barton, of the Mint, has succeeded in ornamenting steel and other articles, with the colours of striated surfaces, and of applying this principle to practical purposes.

In applying the principle of striated colours to ornament steel, the effect, or pattern, is produced upon the polished surface by the point of the diamond, so that either the whole or a part of the surface is covered with lines or grooves, whose distance may vary from the 1000th to the 10.000th of an inch. When these lines are most distant, the prismatic images of the candle, or any luminous body, seen by reflection from the polished surface, are nearest one another, and the common colourless image; and when the lines are least distant, the coloured images are farthest from one another, and the colours are most vivid.

In daylight, the colours produced by these minute grooves are scarcely distinguishable, unless at the boundary between a dark and a luminous object. In sharp lights, however, and particularly in that of the sun, the colours shine with extraordinary brilliancy, and the beautiful tints which accompany every luminous image, can only be equalled by their matchless exhibition on the reflections of the diamond.

The colours transmitted by plates of glass containing a

film of air or water, are well worth an attentive examination. The plates of reflection or transmission of the several colours in a series are so near each other, that the colours dilute each other by mixture, whence the number of series in the open daylight seldom exceeds seven or eight: but if the system be viewed through a prism, by which means the rings of various colours are separated, according to their refrangibilities, they may be seen on that side towards which the refraction is made, so numerous, that it is impossible to count them. Or, if in a dark chamber, the sun's light be separated into its original rays by a prism, and a ray of one uncompounded colour be received upon two glasses, the number of circles will become very numerous. In this experiment it is also seen, that in any series, the circles formed by the less refrangible rays exceed in magnitude those which are formed by the more refrangible rays, and, consequently, that in any series, the more refrangible rays are reflected at less thicknesses than those which are less refrangible. If the light be incident obliquely, the rings of colours dilate and enlarge themselves; whence it follows, that the thickness required to reflect the colours of any series is different in different obliquities.

Water, applied to the edges of the glasses, is attracted between them, and filling all the intercedent space, becomes a thin plate similar to the air. In this case, the rings become much fainter, but vary not in their species, and are contracted in diameter nearly in the proportion of 7 to 8; consequently the intervals of the glasses, at like circles, caused by these two mediums, water and air, are as about 3 to 4; that is, nearly as the sines which measure the angles of incidence and refraction, made at a common surface between them. And hence it may be suspected, that if any other medium, more or less dense than water, be

compressed between the two glasses, their intervals at the rings caused thereby, will be to the intervals at which similar rings are caused by the interjacent air, as the sine which measures the refraction made out of air into that medium is to the sine of the incidence on the common surface.

These are some of the phenomena of light incident on mediums which are environed by mediums of greater density, as air or water, compressed or included between plates of glass. The same appearances follow, though with some little variation, when the colorific medium is denser than that in which it is inclosed.

It is well known that bubbles blown in soap-water exhibit a great variety of colours; but as these colours are commonly too much agitated by the external air to admit of any certain observation, it is necessary that the bubble be covered with a clear glass, in which situation the following appearances ensue: the colours emerge from the vertex or top of the bubble, and as it grows thinner by the subsidence of the water, they dilate into circles or rings, parallel to the horizon, which slowly descend and vanish successively at the bottom. This emergence continues till the water at the vertex becomes too thin to reflect the light, at which time a circular spot of an intense blackness appears at the top, which slowly dilates, sometimes to three-quarters of an inch in breadth, before the bubble breaks.

The refraction of light, we have seen, is attributed to a power of attraction appertaining to all bodies, and exerted at a little distance from their surfaces; reflection, on the contrary, is produced by a power of repulsion, and also takes effect before the light actually strikes the reflecting surface. If these attractive and repulsive energies have

any real existence, the rays of light, under certain circumstances, will be bent, in a manner that cannot be classed under either refraction or reflection. Accordingly, we find, that if a ray of light pass very near a body, without impinging upon it, it is bent inwards, or towards the body; this change in the direction of the ray is called inflection:—if the ray pass at a greater distance, it is bent outwards, or from the body:—this change in the direction of the ray is called deflection. When a beam of the sun's light passes through a hole in a window shutter, the image thrown upon a screen or an opposite wall, is larger than it would be if the rays, crossing at the aperture, proceeded in straight lines from the circumference of the sun's disk to the wall. It becomes, therefore, an object of enquiry, to determine the cause by which it has been expanded; and we find on close examination, that the side of the aperture has inflected, or caused it to diverge from the axis of the beam, the rays which have passed near it all around. *Inflection* was first discovered by Grimaldi, who made many curious experiments and observations relative to it; but the following experiments of Sir Isaac Newton will be better adapted than Grimaldi's to explain the nature of this property of light. At the distance of two or three feet from the window of a darkened room, in which there was a hole three-fourths of an inch broad, to admit the light, he placed a black sheet of pasteboard, having in the middle a hole about a quarter of an inch square, and behind the hole the blade of a sharp knife, to intercept a small part of the light which would otherwise have passed through the hole. The planes of the pasteboard and blade were parallel to each other, and when the pasteboard was removed to such a distance from the window, that all the light coming into the room must pass through this hole in the pasteboard, he received what

came through the hole on a piece of paper, two or three feet beyond the knife, and perceived two streams of faint light shooting out both ways, from the beam of light into the shadow. As the brightness of the direct rays obscured the fainter light, by making a hole in his paper he let them pass through, and had thus an opportunity of attending closely to the two streams, which were nearly equal in length, breadth, and quantity of light. That part which was nearest to the sun's direct light, was pretty strong for the space of about a quarter of an inch, decreasing gradually till it became imperceptible; and at the edge of the knife it subtended an angle of about twelve, or at most of fourteen degrees. Another knife was then placed opposite to the former, and he observed, that when the distance of their edges was about the four-hundredth part of an inch, the stream divided in the middle, and left a shadow between the two parts, which was so dark that all the light passing between the knives seemed to be bent to each other; this shadow grew broader, till upon the contact of the knives the whole light disappeared. He observed, also, fringes of different-coloured light, three made on one side by the edge of one knife, and three on the other side by the edge of the other. Grimaldi, Dr. Hooke, and all the philosophers who made experiments on inflection before the time of Newton, ascribed the broad shadows, and even the fringes which he mentions, to the ordinary refraction of the air; but the investigation upon which he entered to discover their cause, afforded him satisfactory evidence to conclude that bodies have the power of acting upon light at a distance.

We must now briefly notice the experiments of Mr. Brougham on this interesting subject: they are detailed in the Transactions of the Royal Society for 1796. He com-

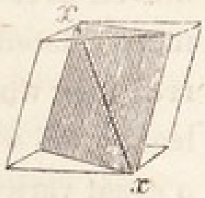
menced by admitting a beam from the sun into a darkened room, through a hole in a metal plate (fixed in the window shutter) of $\frac{1}{40}$th of an inch in diameter; and all other light being absorbed by black cloth hung before the window in the room, at the hole he placed a prism of glass, whose refracting angle was 45°, and which was covered all over with black paper, except a small part on each side, which was free from impurities, and through which the light was refracted, so as to form a distinct and homogeneous spectrum on a sheet of paper, at six feet from the window. In the rays, at two feet from the prism, he placed a black unpolished pin, one-tenth of an inch in diameter, parallel to the paper, in a vertical position, its shadow was formed in the spectrum on the paper, and had a considerable penumbra, especially in the brightest red. It varied very materially in its width; in the violet, it was broadest and most distinct; in the red, it was narrowest and most confused; and in the intermediate colours, it was of an intermediate degree of distinctness. It was not bounded by straight, but by curvilinear sides, which were concave outwardly. This figure of the shadow was not owing to any irregularity in the pin, for the same thing happened with all sorts of bodies that were used; and also, if the prism was caused to revolve on its axis, so that the colours might ascend and descend on these bodies, still, wherever the red fell, it made the least, and the violet the greatest shadow. In the next place, he fixed a screen, having in it a large hole, on which was a brass plate, pierced with a small hole of $\frac{1}{42}$ of an inch in diameter; then causing an assistant to move the prism slowly on its axis, he observed the round image made by the different rays passing through the hole to the paper; that made by the red was greatest; by the violet, least; and by the intermediate rays of an intermediate

size. When he employed the sharp blade of a knife, so as to produce the fringes mentioned by Grimaldi and Newton, those fringes in the red were broadest, and most moved inwards to the shadow, and most dilated when the knife was moved over the hole; and the hole itself on the paper was more dilated during the motion, when illuminated by the red, than when illuminated by any of the other rays, and least of all when illuminated by the violet. From these, and a great variety of other experiments, well devised, and often repeated with the greatest care, he infers, that the rays of light are separable into their primitive colours, by inflection, deflection, and reflection, as well as by refraction; that these properties of the rays are inversely as their refrangibilities; that is, those which deviate the least by refraction, deviate the most by flection, and are reflected the farthest from the perpendicular; and that these different phenomena are all produced by the differences in the magnitude of the particles. He calculates that the size of the red particles are to those of the violet as 1275 to 1253. This he extends to all the other colours by similar calculations, their sizes lying between 1275 and 1253; which are the extreme red, and extreme violet; the red, therefore, according to this hypothesis, is from 1275 to 1272½; the orange from 1272½ to 1270; the yellow from 1270 to 1267; the green from 1267 to 1264; the blue from 1264 to 1260; the indigo from 1260 to 1258; and the violet from 1258 to 1253.

The *polarization* of light is an important part of the science of optics. It has been usual to commence this subject by considering the well-known phenomenon of double refraction, which is exhibited by all crystals, the primitive form of which is neither the cube nor regular hexahedron. Of all known bodies, the Iceland spar, or rhom-

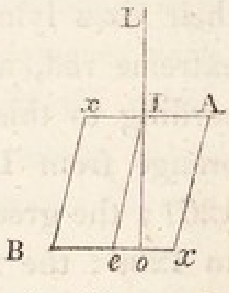
boidal carbonate of lime, shows the fact with the greatest certainty; and as it is a mineral easily procured, and of sufficient size and transparency, it has been generally made use of for this purpose. The crystals of this substance have the form of a rhomboid, having six acute solid angles, and two obtuse. These last, x and x, fig. 1, are formed by the junction of three equal plane angles, which are equally inclined to each other. The line x, x, joining these two angles, is, therefore, similarly situated with respect to the three planes forming each angle, and is called the *axis of the crystal.* A plane, perpendicular to the natural surface of the crystal, and coinciding with this line, is called its *principal section*, which term is also applied to any plane parallel to this section.

Fig. 1.



It is well known, that an object seen through the crystal in its natural form (that form to which it is easily brought by cleavage,) will give two images, one of which will appear in its situation according to the common law of refraction, while the other will be observed thrown towards the lower obtuse angle, but always in the plane of the principal section. (The most convenient method to examine these facts, is to pierce a small hole through any opaque plate, which may be applied to the lower surface of the crystal, and directed to a sheet of white paper.) Let x A, x B, fig. 2, be the principal section of the crystal, and L a pencil of light falling on its surface: one part of the light will proceed in the ordinary direction, (we will suppose perpendicularly,) and is, therefore, called the ordinary ray, while the other portion of the light deviates considerably from this direction, and is called the extraordinary ray.

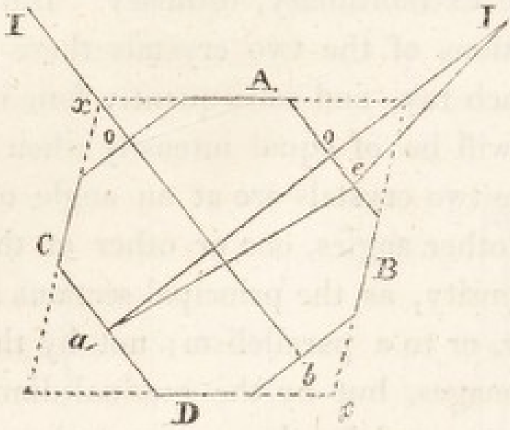
Fig. 2.



In fig. 2. I *o* will represent the ordinary, and I *e* the extraordinary ray.

Let the crystal be cut by two planes A B, and C D, fig. 3. parallel to the axis, and two other planes A C, and D B, perpendicular to the axis, to allow an object to be seen through it in the direction A C, or A B, it will be found that the two images will be farther separated, viewed

Fig. 3.



in the direction A C, which is perpendicular to the axis, while in the direction of the axis there will be only one image. The inference from these experiments is, that there exists some peculiar force acting on the light passing through the crystal, producing a separation of the rays, and that this force emanates from the axis itself. As this produces a deviation of the second image towards, or from, the axis of the crystal, it is considered as positive or negative, or according to Biot, attractive or repulsive.

The two rays into which a pencil of light is divided in passing through a crystal of Iceland spar, are always of the same intensity, and always in the plane of the principal section. But the two emerging rays are not only diminished in intensity by the division of the light between them, but have undergone a most important modification.

If the rays be made to pass through another crystal, placed similarly to the first, there will be no subdivision of the light; the two images will be merely separated to a greater distance, from the increased thickness through which the light passes. If now the two crystals are so placed, that the principal sections are at right angles to each other, there will still be only two images, but the ray ordinarily refracted in the first, will become extraordinary in the second, and the extraordinary, ordinary. But at all intermediate positions of the two crystals there will be a subdivision of each ray, and consequently four images: these four images will be of equal intensity when the principal sections of the two crystals are at an angle of 45° to each other; at all other angles, one or other of the images diminish in intensity, as the principal sections approach to a perpendicular, or to a parallelism; not by the coalescence of the two images, but by the gradual diminution of the intensity of one, and by the augmentation of that of the other. In the three diagrams, fig. 4, 5, and 6, we have supposed the rhomboids reduced to the form of cubes: in each the axis is denoted by x x, the direction of the rays by the lines passing through the figure, and the extraordinary and ordinary rays by the letters *e* and *o*. It is thus seen that each emerging ray is only subject to a farther division, in particular positions of the second crystal; whereas natural light is always divided into two portions of equal intensity. Each ray suffers a physical change; it is not acted on by the force of the second crystal, as natural light would be, but requires that the force be applied in a particular direction relatively to the modification it has received from the first crystal. This has been called polarization. We know nothing of the poles, nor of the molecules to which these poles are said to belong; polarization

must be considered merely as a conventional term to express a phenomenon; and to avoid the repetition of the conditions producing it, it is usual to consider the poles of the ordinary ray as coinciding with the principal section of the crystal, and those of the extraordinary ray with a plane perpendicular to it.

Fig. 4.

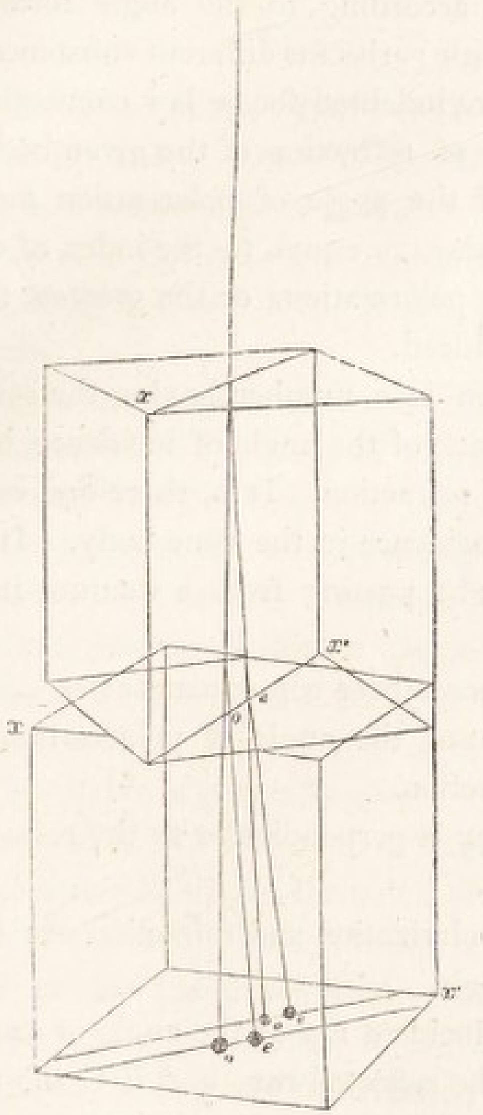


Fig. 5.

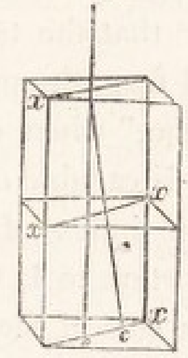
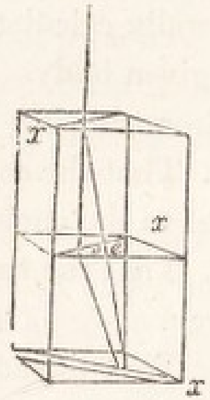


Fig. 6.



In these experiments an effect is produced on the two rays, by their passing through a crystal, which so modifies them, that it requires the action of a second crystal to be

exerted in two directions, at right angles to each other, to produce a similar effect. As direct light is always divided into two rays of equal intensity by a double refracting crystal, it may be used as a test to discover and ascertain the direction of polarization.

When light is reflected from the surface of transparent bodies, it is found to be polarized in the plane of reflection, more or less completely, according to the angle formed with the surface. This angle varies for different substances, and to Dr. Brewster we are indebted for a law connecting the angle with the index of refraction of the given body, viz. "that the tangent of the angle of polarization measured from the perpendicular, is equal to the index of refraction," when complete polarization, or the greatest the body is capable of, is produced.

The index of refraction is a number having the same proportion to 1, that the sine of the angle of incidence has to the sine of the angle of refraction. It is, therefore, constant for all angles of incidence in the same body. It is generally calculated for light passing from a vacuum into the given body.

From this law are deduced three consequences:—

1. That the complement of the angle of polarization is equal to the angle of refraction.

2. That the reflected ray is perpendicular to the refracted ray.

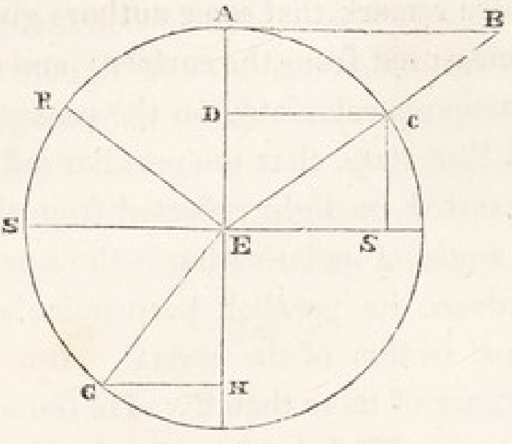
3. That the angles of polarization and refraction are together equal to a right angle.

Let C E, fig. 7. be the incident ray at the angle of complete polarization, R E the reflected ray, and E G the refracted ray.

The sine D C : sine G H : : index : 1

But index=tangent A B; and radius A E=1

Fig. 7.



As A B : A E : : D C : G H

A B : D E : : D C : D E ∴ G H=D E=C S, and the angle C E S=angle G E H.

2dly, H E S is a right angle, from which is taken G E H; but as G E H=C E S=R E S. R E S+G E S=a right angle.

This law gives an easy method to determine the angle of polarization of any body of which the index of refraction is known. Look in a table of tangents for the given index as a tangent, and the corresponding angle will be the angle of polarization. If such a table be not at hand, let S S be the surface, and A E drawn perpendicularly: from a scale make A B=index, A E being 1. Join B E, and the angle A E B will be the required angle.

The index is generally given, for light passing from a vacuum; if it be required to determine the index under other circumstances, divide the index of the given body by the index of the medium from which it passes, and the quotient will be the index required. In bodies, the opacity of which prevents the direct measurement of the angle of refraction, the angle of polarization gives the index of refraction, if this law be rigorous, which it appears to be, for all bodies which have been yet examined; though M. Fresnel seems to think that it is rather an approximation.

We may here remark that some authors give the angle of polarization measured from the surface: and sometimes the index of refraction is calculated on the passage from air.

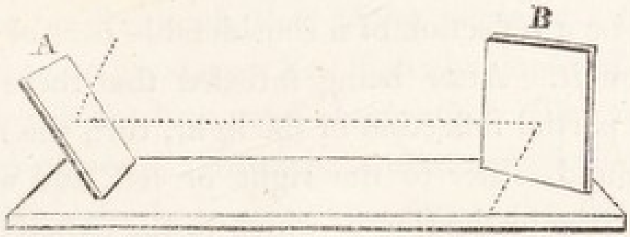
Malus and Biot state, that the peculiar influence of crystals is not exerted on light reflected from their surfaces; and that the angle of polarization is the same whether the plane of incidence be parallel, perpendicular, or oblique, to the principal section of the crystal. But Dr. Brewster found a difference of more than 2°. He found the angle of polarization to be 57° 14′. when the incidence was in the plane of the principal section, and 59° 32′ when in a plane perpendicular to it. The surface was that produced by a careful cleavage of the crystal.

One of the first laws of optics is, that "light falling on a plane mirror is reflected at an angle equal to the angle of incidence;" but if this mirror be transparent, the light so reflected is found to have received a polarity in the plane of reflection, more or less complete as the angle of incidence approaches the angle of polarization for the substance employed. In fact there is some trace of polarization discernible in light reflected from every body, at every angle of incidence except the perpendicular; but this in so feeble a degree, that we may consider it, at present, insensible, except from transparent bodies.

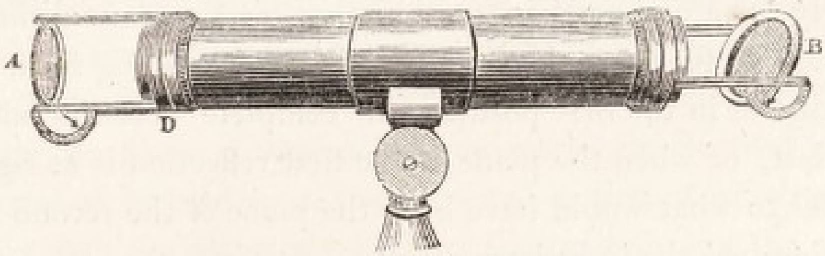
We have already explained that there are, for some bodies, certain angles, at which complete polarization takes place; in some others, though very transparent, yet of high refractive power, complete polarization does not take place at any angle, as in the diamond; in others, as black marble, ebony, black varnishes, &c. in which the refractive density is less, complete polarization takes place, though they be opaque. This angle for water is 52° 45′ from the perpendicular, and for glass about 55°.

In our explanation we may have recourse to an instrument, which, though not indispensable, will be found useful in many experiments where accuracy is required. But for the satisfaction of any one as to the general facts, two pieces of unsilvered mirror glass are all that will be essential, as in the annexed figure. The reflected ray is seen to

Fig. 8.



descend upon the plate A, which would have been polarized if the angles had been 35°, and consequently not reflected. But partial polarization is produced by the plate B.



The above instrument hardly requires description. It consists of a tube having a frame at each end, holding reflectors, A and B, which are capable of being adjusted to any angle with the axis of the tube, and of being turned round the tube, so that the planes of reflection may be at any angle to each other. Suppose the two mirrors (of unsilvered glass) inclined on their axis to the polarizing angle 55° to the incident ray, remove the mirror B, and make a ray of natural light, passing through the axis of the tube,

fall on the mirror A, it will be found that the light will be reflected equally in whatever direction the mirror is turned by the ring D, whether upwards or downwards, to the right or to the left. Let now the mirror B be replaced, and the apparatus so placed that the light reflected from it fall on the other mirror A; if the plane of reflection of the two mirrors coincide, that is, if the plane of each reflection is towards the same direction, to an eye placed opposite A, there will be a reflection of a considerable part of the light incident on it. After being satisfied that there is in this position a partial reflection of the light, turn the ring D a quarter round either to the right or left, and with it the mirror A, (the inclination of which to the axis remains the same,) and on looking on the mirror there will be now found a total obscuration, that is, no light will be reflected, the whole passing through the glass. To be satisfied that this does not take place from any accidental derangement of the instrument, it is only necessary to turn the mirror slowly from one position to the other, and a gradual diminution of the intensity will be observed, passing from its maximum in the first position, to complete obscuration in the last, or when the plane of the first reflection is at right angles to what would have been the plane of the second reflection had the light been direct.

A farther proof that this is no deception, is afforded by substituting a metallic reflector in the place of the mirror B; in which case, no such alteration takes place.

To return to the experiments. Continue to turn the mirror A gradually in the same direction, so that the reflection is again parallel to the first, but in an opposite direction, and the light will be again at a maximum; and if the mirror be still turned in the same direction until it has

made three-fourths of a revolution, the light reflected will again be reduced to nothing.

In this experiment we see that light, having been reflected from a surface at a certain angle, is entirely transmitted by another mirror, if the plane of incidence on the second mirror is perpendicular to the plane of incidence on the first, while natural light would have been equally reflected in every position.

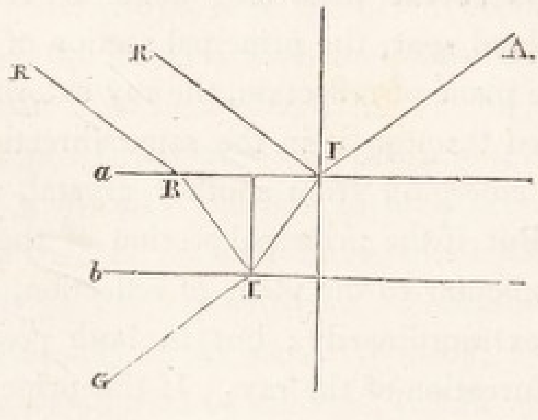
It must be observed, that if the angle of reflection of either mirror be greater or less than the angle of polarization, there will not be a total obscuration. The angle made by the two planes of reflection, is often called the azimuth. To succeed perfectly in this experiment, the back of each mirror should be blackened, to prevent the admission of extraneous light. It will now be not difficult to show, that the direction of polarity in the reflected light is, to the plane of reflection, similar to the polarity of the ordinary ray in Iceland spar, to its principal section, or an identity of the modification produced in the reflected ray, and the modification produced by the action of the crystal on the ray ordinarily refracted; for, if the ray reflected from water or glass at the polarizing angle be received on a crystal of Iceland spar, the principal section of which coincides with the plane of reflection, the ray entering the crystal will proceed through it in the same direction that the ordinary ray, emerging from another crystal, would have proceeded. But if the principal section of the crystal be placed perpendicular to the plane of reflection, the ray will be refracted extraordinarily; but in both positions there will be no bifurcation of the ray. If the principal section of the crystal be any otherwise situated, as to the plane of reflection, there will be two rays, but of equal intensity,

when the angle contained between these two planes be 45°. If, again, the ordinary ray emerging from a crystal be made to fall at the proper angle, on the surface of water, or any other reflecting surface capable of polarizing light completely, it will be reflected when the principal section and plane of reflection coincide, but entirely transmitted when the planes are perpendicular to each other. But if the extraordinary ray fall on the surface, the reflection will take place when the planes are at right angles, and a total transmission will result when the planes coincide.

We are therefore justified in assuming that the physical change the light has suffered, is the same in the two cases. That whether an ordinary ray be examined by subsequent reflection, or the reflected ray by a doubly refracting crystal, the inference is, that the polarity of each is in the same direction: the one in the plane of the principal section, and the other in the plane of reflection.

Light is not only reflected from the first surface of transparent bodies, but another portion is reflected from the second surface. We will suppose these two surfaces parallel,

Fig. 9.



and it will not be difficult to see, that if the light be com petely polarized by reflection from the first surface *a*, the

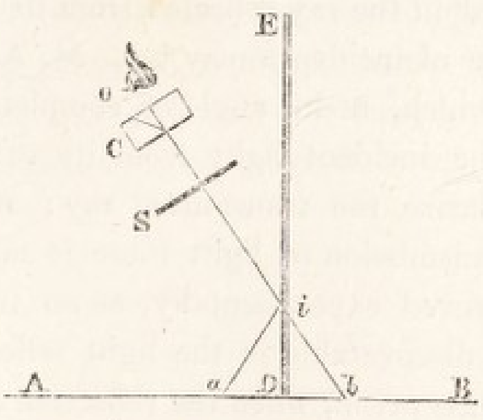
portion reflected from the second surface *b* will also be completely polarized, and in the same plane.

Let A I be the incident ray, and I R the reflected polar ray ; I I, the refracted ray, partially reflected and afterwards refracted to R′ and I′ G, the remaining refracted light will be perpendicular to I′ R′, the reflected ray, a condition we have seen before producing complete polarization.

From various experiments it has been proved, that the quantity of light reflected even from the two surfaces of a transparent body, is small in proportion to the incident light ; and it is now convenient to inquire the condition of the refracted portion, under circumstances in which polarization of the reflected light is produced. If the ray I G be examined by a rhomboid, it will be found divided into two rays, but not of equal intensity ; for the ordinary or extraordinary ray will be found the most intense, as the section of the crystal is parallel or perpendicular to the plane of refraction. This condition of light is called partial polarization, and is the same as the state of reflected light when the incidence is not such as to produce complete polarization.

M. Arago gives the following experiments :

Fig. 10.



Let us suppose a plate of glass, E D, placed perpendicu-

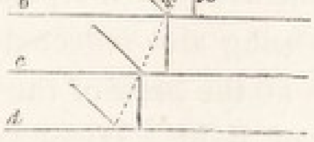
larly on a sheet of fine white paper A B, the eye placed at O will see at the same time the reflected ray *a*, *i*, *o*, and the refracted ray *b*, *i*, *o*. Interpose an opaque plate perforated with a small hole S; let the eye at O be furnished with a doubly refracting crystal C: if by a black screen placed between *b* and *i*, we stop the ray *b i*, which would have been transmitted by the glass plate, the hole in the plate S is illuminated by the reflected light alone; and if the principal section of the crystal coincide with the plane of reflection, we see two images of the pole, of which the ordinary is the most brilliant. If the screen be now so placed as to intercept the reflected ray *a*, *i*, *o*, there will be still two images, but now the extraordinary will be the most brilliant.

Now, if the screen be entirely removed, allowing both reflected and refracted light to reach the crystal, the intensity of the two images is found by actual experiment to be exactly equal. It is hence to be inferred, that the plane which contains the poles of light, polarized by transmission, is perpendicular to the plane which contains poles of light polarized by reflection; and that the quantity of polarized light, contained in the ray transmitted by a transparent plate, is exactly equal to the quantity of polarized light contained in the ray reflected from its surface, whatever the angle of incidence may be. M. Arago observes, that a body which, at its angle of complete polarization, reflects half the incident light from its surface, will also completely polarize the transmitted ray; and that when there is no transmission of light there is no polarization. This seems proved experimentally, as no trace of partial polarization is discoverable in the light reflected from the interior of a glass prism, when the reflection is total.

As transparent substances reflect but a small portion of

the incident rays, the quantity of polarized light in the transmitted rays is small in proportion to the light which has not undergone that modification. Dr. Brewster considers the transmitted ray as consisting of one portion completely polarized in a plane at right angles to the plane of incidence, and another portion of light "which has suffered a physical change more or less approaching to complete polarization." Light having passed through a pile of plates, is at last polarized in a plane perpendicular to the plane of polarization of the reflected light. "This effect requires the agency of twenty-four plates at an incidence of 61°; consequently," says Dr. Brewster, "twelve plates will not polarize the whole pencil at that angle. Let us now suppose that the quantity not polarized amounts to twenty out of a hundred, then if these twenty were absolutely unpolarized, and in the same state as direct light, they would require to pass through twenty-four plates in order to be completely polarized. But experiments prove that they require to pass only through twelve other plates to be completely polarized; it therefore follows, that the twenty rays have been half polarized by the first twelve plates, and the polarization completed by the other twelve."

This reasoning may be good, but as Malus, Biot, and Arago, consider this partially polarized light to consist of light completely polarized, and light in the state of direct or natural light, and as this view of the question admits of a ready explanation, we shall adopt it.



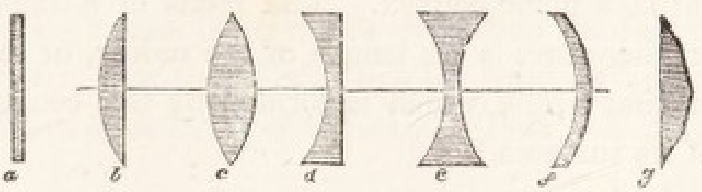
Let *a*, *b*, *c*, *d*, be supposed to represent the successive plates through which the incident ray 1000 is to pass, and at a given angle, 50 out of the 100 be completely polarized by reflection, and a similar quantity of rays by refraction; the light emerging from the first lamina will consist of 900 in the state of direct light, and 50 of light polarized in a plane perpendicular to the plane of incidence. We have already seen that light polarized in one plane, will not be reflected in a plane perpendicular to its plane of polarization, and consequently the portion 50 of transmitted light will escape reflection from the lamina *b*, and therefore the light reflected from *b*, which we have supposed $\frac{1}{20}$th of the incident light, must be taken from the 900 of direct light. In this manner we may suppose the quantity of direct light constantly diminished, and the polarized light increased by each succeeding transmission. According to this view, complete polarization could never be produced, but the quantity of direct light, after a few transmissions, would be absolutely imperceptible.

It cannot be necessary to explain the result of submitting the ray emerging from a succession of plates to another pile of plates, to a doubly refractive crystal, or to a reflection from a polarizing surface. In all these cases its polarization relatively to the plane of incidence on the first surface is precisely similar to the extraordinary ray transmitted by a crystal, relatively to its principal section.

We will, however, mention one consequence of the foregoing laws; that polarized light falling on the first surface of a pile of plates, will be partially reflected when the plane of incidence coincides with the plane of polarization; and a farther portion being also reflected at each successive plate, an eye placed at the back of the plates will receive no sensible quantity of light. If, on the contrary, the

plane of polarization be perpendicular to the plane of incidence, the whole light will be transmitted. It therefore follows, that an apparatus may be constructed of the most transparent plates of glass, in two piles or bundles, forming a system perfectly transparent in one position of the piles, yet perfectly opaque in another. This effect is only to be produced by a great number of plates of glass, if the incidence be near the perpendicular; yet some substances possess this property of polarizing transmitted light, whatever the incidence. A thin plate of tourmaline cut parallel to the axis of the crystal, completely polarizes the light at any incidence in a plane perpendicular to the axis; and a second plate will transmit or stop all the rays, as the axis of the two plates are parallel or perpendicular to each other.

A *lens* is a transparent body of a different density from the surrounding medium, commonly of glass, and used by opticians to collect or disperse the rays of light. They are in general either convex, that is, thicker in the middle than at the edges, which collect, and by the force of refraction, converge the rays, and consequently magnify; or concave, that is, thinner in the middle than at the edges, which, by the refraction, disperse the rays of light, and diminish the objects that are seen through them.



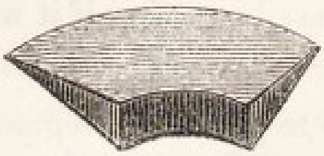
A plano-convex lens is represented at *b*, while *c* is a double convex: *d*, a plano-concave; *e*, a double concave; *f*, the meniscus formed lens; and *g*, a lens ground with a series of flat surfaces, usually employed to multiply or encrease the apparent number of objects. The plane plate of

glass at *a*, is merely employed to show the difference between a lens and a mere transparent medium which does not produce any peculiar optical effects.

The principal focus, or focus of parallel rays, in convex lenses, is readily ascertained upon mathematical principles. It may, however, be found with sufficient accuracy for common purposes, by holding a sheet of paper behind the glass, when exposed to the rays of the sun, and observing when the luminous spot is smallest, and when the paper begins to burn. Or when the focal length does not exceed three feet, it may be found by holding the glass at such a distance from the wall opposite a window sash, as that the sash may appear distinct upon the wall. It will be observed, that in a double convex lens, the rays of light are twice refracted: first, on entering the convex surface of the dense medium, the glass; and secondly, on going out of the same dense medium, and entering the rare medium, or the air, which, from the form of the glass, we know, must present a concave surface. Now, rays are equally converged by entering a convex surface of a dense medium, and a concave surface of a rarer medium. The focus of a double convex lens, then, is at only half the distance of the focus of one which has only one convex surface, that is, a plano-convex. The focus of a double convex lens, therefore, is the length of the radius, or semi-diameter of that circle, which is formed by the convexity of either of its surfaces.*

* To acquire a practical acquaintance with the laws of refraction and the properties of lenses, the student should make experiments with lenses of different foci, diameters, and colours. The room should be darkened, and the sun's rays admitted through an aperture cut in the shutter. The lenses should be fitted into cells connected with a sliding board, or adapted to convenient frames. By these means the lenses may be combined in any required way. It would be proper,

Owing to the great difficulty that arises in the casting and grinding the ordinary lens, when of large dimensions, it has been proposed by Dr. Brewster to construct them of a series of zones, or rings, as is shown in the section beneath, accompanied by one of the segments.



By this combination of segments, a lens of large size may be formed, and will obviously possess the same properties as if it consisted of solid glass. The advantages of this construction may be very shortly enumerated. The difficulty of procuring a mass of flint glass, proper for a solid lens, is in this construction completely removed. If impurities exist in the glass of any of the spherical segments, or if an accident happens to any of them, it can be easily replaced at a very trifling expense. Hence, the spherical segments may be made of glass much more pure and free from flaws and veins, than the corresponding portions of a solid lens.

From the spherical aberration of a convex lens, the focus of the outer portion is nearer the lens than the focus of the central parts, and, therefore, the solar light is not concentrated in the same point of the axis.* This evil may, in a

also, to have lenses ground to the figure of a meniscus, or watch-glass, and fitted up so that two or more of them might be connected in one frame, so as to include fluids between them, and thus exemplify the refractive powers of fluid lenses. The dust usually in motion will, in the darkened room, give the various and natural figures of the converging and diverging rays with tolerable accuracy.

* The axis of a lens is a line supposed to be drawn through the

great measure, be removed in the present construction, by placing the different zones in such a manner that their foci may coincide.

A lens of this construction may be formed by degrees, according to the convenience and means of the artist. One zone, or even one segment, may be added after another, and, at every step, the instrument may be used as if it were complete.

If it should be thought advisable to grind the segments separately, or two by two, a much smaller tool will be necessary, than if they formed one continuous lens. But, if it should be reckoned more accurate to grind each zone by itself, then the various segments may be easily held together by a firm cement. Each zone may have a different focal length, and may, therefore, be placed at different distances from the focal point, if it is thought proper.

From what we have seen of the nature of refraction and reflection, it will be evident that a burning lens must be convex, a burning mirror, concave; because both produce their effect by concentrating into a very small compass the rays of light and heat incident upon a large surface. As the rays which pass through a convex lens, or are reflected from a concave mirror, are united at its focus, their effect is so much the greater, as the surface of the lens or mirror exceeds that of the focus. Thus, if a lens four inches broad collect the sun's rays into a focus at the distance of one foot, the image will not be more than one-tenth of an inch broad. The surface of this little circle is 1600 times less than the surface of the lens, and, conse-

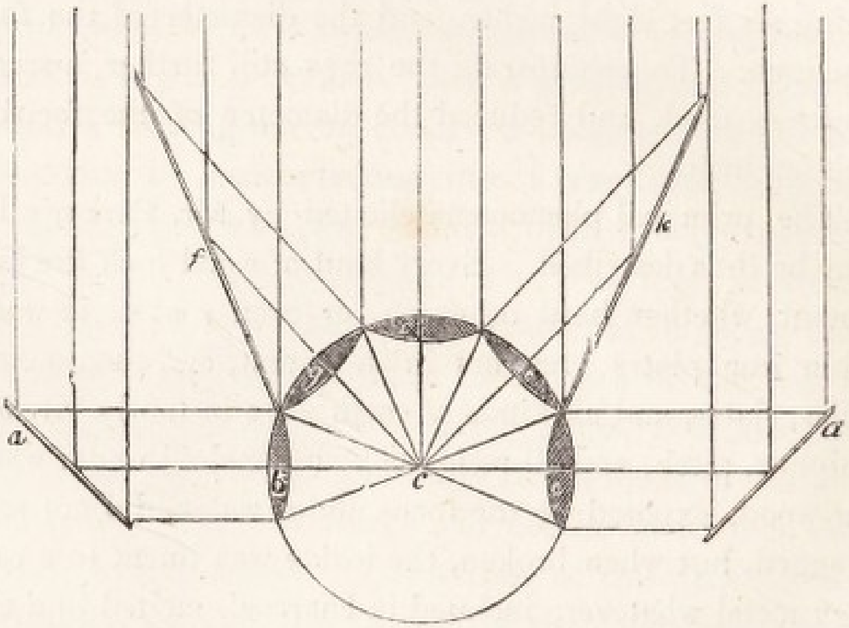
centre of its spherical surface, or surfaces. When one side of the lens is plane, the axis of course falls perpendicularly upon that side. The axis of a lens continued, would pass exactly through the centre of that sphere, of which the lens is the segment.

quently, the density of the sun's rays within it is proportionately increased. It is not, therefore, surprising, that large lenses and mirrors burn with irresistible intensity. The most remarkable burning lens which has ever been constructed, was made by Mr. Parker, at an expense of upwards of £700. It was undertaken with a view to fuse and vitrify such substances as resist the fire of an ordinary furnace; and more especially of applying heat in vacuo, and under other circumstances in which it cannot be applied by any other means. His lens was of flint glass, three feet in diameter, and when fixed in its frame, exposed a surface of two feet eight inches and a half in diameter, without any other material imperfection besides a disfigurement of one of the edges, occasioned by a piece of scoria, which had found its way into its substance. Its weight was two hundred and twelve pounds; the focal length being six feet eight inches, and the diameter of the focus one inch. To concentrate the rays still further, a second lens was used, and reduced the diameter of the focus to half an inch.

The principal phenomena elicited by Mr. Parker's lens may be thus described. Every kind of wood took fire in an instant, whether hard or green, or even soaked in water. Thin iron plates grew hot in an instant, and then melted. Tiles, slates, and all kinds of earth were instantly vitrified. Sulphur, pitch, and all resinous bodies melted under water. Fir-wood, exposed to the focus under water, did not seem changed, but when broken, the inside was burnt to a coal. Any metal whatever, inclosed in charcoal, melted in a moment, the fire sparkling like that of a forge. The substances most difficult to be operated upon, were those of a white colour. When copper was melted, and thrown quickly into cold water, it produced so violent a shock as

to break the strongest earthen vessels, and the copper was entirely dissipated. Though the heat of the focus was so intense as to melt gold in a few seconds, yet there was so little heat at a short distance from the focus, that the finger might be placed about an inch from it without injury. Mr. Parker had the curiosity to try what the sensation was at the focus, and having put his finger there for that purpose, he described the sensation, not as resembling that produced by a fire or lighted candle, but like that of a sharp cut with a lancet.

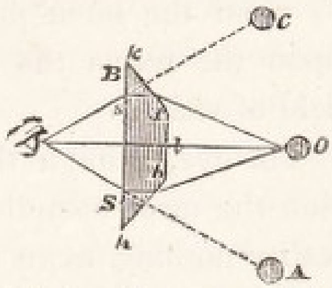
Dr. Brewster has materially simplified the construction of the burning lens, and by combining reflection with refraction, he has suggested an arrangement unlimited in its power of action. Dr. B's *burning sphere* may be best understood by reference to the section beneath.



The lenses, of which sections are given, are so combined with the reflectors, as to form an entire circle with a common focus at *c*. The whole spherical surface, of which only a section is here represented, may be composed of

lenses; each of which, with the exception of the central lens, is furnished with a plane mirror, as at *a a k f*. When this sphere is employed, it must be so placed, that the sun's rays fall at right angles upon the central lens, and they will be concentrated at *c*. The next lens is furnished with a large portion of the sun's rays by the reflector, and so on through the whole series of lenses; more than half the sphere being furnished with an arrangement of this description, while the reflector behind throws back any rays which may have passed the object to be ignited.

The *multiplying-glass* is made by grinding down the round side of a convex-glass B S, into several flat surfaces, as *k d*, *d b*, and *b k*. An object O will not appear magnified when seen through this glass by the eye; but it will appear multiplied into as many different objects as the glass contains plane surfaces. For, since rays will flow from the object O to all parts of the glass, and each plane surface will refract these rays to the eye; the same object will appear to the eye in the direction of the rays, which enter it through each surface. Thus, a ray O *l*, falling perpendicularly on the middle surface, will go through the glass to the eye, without suffering any refraction; and will therefore show the object in its true place at O: while a ray O *d*, flowing from the same object, and falling obliquely on the plane surface *d k*, will be refracted in the direction *d s*, by passing through the glass; and upon leaving it, will go on to the eye in the direction of *s*; which will cause the same object O to appear also at C, in the direction of the ray C *s*, producing the right line *s* C. And the ray A S, flowing from the object O, and falling obliquely on the plane surface *b k*, will be



refracted to the eye, and as such cause the same object to appear at A, in the direction of A S. If the glass be turned round the central line, as an axis, the object O will keep its place, because the surface is not changed; but all the other objects will seem to go round O, because the oblique planes on which the rays fall, will go round by the turning of the glass.

From this brief view of the nature of refraction, as applied to lenses, it may be advisable to examine the most wonderful of all natural lenses, the *human eye*. For precisely upon the same principle as the ordinary double convex lens magnifies and inverts the objects viewed through it, upon the same principle does the natural lens paint upon the retina the various objects that fall within the field of vision.

The eye, though the most wonderful, and at the first view the most complicated part of animal anatomy, is in reality nothing more than a camera-obscura; the various humours forming one powerful lens of an exceeding short focal distance on one side, while on the other, it is allowed to embrace a very considerable space, and this is called the field of vision.

In order that we may properly understand the nature of vision, it will be necessary to furnish a brief anatomical description of the eye; which is composed of several coats or cases, one within the other, and filled with transparent humours of different degrees of density. The outer coat of the eye is called the sclerotica. It is exceedingly strong, and the muscles that move the eye are attached to it. What is called the white of the eye, is a part of this coat. The cornea bulges out a little from the eyeball; it is circular, and exceedingly transparent. The next coat to the sclerotica is called the choroides, which serves as a lining to it. It is of a dark colour in the human eye, but white in

cats and owls, and green in most animals that live on grass and vegetables. Its texture is soft and pulpy, and too weak to be susceptible of muscular motion, except at its extremities towards the front of the eye. Like the sclerotica, it is distinguished into two parts; the fore part being called the iris, while the hinder part retains the name of the choroides. The iris commences immediately under the commencement of the cornea. It there attaches itself more strongly to the sclerotica by a cellular substance, forming a kind of white, narrow, circular rim, called the ciliary circle. The iris is that remarkable circle, which gives the eye its character as to colour; it is composed of two sets of muscular fibres; the one tending, like radii, towards the centre of the circle, and the other forming a number of concentric circles round the same centre. The central part of the iris is perforated, and the aperture, which is called the pupil, is always round, but varied in diameter by the action of the two sets of muscular fibres composing the iris. When a very luminous object is viewed, the circular fibres contract, the radial are relaxed, and thus the size of the pupil is diminished; on the other hand, when the objects are dark and obscure, the radial fibres of the iris contract, the circular are relaxed, and the pupil is enlarged, so that it admits a greater quantity of light. By candle-light, the contraction and dilation of the pupil may be very distinctly observed, with the assistance of a looking-glass. If, with our eyes directed to the mirror, we bring the candle close to our face, we shall find the pupil become very small; if the candle be removed, and completely shaded for about a minute, and then brought to its former place, it will be found that the pupil has greatly dilated, and that it again contracts as the light draws nearer: if the light shine much more strongly on one eye than the other, the pupil of the

shaded eye will not contract so much as the other. The whole of the choroide membrane is opaque, by which means no light can enter the eye but what passes through the pupil: but to render the chamber of the eye still darker, the posterior surface of this membrane is covered with a dark-coloured mucus, called the pigmentum. Under the iris, there is a prolongation of the choroides, which forms a circular band of radial fibres, turning inwards towards the centre of the eye, and filled up between with a black mucus, giving it the appearance of a membrane. This circular band is called the ligamentum ciliare, or ciliary ligament. The third and *last* coat of the eye is called the retina. This is a fine and delicate membrane, being an expansion of the optic nerve, which proceeds from the brain. It is spread like a net of exquisite delicacy, all over the concave surface of the choroides, and terminates at the ciliary ligament. It receives the images of objects, which are depicted upon it by the rays of light that enter at the pupil. It is of itself transparent, and of an ash-coloured white, but appears black on account of the dark-coloured pigmentum behind it. The optic nerve which passes through a small hole in the bony cavity containing the eye, and conveys to the sensorium the impressions made on the retina, is not in the centre of the eye, but a little on one side, inclining towards the nose.*

* A controversy was agitated in the latter part of the seventeenth century, concerning the seat of vision: some contending that this function was performed by the retina, and others attributing it to the choroides. The most powerful argument used against the retina is, that the pencils ought to be converged on an uniform surface, to form a distinct image; whereas the retina is irregular, perfectly transparent, and presents no such surface. On the other hand, it is more consonant to physiology to suppose this sense, as well as every other, lodged in the nerves: and the retina, being an expansion of the optic nerve, seems intended by Providence as the organ of this sense.

The tunica choroides is described by some authors as consisting of two laminæ. This description, however, applies much more accurately to the eyes of some animals, particularly to those of sheep, than to those of man. Those who suppose the choroides to consist of two laminæ, describe the external one as terminating at the ciliary ligament, and the internal one as extending further to form the iris. The iris is described as consisting of two laminæ, and it is very certain that two sets of fibres may be observed. These are supposed to be muscular, and from the mobility of the iris there seems no reason to doubt of their being really so. Some of the fibres are orbicular, and lie round the pupil; others are straight, and extend from the circumference of the iris to its centre. We have seen that the iris has motions of such a nature, that the pupil is contracted on the approach of a strong light, and is dilated in proportion as the light is less vivid. By this admirable yet simple contrivance, the eye adapts itself to the different proportions of light to which it is exposed. If the iris was always as much contracted as it is when exposed to the light of noon-day, a weaker light, such as that of the moon, could not be admitted in sufficient quantity to answer any useful purpose. On the contrary, if the pupil was immovably dilated, we might take advantage of the scattered rays of light, but should be distressed and blinded by the bright effulgence of the mid-day sun. When a strong light succeeds to darkness, we are under the necessity of closing the eyelids, or of turning away the head, till the pupil has been accommodated to the change by the contractile powers of the iris.

The three transparent substances inclosed by the coats of the eye are called the aqueous, crystalline, and vitreous humours. The first of these, or *aqueous* humour, resembles

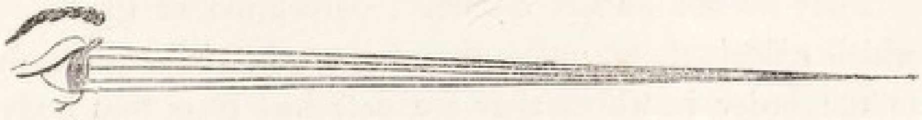
water, whence its name. It gives a protuberant figure to the cornea, filling the two cavities between the cornea and ciliary ligament, which cavities communicate by the pupil. The refractive power of the aqueous humour is similar to that of water. The second, or *crystalline* humour, is like the former, transparent, in which it exceeds that of the purest crystal; it has the consistence of a hard jelly, growing somewhat softer from the middle towards the edges. Its form is that of a double convex lens, but more convex on the interior than the exterior surface. Resembling a lens in its form, it also resembles one in its use: it converges the rays which pass through it from every visible object to its focus on the retina. It is inclosed in a fine transparent cover, or membrane, which is attached to the ligamentum ciliare, and by that means it is suspended. The radial fibres of the ligamentum ciliare have the power of contracting and dilating occasionally, by which means they alter the shape or convexity of this natural lens, and shift it a little backward or forward in the eye, so as to adapt its focal distance from the retina to the different distances of objects. Without this, or some equivalent arrangement, we should only see those objects distinctly that were at one distance from the eye. At the back of the crystalline lies the third, or vitreous humour. The *vitreous* humour was so called from a supposed resemblance to melted glass; it is a clear and gelatinous fluid, very much resembling the white of an egg. It fills about three-fourths of the globe of the eye, and extends from the posterior part of the eye as far as the ciliary ligament. It is contained in a fine transparent capsule, or membrane, and when carefully removed from the globe of the eye, preserves its consistence for some time, being supported by its capsule, but afterwards runs off, and the capsule diminishes in size. The

thin capsule which surrounds the vitreous humour, sends off a number of membranous processes into the vitreous substance, where they form cells, which communicate with each other, and afford a high degree of firmness and tenacity to the whole mass.

Dr. Brewster has very accurately ascertained the amount of refraction in the various coats and humours of the human eye, as well as the relative measures of those bodies; and as the results differ from those of Dr. Wollaston and others, who had previously examined the subject, they may be considered of considerable importance in the anatomy as well as the optical properties of that organ. Taking the refractive power of water at 1.3358, the following table will convey the result of Dr. B's. experiments.

Refractive power of the aqueous humour	1.3366
Vitreous humour	1.3394
Outer coat of crystalline	1.3767
Middle coat of ditto	1.3786
Central part of ditto	1.3990
Whole crystalline	1.3839

	Inch.
Diameter of the crystalline	0.378
Cornea	0.400
Thickness of the crystalline	0.172
Cornea	0.042



Above, is shown a pencil of rays, radiating from a luminous point; and these, when they arrive at the surface of the cornea, form cones, the points of which are at the object, and the bases on the cornea. Those which impinge

on the opaque sclerotica are reflected, and have no concern in the production of vision: while those which, by falling very obliquely, form a very considerable angle with the cornea, are also reflected without penetrating into the aqueous humour. The rays, which fall within an angle of about forty-eight degrees, pass through this membrane, undergoing a certain refraction, by which they are brought nearer to the line of the axis of the cornea; and, if produced, would converge into a focal point beyond the bottom of the eye. From the cornea, the rays pass into the aqueous humour. They are there divided by the dispersive powers of this fluid, so that, if continued in the same medium, they would not only converge beyond the back of the eye, but on account of the aberration caused by their different refrangibility, would produce a confused and coloured image.

The rays collected by the cornea pass through the pupil. Those which come in an unfavourable direction are either reflected by the iris, or absorbed by the pigmentum on its posterior surface. The pupil admits only those rays which are nearest to the axis of vision. They then meet with the crystalline, which, by its refractive power, collects them, and brings them into foci, after passing through the less refractive medium of the vitreous humour on the concave surface of the retina.

They do not impart a correct perception of the body which reflects them, unless they fall on the retina precisely in the order in which they are detached from that body. To produce this effect, it is necessary that all the rays which proceed from any one point, should be collected in one point of the retina; and that all the points of union thus formed, should be disposed in the same manner as in the body, of which they form an image.

The cone of rays which proceeds from any luminous point to the cornea, forms another cone, the apex of which falls on the retina. These two cones have their axes almost in a straight line. That which is perpendicular to the middle of the crystalline proceeds directly to the bottom of the eye; that which comes from above falls inferiorly; that on the left proceeds to the right, and so on with respect to the others; thus an inverted image is formed on the retina.

There are five natural methods by which we judge of the distance of objects from the eye. 1st. by the angle which is made by the optic axes; for want of this direction, it has been observed, that persons who are blind of one eye, frequently make a slight mistake as to the situation of objects. Secondly, by the apparent magnitude of the objects. By depending upon this method, we are frequently deceived in our estimates of distance by any extraordinary large objects; as in approaching a large city, or edifice, we fancy them nearer than they really are. This furnishes us with a reason why animals and other small objects seen contiguous to large mountains appear exceedingly small; for we imagine the mountain to be nearer to us than it actually is. When we look down also from a high building, the objects beneath us appear much smaller than they would at the same distance on the level ground; the reason is, plainly, because we have no distinct idea of distance in that direction, and therefore judge by the impressions upon the retina, whereas custom has corrected our judgment in the other case. The third method of determining the distance of objects is by the force and vividness of the colours; and the fourth is analogous to it; namely, by the different appearance of the minute parts. When these appear distinct, we judge the object to be near; and the con-

trary, when they appear faint and confused. Fifthly, we are assisted in judging of the distance of any particular object, by the other objects which are interposed. On this account distances upon uneven ground do not appear so great as upon plain; for the valleys, rivers, and other objects that lie low, are many of them lost to the sight. This, too, is the reason why the banks of a river appear contiguous, when the river lies low and is not seen.

Though every object that is before our eyes has its image in both organs, yet objects are not seen double; because, having previously ascertained, by help of the touch, that such an object was single, at the same time that each optic axis was directed towards it, and its image was painted in the corresponding parts of each retina, we have connected the idea of unity with the sentiment of those impressions, and have accustomed ourselves to identify two sensations, which, so to speak, are in unison with one another. But if the two optic axes no longer concur towards the same point, as when we slightly press one eye sideways with the hand, the object appears double, and it is evident that the two images do not then fall on the corresponding parts of the retina.

It has often been a subject of inquiry, why we see objects in their true position, though the image on the retina is inverted, but no satisfactory solution of the difficulty has ever been given. And we should be as little likely to receive an answer, if we were to ask, why we do not perceive every object bent, because the image of it is depicted upon a concave surface. It is certain, that unless distinct images are painted on the retina, objects cannot be clearly perceived. If from too little light, remoteness, or any other cause, a picture is indistinctly painted on the retina, an obscure or indistinct idea of the object is conveyed to the

mind. The picture on the retina is, therefore, so far the cause of vision, that our ideas of visible objects vary as it varies, and when it is not formed, nothing is seen. Yet we may fairly conclude, that the mind does not look upon the image on the retina; for in cases of the gutta serena, a disorder which affects only the optic nerve, the pictures on the retina are as perfectly formed as in the best eyes, although the patient is afflicted with incurable blindness. It is the optic nerve, therefore, which conveys the impressions made on the retina to the brain; but how they are communicated to the mind, is screened from the view of man. It has been supposed that we acquire by experience the habit of seeing objects erect; but there are many striking facts to prove the contrary: persons who have been blind from infancy, and who have been suddenly restored to sight by a surgical operation, have not been led into the smallest mistake. In fact, no reason can be given why the mind should not perceive as accurately the position of bodies, when the rays reflected from the upper part of those bodies fall upon the lower parts of the eye, as if the contrary took place.

The impressions of light on the retina appear to be always in a certain degree permanent, and the more so as the light is stronger; but it is uncertain whether the retina possesses this property merely as a phophorescent body, or in consequence of its peculiar organization. The duration of the impression is usually limited to less than half a second: hence, a luminous object revolving in a circle, makes a lucid ring; and a shooting star leaves a train of light behind it, which is not always real. If the object is painfully bright, it generally produces a permanent spot, which continues to pass through various changes of colour for some time, and then gradually vanishes. Dr. Roget, in an ingenious paper published in the Transactions of the

Royal Society, has farther illustrated this subject by reference to the revolution of a wheel made to revolve behind a series of perpendicular bars.

It may now be advisable to examine another, and no less important part of the anatomy of this organ, or the arrangement made for its protection from any inconvenience that may arise from the attacks of insects, or the particles of dust which are continually floating in the air. This is effected by the *eyelids*, which, like two substantial curtains, protect and cover the eyes when we are asleep; and, while waking, they diffuse, by their motion, and by peculiar secreting organs, a fluid over the eye, which cleans and polishes it.

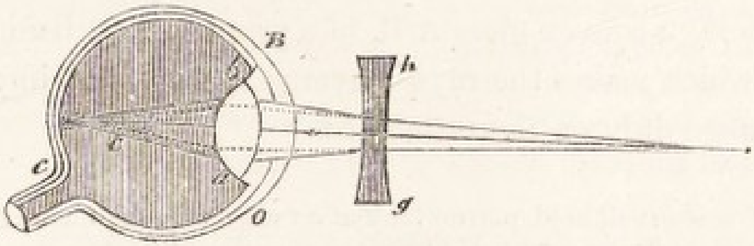
The *eyebrows* also defend the eye from the rays of light which might otherwise prove too strong for the optic nerve; and that the *eyelid* may shut with greater exactness, each edge is stiffened by a cartilaginous arch, from which proceed the eyelashes, thus serving to warn the eye of dangers, while it protects it from the straggling mote.

The more we investigate the works of nature, the greater reason have we to admire the wisdom of its Author; and that wonderful adaptation of our organs, in the minutest particulars, to the general laws which pervade the universe. The mechanism of the eye affords a striking illustration of this remark. We have hitherto supposed the eye to be a lens possessing the power only of enlarging and contracting its dimensions; and from the previous description given of the rays of light, it may be considered as incapable of obviating the confusion which must arise from their different degrees of refrangibility. But here the use of that wonderful structure of parts, and the different fluids in the eye, is clearly seen. The eye is, in fact, a compound lens; each fluid has its proper refrangible power. The shape of the

lenses is altered at will, according to the distance of the object; and the three substances having the proper powers of refrangibility, the effects of an achromatic glass are without difficulty produced by the eye.

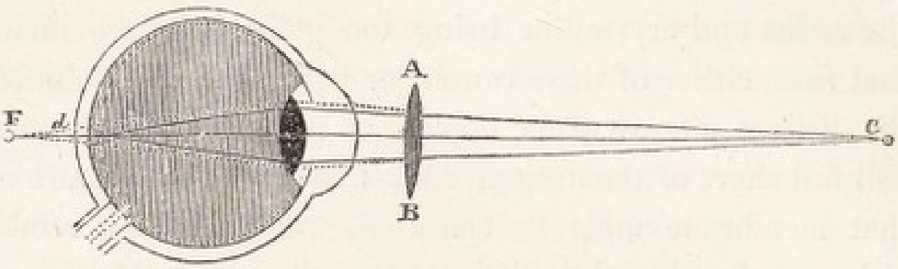
The causes which produce *defective vision* must now be examined.

There are two most important morbid affections of the eye, and these produce indistinct vision by directly opposite means. The first is caused by the cornea, and crystalline, or either of them, being too convex, or the distance between the retina and crystalline being too great. It is evident, that from either of these causes, or both of them combined, the distinct picture of an object, at an ordinary distance, will fall short of the retina, and, therefore, the picture on that membrane must be confused, which will also render vision confused and indistinct; so that, in order to see things distinctly, people whose eyes are so formed, are obliged to bring the object very near their eyes; by which means the rays fall upon the cornea in a more diverging state, and as such, distinct vision is effected: from the circumstance of such persons being obliged to hold objects near their eyes, in order to see them distinctly, they are called short-sighted.



A case of this kind is shown by the dotted lines in the accompanying diagram, in which the rays, by diverging from the focal point to the retina, will form a very con-

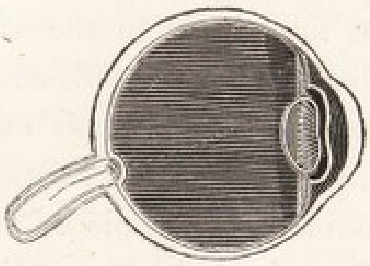
fused image; and as such, the observer will have an indistinct view of the object. This inconvenience is remedied by placing a concave glass *g h*, before the pupil *o* B, which glass, by causing the rays to diverge between it and the eye, lengthens the focal distance, so that if the glass be properly chosen, the rays will unite at the retina, and form a distinct image of the object upon it; *a b* serves to mark the boundary of the crystalline lens, and *c* shows the optic nerve.



Another cause of defective vision may now be noticed. It is evident from the above figure, that if either of the humours be too flat, the focal point of the rays *e*, will not be on the retina, but beyond the eye, as at F. Consequently, those rays which flow from the object *c*, and pass through the humours of the eye, are not converged enough to unite at *d*, but pass on to F, and as such, the observer can have but a very indistinct view of the object. This is remedied by placing a convex glass A B, of a proper focus, before the eye; which makes the rays converge sooner, and imprints the image duly on the retina at *b*.*

* If a short-sighted person look at an object through a small hole made in a card, he will be able to see even remote objects with tolerable distinctness, for this lessens the circle of dissipation on the retina, and thus lessens the confusion in the picture. For the same purpose, we commonly observe short-sighted people, when they wish to see distant objects more distinctly, almost shut their eyelids: " and it

In the preceding description of long and short vision, we have contented ourselves with furnishing such a view of the eye as was best calculated to explain the direction taken by the rays of light in approaching the retina; another view may, however, now be subjoined, furnishing an exact representation of the interior of that important organ.



The ciliary process is here represented, faithfully copied from the anatomy of the organ, and the projecting form of the cornea immediately above the pupil, with its adaptation to the purposes of vision, may now be readily understood.

is from this," says Dr. Poterfield, "that short-sighted persons were anciently called myopes."

The sight of myopes, we have seen, is remedied by a concave lens of proper concavity, and they do not require different glasses for different distances. If they have a lens which will enable them to see distinctly at the distance most commonly used by other persons, for example, at the distance at which persons, whose eyes are good, generally read, they will, by the help of the same glass, be able to see distinctly, at all the distances at which good-sighted people can see distinctly; for the cause of short-sightedness is not a want of power to vary the conformation of the eye, but is owing to the whole quantity of refraction being too great for the distance of the retina from the cornea.

The other defect, it has been shown, is of an opposite nature, and persons labouring under it are called long-sighted, or presbytae: Whence, in order to read, such persons are obliged to remove the book to a great distance, which lessens the divergency of the rays falling on the eye, and makes them converge to a focus sooner, so as to paint a distinct image on the retina.

Some have conceived that the retina is not equally sensible in all its parts, and that a certain portion only, near the axis of the eye, is capable of conveying distinct impressions of minute objects. Comparetti says, that distinct vision is effected only in the optic axis, which is moved most rapidly over every point of the object; and that what is seen apparently out of the axis, is caused by the direction of the first impression in the axis. We believe, however, that the limits of distinct vision are far more extensive. Dr. Young, speaking of his own eye, says, that the visual axis being fixed in any direction, he can see at the same time a luminous object placed at considerable distances from it; the angle, however, differs. Upwards, it extends to fifty degrees, inwards to sixty, downwards to seventy, and outwards to ninety degrees. These internal limits of the field of view nearly correspond with the external limits formed by the different parts of the face, when the eye is directed forwards and somewhat downwards, which is its most natural position; and both are well calculated for enabling us to perceive the most readily such objects as are the most likely to concern us. The extent of the retina is every way greater than the limits of the field of view. The whole extent of perfect vision is little more than ten degrees; or, more strictly speaking, the imperfection begins within a degree or two of the visual axis, and at the distance of five or six degrees becomes nearly stationary, until, at a still greater distance, vision is wholly extinguished. The imperfection may be owing partly to the unavoidable aberration of oblique rays, but principally to the insensibility of the retina; for, if the image of the sun itself be received on a part of the retina remote from the axis, the impression will not be sufficiently strong to form a permanent spectrum, although an object

of very moderate brightness will produce this effect, when distinctly viewed. The motion of the eye has a range of about fifty-five degrees in every direction, so that the field of perfect vision, in succession, is by this motion extended to one hundred and ten degrees.*

Dr. Monro has published some excellent remarks on the variety that appears in the eyes of different animals. He observes, that all quadrupeds have, at the internal canthus of the eye, a strong and firm membrane, with a cartilaginous edge, which may be made to cover some part of their eye; and this is greater or less in different animals, as their eyes are more or less exposed to danger in seeking after their food. This *membrana nictitans*, as it is called, is, however, not very large in all these animals. Cows and horses have it so large as to cover one-half of the eye, like a curtain, and at the same time it is transparent enough to allow abundance of the rays of light to pass through it. Fishes have a cuticle constantly over their eyes, as they are ever in danger in that inconstant element, the water.

All quadrupeds have a seventh muscle belonging to the eye, called *suspensorius*. It surrounds almost the whole

* Mr. Adams in his "Essay on Vision," has given some useful rules for the preservation of the sight:—

1st. Never sit for any length of time in any gloom, or exposed to a blaze of light. From this rule may be deduced the impropriety of going hastily from one extreme to the other, whether of darkness or of light; and it may be inferred, that a southern aspect is improper for those whose sight is weak. 2. We should avoid reading any very small print. 3. Do not read in the dusk, nor, if the eyes are disordered, by candle-light. 4. The eye should not be permitted to dwell on glaring objects, more particularly on the first waking in the morning. 5. The long-sighted should accustom themselves to read with rather less light, and somewhat nearer to the eye than usual; while those who are short-sighted, should accustom themselves to read with the book off as far as possible.

optic nerve, and is fixed into the sclerotic coat as the others are. Its use is to sustain the weight of the globe of the eye, and to prevent the optic nerve from being too much stretched, without obliging the four straight muscles to be in a continual contraction, which would be inconvenient: at the same time, this muscle may be brought to assist any of the other four, by causing one particular portion of it to act at a time.

The next thing to be remarked is the figure of the pupil, which is different in different animals, but always exactly accommodated to the creature's way of life, as well as to the different species of objects that are viewed. In man, it is circular; an ox has it oval, with the longest diameter placed transversely, to take in a large view of its food; in the cat, it is oval, but the longest diameter placed perpendicularly; they can either exclude a bright light altogether, or admit only as much as is necessary. The pupil of different animals varies in wideness, according as the internal organs of vision are more or less acute: thus cats, and owls, who seek their prey in the night, or in dark places, (and, consequently, must have their eyes so formed, as that a few rays of light may make a lively impression on the retina,) have their pupils in the day-time contracted into a very narrow space, as a great number of rays would oppress this delicate organ; while in the night, or where the light is faint, they open the pupil, and very fully admit the rays. In the same way, when the retina is inflamed, a great number of rays of light would occasion a painful sensation; therefore, the pupil is contracted; on the contrary, in dying people, it is generally dilated, as the eyes on such occasions are very difficultly affected, and in some measure insensible. The posterior part of the choroid coat, which is called the *tapetum*, is of different colours in different animals;

for oxen, feeding mostly on grass, have this membrane of a green colour, that it may reflect upon the retina all the rays of light which come from the objects of that colour, while other rays are absorbed: thus the animal sees its food better than it does other objects. Cats and owls have their tapetum of a whiteish colour; and for the same reasons have their pupil very dilateable, and their organs of vision acute: and we shall find, that all animals see more or less distinctly in the dark, according as their tapetum approaches nearer to a white or black colour. Thus dogs, who have it of a greyish colour, distinguish objects better in the night than man, whose tapetum is dark brown.

The *Microscope* is a most important optical instrument, and its construction will be best understood by a reference to its most simple form, which will be found nearly to resemble the eye.

This instrument owes its power of magnifying objects to a judicious arrangement of glasses; and, in common language, the microscope is said to magnify the objects which are seen through it; this, however, is true, only with regard to their apparent, and not their real magnitude. The apparent magnitude of an object is measured by the angle under which it is seen by the eye. Hence, an object at the distance of half a mile, will appear twice as large as it would if it were at a mile's distance: because the angle which it would make on the eye would be twice as large in the one case as the other. Upon the same principle, if at the distance of six or seven inches we can but just discern an object, and then by interposing a lens, or other body, we can view that object at a nearer distance, the object will appear as much larger through the lens than it did to the naked eye, as its distance from the lens

is less than its distance was from the eye. That this is not because the object is magnified by the lens is evident from the circumstance, that the same thing will happen if, instead of a lens, a piece of brown paper with a small hole, made with a pin or needle, be interposed between the object and the eye. If the edge be brought within an inch or two of a book, it will be impossible to distinguish the letters; but if, at the same distance, it be examined through a hole in the way already described, the letters will not only be visible, but apparently very much magnified. This would not be the case, if the letter was seen through the same hole at the distance of six or seven inches from it.

A variety of ingenious methods have been suggested for the construction of *microscopic spherules* possessing great magnifying power. The one best known, is to take up with the point of a wetted wire small fragments of crown glass, and placing them in the flame of a spirit-lamp, till, by producing fluidity, their particles may be enabled to take a spherical form. Another method consists in drawing out a thin strip of glass into threads, and afterwards holding the extremities of the threads in the flame of a lamp till they take the same form as the melted fragments. The spherules thus formed, may be afterwards detached from the filament which supported them, and being placed between two thin plates of metal, pierced with a small aperture, they form a useful miscroscopic instrument. Mr. Siveright has, however, effected a considerable improvement in these instruments, and his mode of constructing them is thus described:—Take a piece of platinum-leaf, about the thickness of tinfoil, and make two or three circular holes in it, from 1-20th to 1-10th of an inch in diameter, and at the distance of about half an inch from each other. In the holes put pieces of glass, which will adhere to them without fall-

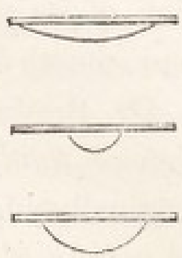
ing through, and which are thick enough to fill the apertures. When the glass is melted at the flame of a candle with the blow-pipe, it forms a lens, which adheres strongly to the metal, so that the lens is formed and set at the same time. The pieces of glass used for this purpose should have no mark of a diamond or file upon them, as the mark always remains, however strongly they are heated with the blowpipe, and they should not exceed one-tenth of an inch in diameter; an eye or loop, made by bending the extremity of a platinum wire, may be used instead of the platinum-leaf. Mr. Siveright has also formed a plano-convex lens by means of fusion; to effect which, he took a plate of topaz, with a perfectly flat and polished natural surface, and having laid a fragment of glass upon it, he exposed the whole to an intense heat. The upper surface of the glass assumed a spherical surface, in virtue of the mutual attraction of its parts, while that beneath became perfectly flat and smooth from its contact with the stone.

Dr. Brewster has very materially improved the construction of *fluid microscopes*. An apparatus of this kind was originally suggested by Mr. Stephen Gray. They consisted merely of a drop of water, which was taken up on the point of a pin, and placed in a small hole one-thirtieth of an inch in diameter, in the middle of a spherical cavity, about one-eighth of an inch broad, and a little deeper than half the thickness of the plate. On the opposite side of the plate was another spherical cavity, half as broad as the former, and so deep as to reduce the circumference of the small hole to a sharp edge. When the water is placed in these cavities, it will form a double convex lens with unequal convexities, which may be employed like any other single microscope in the examination of minute objects.

As water, however, has a considerable dispersive power,

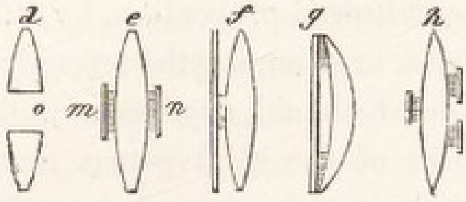
and a low power of refraction, fluid microscopes of a more perfect kind may be formed, by using sulphuric acid, castor oil, oil of ambergrease, or alcohol. The sulphuric acid has a very low dispersive power, and a greater refractive power than water, and will, therefore, make a more perfect lens than any other fluid body. Castor oil may be employed with almost equal advantage; and oil of ambergrease and alcohol would answer the same purpose, from their optical properties, though their volatility may render them less easily managed.

The best method of constructing fluid microscopes, is to take Canada balsam, balsam of Copaiba, or pure turpentine varnish, and let a drop of any of them fall upon a thin piece of parallel glass. The drop will form a plano-convex lens, and its focal length may be regulated by the quantity of fluid which is used. These fluid lenses are represented beneath, supported by plates of glass. If the lens is uppermost, the gravity of the fluid will make it more flat, and diminish its focal length. This, however, may be avoided, and the contrary effect produced, by inverting the piece of glass. If these lenses are preserved from dust, they will be as durable as those which are made of glass; and when thick Canada balsam is used, the lenses will soon be indurated into a hard gummy substance, and resist any change of figure from the gravitation of their parts.



The same ingenious philosopher has proposed a valuable mode of adjusting microscopes, so that the observer can obtain distinct vision, while viewing objects situated at different distances. To effect this, when the more remote of the two points which are to be seen at the same time, is at a greater distance than seven or eight inches, the shortest

limit of distinct vision, the adjusting microscope may be formed by drilling a small hole through the lens as at *d*, or by cementing upon the centre of each of its surfaces two small circular pieces of glass, with a drop of Canada balsam, shown at *e*. The central part of the lens will thus be reduced to a plane surface, as is seen in the diagram.



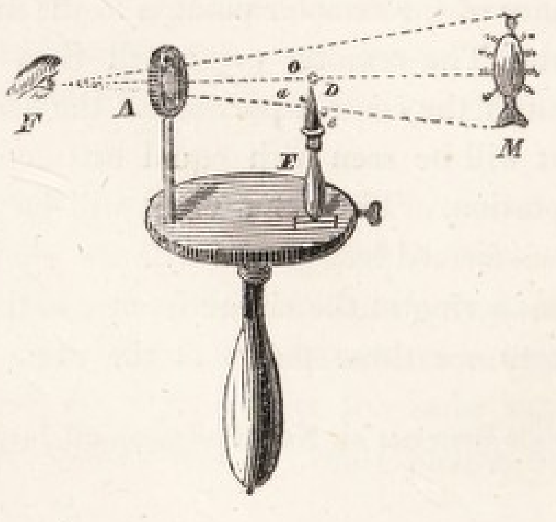
When the rays from the more distant point pass through the perforation *o*, or through the planes *m n*, and fall upon the central part of the pupil, they will form a distinct image of it upon the retina; while the rays from the nearer point, passing through the lens, will be incident upon the outer portion of the pupil, and form an equally distinct image of it upon the retina. If the distance of both the points is less than seven or eight inches, a plane of glass *f*, should be cemented to the lens *d*, by any viscid fluid, which has such a refractive power, that the encreased focal length of the central part of the lens may be to its real focal length, as the distance of the remoter point is to the distance of the nearer point. The remoter point will then be seen distinctly through the central portion of the lens, while the nearer point will be seen with equal distinctness through the outer portion. The same effect will be produced by the memiscus-formed lens *g*, and with its plane, where the cement forms a ring at the circumference of the lens.*

In order to see three points at the same instant with

* Vide Brewster on New Philosophical Instruments.

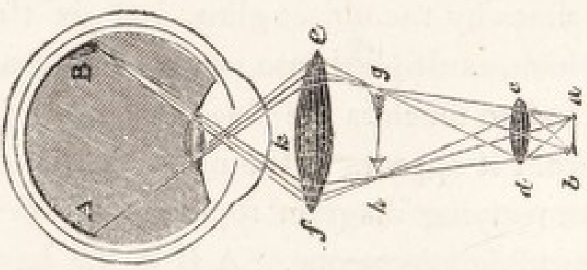
perfect distinctness, we must adopt the construction shown at *h*, where a very small circular plane of glass is cemented by Canada balsam to the anterior surface of the lens, and a small circular ring of glass, cemented on the opposite side to the portion of the lens immediately surrounding the first circular plane. The lens will thus be divided into three zones, having three different focal lengths, which may be varied in any required proportion, by altering the radii of the two surfaces, or changing the refractive power of the cement. In order to avoid any loss of light arising from the circumferences of the glass planes not being transparent, each of them may be extended to the very circumference of the lens.

The form of a very convenient microscope is shown beneath; consisting of a circular stand of mahogany, perforated with a small aperture, in which is placed a wire, supporting a small lens C, whose focal distance is C D. At that distance is a pair of plyers D E, which may be adjusted by means of the sliding screw, as in the figure, and opened by means of the two little studs *a e*; with these the observer may take up any small object O, and view it with the eye placed in the other focus of the lens at F; and according to the focal length of the lens, the object O



will appear more or less magnified, as represented at M. If the focal length be half, or one-fourth of an inch, the length, surface, and bulk of the object will be magnified, as before described. This small instrument may be put into a case, and carried about in the pocket without inconvenience. Lenses whose focal lengths are from three to five-tenths of an inch, are best calculated for common use.

The double or *compound microscope* differs from the preceding in this respect, that it consists of at least two lenses, by one of which an image is formed within the tube of the microscope, and this image is viewed through the eye-glass instead of the object itself, as in the single microscope. In this respect, the principle is analagous to that of the telescope, which we shall presently examine; only that, as the latter is intended to view distant objects, the object-lens is of a long focus, and consequently of a moderate magnifying power, and the eye-glass of a short focus, which magnifies the image made by the object-lens. But the microscope being intended only for minute objects, the object-lens is of a short focus, while the eye-glass, in this case, is not of so high a magnifying power.



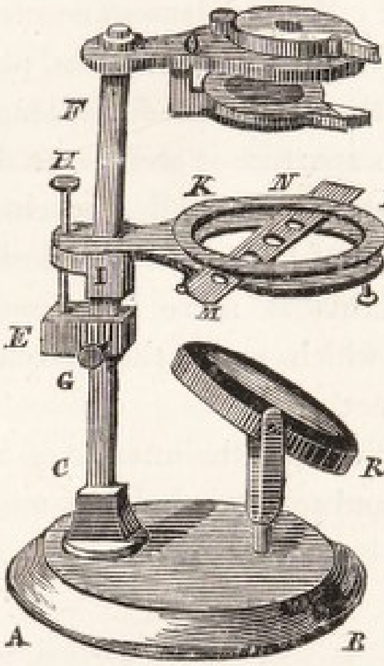
This compound microscope consists of an object-glass *c d*, and an eye-glass *e f*. The small object *a b*, is placed at a little greater distance from the glass *c d*, than its principal focus, so that the pencils of rays flowing from the dif-

ferent points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed; which image is viewed by the eye through the eye-glass *e f*; for the eye-glass being so placed, that the image *g h*, may be in its focus, and the eye about the same distance on the other side, the rays of each pencil will be parallel after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k*, where they will begin to converge by the refractive powers of the humours; and after having crossed each other in the pupil, and passed through the crystalline and vitreous humours, they will be collected into points on the retina, and form the large inverted image A B.

The magnifying power of this microscope is as follows: if we suppose the image *g h* to be six times the distance of the object *a b* from the object-glass *c d*, then will the image be six times the length of the object; but since the image could not be seen distinctly by the bare eye at a less distance than six inches, if it be viewed by an eye-glass *e f*, of one inch focus, it will be brought six times nearer the eye, and consequently viewed under an angle six times as large as before, so that it will be again magnified six times, that is, six times by the object-glass, and six times by the eye-glass, which, multiplied into one another, makes thirty-six times; and so much is the object magnified in diameter more than what it appears to the unassisted eye.

The accompanying diagram represents a very valuable, as well as portable microscope. A B is the basis or foot, C the stem, and E F two square sockets of brass, moveable upon the square part of the stem, being connected by a common screw. This motion is checked by the constant pressure of a spring. G is a screw by which the part E is fixed to the stem. H is an adjusting-screw, by which the

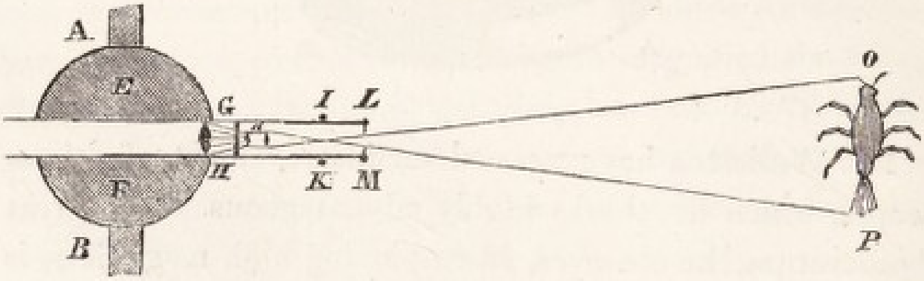
part F is gradually moved up and down; so that the stage K L, on which the objects are placed, has M N the slider, with its objects, duly adjusted to the focus of the magnifiers. O is a circular piece of brass, on which are fixed three lenses, turning on centres fixed in O, and which may be used either separately, or combined together; R is the speculum that reflects the light through the microscope.



Dr. Wollaston has proposed an improvement of microscopes, which he thinks highly advantageous. The great desideratum, he observes, in employing high magnifiers, is sufficiency of light; and it is accordingly expedient to make the aperture of the little lens as large as is consistent with distinct vision. But if the object to be viewed is of such magnitude as to appear under an angle of several degrees on each side of the centre, the requisite distinctness cannot be given to the whole surface by a common lens, in consequence of the confusion occasioned by the oblique in-

cidence of the lateral rays, excepting by means of a very small aperture, and proportionable diminution of light. In order to remedy this inconvenience, he used two plano-convex lenses ground to the same radius, and applied their plane surfaces on opposite sides of the same aperture in a thin piece of metal. Thus he virtually obtained a double convex lens, with this advantage, that the passage of oblique rays was at right angles with the surfaces, as well as the central pencil. With a lens so constructed, the perforation that appeared to give the most perfect distinctness was about one-fifth part of the focal length in diameter; and when such an aperture is well centred, the visible field is at least as much as twenty degrees in diameter. It is true, that a portion of light is lost by doubling the number of surfaces, but this is more than compensated by the greater aperture, which, under these circumstances, is compatible with distinct vision.

We may best illustrate the interior of a microscope with a moveable tube and scioptric ball, by a figure.



Let A B be a section of the window-shutter of a dark room, containing a scioptric ball E F, in the forepart of which is screwed the tube G I K H, at one end of which is a lens G H, which, by converging the sun-beams into a narrow compass, strongly enlightens the small object *a*,

placed on a slip of glass or talc, in the tube G H, where a slit is made on each side for that purpose. Within this tube there is another slider, L M, which contains a small magnifying lens.

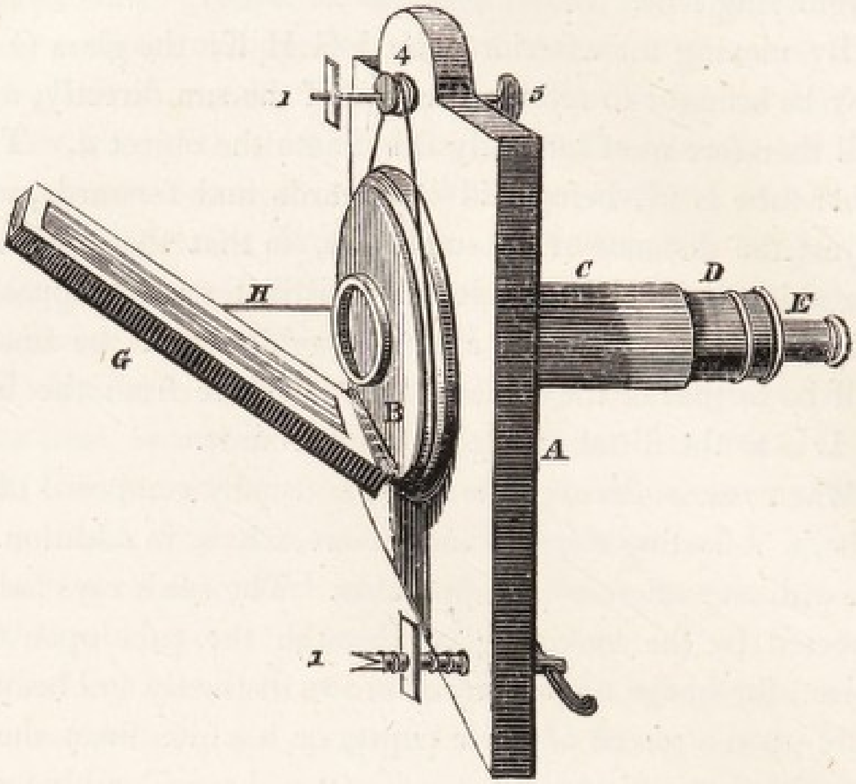
By moving the exterior tube I G H K, the glass G H may be brought to receive the rays of the sun directly, and will therefore most intensely illuminate the object *a*. The other tube L M, being slid backwards and forwards, will adjust the distance of the small lens, so that the image of the object *a* shall be made very distinct on the opposite side of the room, at O P; and the magnitude of the image will be to that of the object, as the distance from the lens M L is to the distance of the object from it.

The *camera-obscura microscope* is usually composed of a tube, a reflecting mirror, and a convex lens, in addition to the ordinary microscopic apparatus. The sun's rays being directed by the looking-glass through the tube upon the object, the image or picture is thrown distinctly and beautifully upon a screen of white paper, or a white linen sheet, placed at some distance to receive it, and considerably magnified.

The apparatus for this purpose, as represented in the accompanying engraving, is as follows: A, a square wooden frame, through which two long screws pass, and by means of two nuts 1 1, fasten it firmly to a window-shutter, in which a hole is made for its reception, the two nuts being let into the shutter.

A circular hole is made in the middle of this frame, to receive a piece of wood of a circular figure B. The edge projects a little beyond the frame, and contains a shallow groove, furnished with a band, which, by twisting round, and then crossing over a brass pulley 4, affords an easy

motion for turning round the circular piece of wood B, with its connecting parts, to follow the course of the sun.



C is a brass tube, screwed into the middle of the circular piece of wood, forming a case for the uncovered brass tube D, which may be drawn backwards or forwards. E, a smaller tube, of about one inch in length, screwed to the end of the larger tube D.

In the large tube is a convex lens, whose focus is about twelve inches, designed to collect the sun's rays, and throw them more strongly upon the object. G, a looking-glass of an oblong figure, set in a wooden frame, fastened by hinges to the circular piece of wood B, round which it revolves.

H, a jointed wire passing through the wooden frame, to enable the observer, by putting it backwards or forwards,

to elevate or depress the glass, according to the sun's altitude.

When the microscope is employed, the room must be rendered as dark as possible; for, on the darkness of the room, and the brightness of the sun-rays, depend the sharpness and perfection of the image. Then putting the looking-glass G, through the hole in the window-shutter, the observer must fasten the square frame A, to the said shutter, by its two screws and nuts 1 1.

This done, adjust the looking-glass to the elevation and situation of the sun, by means of the jointed wire H, together with the pulley and band.

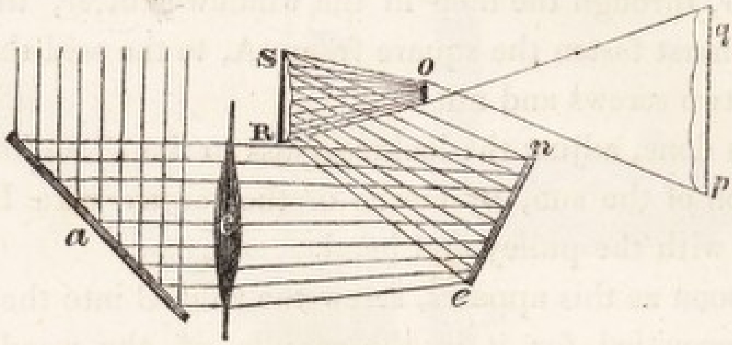
As soon as this appears, screw the tube C into the brass collar provided for it in the middle of the woodwork, taking care not to alter the looking-glass; then screwing the magnifier to be employed, to the end of the microscope, take away the lens at the other end, and place a slider, containing the object to be examined, between the thin brass plates, as in the common microscope.

Things being thus prepared, screw the body of the microscope to the short brass tube E, and pull out the tube D, less or more, as the object is capable of enduring the sun's heat. Dead objects may be brought within about an inch of the focus of the convex lens; but the distance must be altered for living insects, or they will speedily be deprived of life.

The short tube E, which the microscope is screwed to, enables the observer, by moving it backwards or forwards in the tube D, to bring the objects to their true focal distance, which will be known by the sharpness and clearness of their appearance; they may also be turned round by the same means, without the effect being injured.

The solar microscope we have just been examining, is

calculated only to exhibit transparent objects, or at least such as permit a part of the incident light to pass through them; to view opaque objects, another mirror must be used, in order that they may be seen by the light that they reflect.



In the above figure, the mirror *a*, and the lens *c*, are the same as in the common solar microscope; but the converging rays from *c* are met by a mirror *e n*, placed diagonally, and which reflects the rays upon the opaque object S R; from the object they are reflected to the magnifier *o*, from which they proceed, diverging to the screen *p q*, where the object will be painted and its apparent size increased.

Professor Amici has constructed a very excellent catoptrical microscope, in which he seems to have avoided the imperfections to which the instruments formerly constructed upon the same principle were liable, and to have combined several advantages which are not possessed by the dioptrical microscopes now in use.

The body of this instrument consists of a horizontal brass tube, twelve inches in length, and one 1-10th in diameter. At one end of the tube is placed a concave speculum of metal, whose axis coincides with that of the tube, and whose superficies is elliptical, and so calculated, that of the two foci,

the one falls at the distance of two 6-10ths, and the other at twelve inches from its centre. A thin arm within the tube, carries a small plain mirror of metal of another form, placed at the distance of one 6-10th inches from the former, opposite to it, in an oblique direction, and supported by an oblique section of a metal cylinder 5-10ths of an inch in diameter. The centre of the polished surface of this mirror coincides with the axis of the concave mirror, which is situated at the distance of one 5-10th inches from the centre of the other.

This plain mirror is so placed, that, while it receives the image of the object (which is placed on a moveable object-bearer, attached to the pillar below it) by means of a small aperture in the under part of the body of the tube, it throws it towards the concave mirror, in which it may be examined by the eye of the observer, applied to the opposite end of the tube, through a greater or smaller number of magnifying eye-glasses, which may be fitted to it.

The internal diameter of the tube, which regulates that of the large mirror, may be one 1-10th inches, and the thickness of the surrounding metal about 1-20th. Upon this construction, the object to be examined may always be at the distance of half an inch from the edge of the tube, and consequently be very well lighted on every side; transparent objects, from below, by means of a common illuminating mirror, fitted to the pillar, and moveable; and opaque bodies, from above, either by the natural light falling directly in, or by concentrating an artificial light by means of a convex glass fitted to the object-bearer,—or still better by means of a pierced mirror of metal, which is fitted to the tube below, over the object, so as to be brought more or less near it. The large illuminating mirror below should be concave, having a diameter of three inches, and a focal distance of 2,5 at the utmost.

The effects of the two last-mentioned mirrors may be reciprocally combined, by means of a common corresponding adaptation, by receiving and reflecting the rays of light, so as to produce the highest degree of intensity of light, and the most perfect illumination of the object on all sides, both as a whole, and in its different parts; an advantage, indeed, which can scarcely be attained in dioptrical instruments by similar means.*

A few hints illustrative of the use of this instrument may now be adduced. Whatever object offers itself as the subject of our examination with the microscope, the size and nature of it are first to be considered, in order to examine it with such glasses, and in such a manner, as may show it best. The first step should always be to view the whole of it together, with a magnifier that will take the whole of it in at once; and after this, the several parts of it may the more fitly be examined, whether remaining on the object, or separated from it. The smaller the parts are, the more

* The following, according to Amici, are the advantages of his microscope.

1. The observer has the convenience of being able to examine the object in a horizontal position, while, in those constructed on the dioptrical principle, the object is examined in a vertical position, that is, from above. Therefore, the observer may be seated, has no occasion to bend his head, and can examine objects more conveniently, or for a longer time, than with a large dioptrical instrument on the common construction.

2. The different degrees of magnifying power can be easily and speedily applied and changed, nothing more being necessary for this purpose than to change the eye-glass, without varying the position or distance of the object, so that it may be examined with great rapidity in all different degrees of magnitude, without the least variation of the point of view; while in the dioptrical instruments, it is not only necessary to change the object-glass, but also the visual distance, which not only occasions loss of time, but very seldom admits of the object being again seen in the same position, and in the same point of view.

3. As in this new instrument the object always remains in the same

powerful ought the magnifiers to be which are employed. The transparency or opacity of the object must also be considered, and the glasses employed, must be selected accordingly; for a transparent object will bear a much greater magnifier than one which is opaque, since the nearness of the eye, when a high magnifier is used, unavoidably darkens an object in its own nature opaque, and renders it very difficult to be seen, unless by the help of an apparatus contrived for that purpose, like Ellis's microscope, with a silver speculum. Most objects, however, become transparent by being divided into extremely thin parts.

The degree of light must always be suited to the object. If that be dark, it must be seen in a full and strong light; but if transparent, the light should be proportionably weak; for which reason there is a contrivance, both in the single and double microscope, to cut off the superabundant rays, when such transparent objects are to be examined with the largest magnifiers. The light of a candle is, for many ob-

position, and is kept constantly at the distance of half an inch from the body of the microscope, it consequently admits of our examining objects immersed in fluid, and animals swimming, and that nearly at an equal depth, and in every degree of magnitude. With dioptrical instruments, on the other hand, this is quite impossible, on account of the shortness of the focal distance in the highest degrees of magnifying power, as the object-lens must be brought so near the object as almost to come in contact with the fluid.

4. The light may be brought to bear upon all sides, and in all directions, even by means of a lamp or taper, as the flame can be brought very near the illuminating mirror without being troublesome to the observer.

5. As metallic specula do not disperse the light, and consequently produce no colours, the objects appear of their natural colour.

6. The diameter of the concave mirror being so large, compared with its focal distance, we may expect so much more distinctness.

7. As the distinctness of the image produced by reflection, is greater than that produced by refraction, the degree of magnifying power may be carried much higher.

jects, and especially for such as are very bright, transparent, and minute, preferable to daylight; for others, a serene daylight is best: but sunshine is the worst light of all; for it is reflected from objects with so much glare, and exhibits such gaudy colours, that nothing can be determined from it with any certainty. This remark, however, does not extend to the solar microscope; for with that instrument, the brighter the sun shines, the better; as with the solar microscope, we do not see the object itself, on which the sunshine is cast, but only the image or shadow of it greatly extended on a screen; and, therefore, no confusion can arise from the strong reflection of the sun's rays from the object to the eye, as with other microscopes. And with the solar microscope, we must rest contented with viewing the true figure of an object, without expecting to find its natural colour; since no shadow can possibly exhibit the colour of the body which it represents.

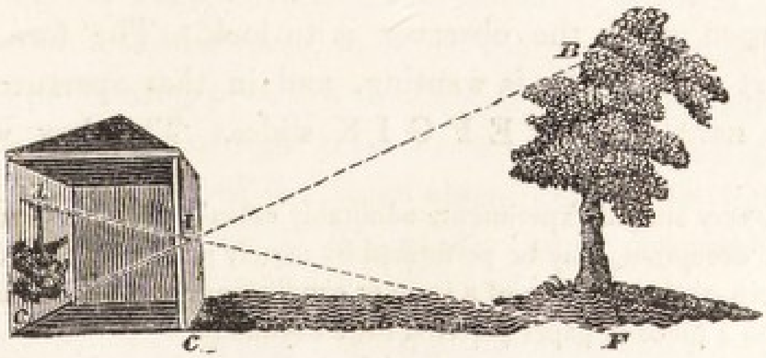
Most objects require also some management in order to bring them properly before the glasses. If they are flat and transparent, and such as will not be injured by pressure, the best way is to inclose them between two thin pieces of Muscovy talc, fastened by brass rings in a hole made through a slip of metal or ivory, called a slider. By this means, we may very conveniently preserve the feathers of butterflies, the scales of fishes, and the farina of flowers, as also the parts of insects, the whole bodies of minute ones, and a great number of other objects. Each slider should contain three, four, or more holes, which should not be filled promiscuously; but all the objects preserved in one slider should be such as require the same magnifying power to view them, that there may not be a necessity of changing the glasses for every object; and the sliders should be marked with the number of the magnifier to be

used in viewing what it contains. In placing the objects in the sliders, it is proper to have at hand a small magnifier, of about an inch focus, to examine and adjust them by, before they are fixed down by the rings.

The circulation of the blood may be most easily seen in the tails and fins of fishes, in the fine membranes between the toes of a frog, or best of all, in the tail of a water-newt. Such parts of objects of this description, as are intended to be particularly viewed, must be expanded within a glass tube; several sizes of glass tubes usually accompany a microscope, and such a one should be selected as will just admit the object, which will then remain more quiet to be examined.

If fluids come under examination, to discover the animalcula they contain, a small drop is to be taken with a hair-pencil, or on the point of a clean pin, and placed on a plate of glass. If they are too numerous to be thus seen distinctly, some warm water must be added to the drop; they will then separate, and may be seen extremely well. But if a saline solution is to be examined, another method must be resorted to; as the plate of glass must be heated till part of the fluid is evaporated, when the crystals are seen to shoot forth in the most beautiful figures.

The *camera obscura* is of two sorts. The first and most simple method of exhibiting the images of objects natu-

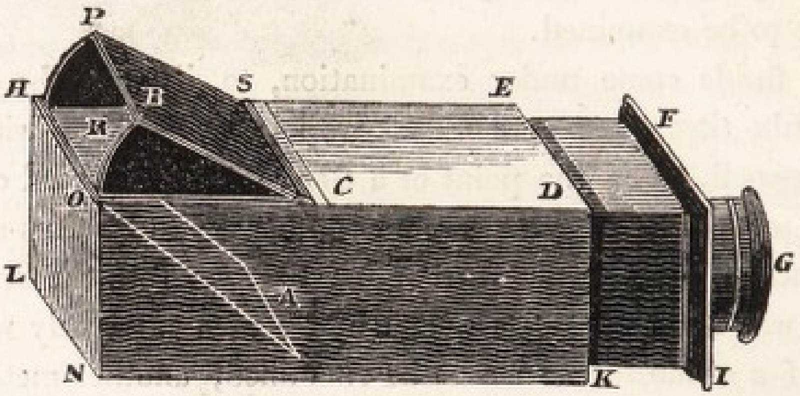


rally, in a dark chamber, consists in perforating a shutter

with a very minute aperture, and the image of any neighbouring object will be seen on the opposite wall. That it must be inverted, will be evident, from a reference to the section of an apartment in the preceding diagram.

As the lines from the base of the tree F, cannot enter the small hole, it will be evident, that the ray will invert a portion of the image, which will now fall at *d*, while the ray B will be carried down to *c*; a similar effect will also be produced by the passage of the intermediate rays.*

A *portable camera obscura* may also be constructed similar to the annexed figure.

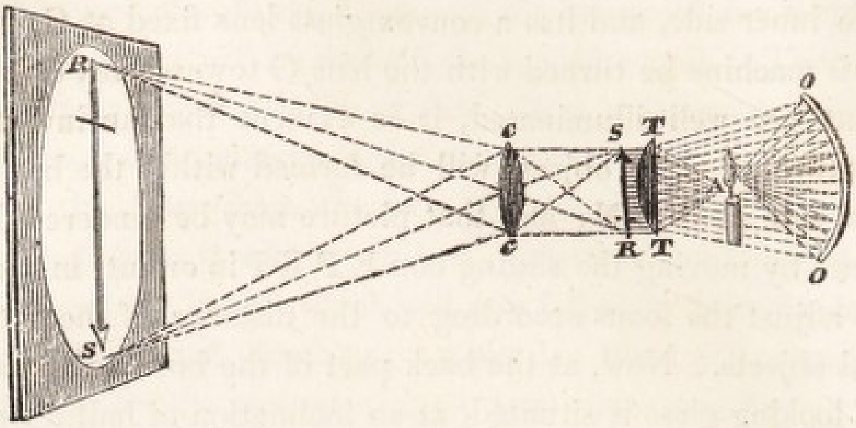


The external box H L O N E D K, has a shutter or cover P B, moving on a hinge S C, and when open, as in the figure, it carries two lateral boards, which serve to exclude the light as much as possible from the rough glass R, placed immediately beneath the shutter P B S C, and upon which the observer is to look. The fore side, or part of the box is wanting, and in that aperture another narrower box E F G I K slides. This box wants

* A very simple experiment, admirably calculated to illustrate this optical deception, may be performed by merely piercing a card with a small pin, and the image of a lamp or candle may then be seen inverted upon a piece of paper placed a little beyond it.

the inner side, and has a convex glass lens fixed at G. If this machine be turned with the lens G towards any objects that are well illuminated, it is evident that an inverted picture of these objects will be formed within the box on the side H O L N; and that picture may be rendered distinct by moving the sliding box E F K I in or out, in order to adjust the focus according to the distance of the external objects. Now, at the back part of the box, a flat piece of looking-glass is situated, at an inclination of half a right angle, as is shown by the lines O A; in consequence of which, the rays of light fall upon the looking-glass, and are reflected upwards to the rough glass R, which forms that part of the side of the box which lies under the cover P B S C. The picture then is formed upon that rough, or semitransparent glass, and will appear erect to a spectator situated behind the box, and looking down upon the glass R; because that part of the picture, which falls upon the lower part of the looking-glass, is reflected to the upper part of the rough glass: viz. to the part next the hinge S C, and *vice versa*, as may readily be understood by reference to the figure.

The *magic lantern* may be thus described: let a candle or lamp A, be placed in the inside of a box, so that the light may pass through the plano-convex lens T T, and strongly illuminate the object R S, which is a transparent painting on glass, inverted, and moveable before T T, by means of a sliding piece, in which the glass is set or fixed. The illuminating power of the lamp is materially increased by the reflection of light from a concave mirror *o o*, placed at the other end of the box, which causes the light to fall upon the lens T T, as is shown by the dotted lines in the figure. Lastly, a lens *c c*, fixed in a sliding tube, is brought to the requisite distance from



the object S R, and a large erect image R S is formed upon the opposite wall.

In the common lanterns, the figures are painted on the glass, but all the rest of the glass is left transparent; consequently, the image on the screen is a circle of light, having a figure on it. But in the *phantasmagoria*, all the glass is made opaque, with the exception of the figure, which being painted in transparent colours, the light shines through it: for this reason, therefore, no light can come upon the screen but what passes through the figure itself; consequently, we have upon the screen a figure only, without any circle of light, as in the common magic-lantern. Instead, also, of the representation being made upon a wall or a sheet, as is usually the case, it is thrown upon a thin screen of silk placed between the lantern and the spectator. The appearance of the image approaching and receding, is owing simply to removing the lantern farther from the screen, or bringing it nearer to it: for the size of the image must increase as the lantern is carried back, because the light radiates in the form of a cone; and as no part of the screen can be seen, the figure appears to be formed in the air, and to move farther off when it becomes smaller, and to come nearer as the lantern is carried towards the screen.

The *telescope* was invented about the end of the sixteenth century, and the discovery is commonly supposed to have been casual. The account which is generally received is, that Zacharias Jansen, a spectacle-maker of Magdeburgh, trying the effects of a convex and concave glass united, found that, when placed at a certain distance from each other, they had the property of making distant objects appear nearer to the eye; but the optical laws which led to this result, were not fully examined till the time of Kepler.

The *astronomical telescope* will first claim our notice.* This instrument consists of two convex lenses, A, B, K, M, fig. 1, plate 1, each fixed at the extremity of a different

* A very beautiful analogy between this instrument and the microscope has been drawn by Dr. Chalmers. He says, speaking of the two instruments:—"The one led me to see a system in every star. The other leads me to see a world in every atom. The one taught me that this mighty globe, with the whole burden of its people, and of its countries, is but a grain of sand on the high field of immensity. The other teaches me, that every grain of sand may harbour within it the tribes and the families of a busy population. The one told me of the insignificance of the world I tread upon. The other redeems it from all its insignificance; for it tells me that in the leaves of every forest, and in the flowers of every garden, and in the waters of every rivulet, there are worlds teeming with life, and numberless as are the glories of the firmament. The one has suggested to me, that beyond and above all that is visible to man, there may be fields of creation which sweep immeasurably along, and carry the impress of the Almighty's hand to the remotest scenes of the universe. The other suggests to me, that within and beneath all that minuteness which the aided eye of man has been able to explore, there may be a region of invisibles; and that, could we draw aside the mysterious curtain which shrouds it from our senses, we might there see a theatre of as many wonders as Astronomy has unfolded, a universe within the compass of a point so small, as to elude all the powers of the microscope, but where the wonder-working God finds room for the exercise of all his attributes, where he can raise another mechanism of worlds, and fill and animate them all with the evidences of his glory."

tube. One of the tubes is very short, as its use is merely to adjust the focus in proportion to the distance of the object viewed; and it slides within the other. The tubes are not represented in the figure, as the external form of telescopes is familiar to almost all. Contrary to the arrangement which takes place in the microscope, the glass which has the longest focus is presented to the object, and therefore constitutes the object-glass.

P R represents a very distant object, from every point of which rays come so very little diverging to the object-lens K M of the telescope, as to be nearly parallel: *p r* is the picture of the object P R, which would be formed upon a screen situated at that place. Beyond that place, the rays of every radiant single point proceed divergently to the eye-glass A B of greater convexity, and which causes the rays of each pencil to become parallel, in which direction they enter the eye of the observer at O.

The axes of the two lenses are coincident, in the direction Q L O; L *q* is the focal distance of the object-glass, and E *q* is the focal distance of the eye-glass; consequently, the distance between the two glasses is equal to the sum of their focal distances. An object viewed through this telescope, by an eye situated at O, will appear magnified and distinct, but inverted. The object seen without the telescope, will be, to its appearance through the telescope, as *q* E to *q* L; that is, as the focal distance of the eye-glass to the focal distance of the object-glass. For the pencils of rays, which, after their crossing at *r q p* proceed divergently, fall upon the lens A B, in the same manner as if a real object were situated at *r q p*, and, consequently, after passing through that lens, the rays of each pencil proceed parallel. Now to the eye at O, the apparent magnitude of the object P R is measured by

the angle B O A, or by its equal *p* E *r*; but to the naked eye at L, when the glass is removed, the apparent magnitude of the object is measured by the angle P L R, or by its equal *r* L *p*: therefore the apparent magnitude to the naked eye, is to the apparent magnitude through the telescope, as the angle *r* L *p* is to the angle *p* E *r*; or as the distance *q* E is to the distance *q* L.

If the angles *r* L *p* and *p* E *r* were equal to each other, the telescope would not magnify; and they would be equal, if the lenses were of equal focal distance. Hence, as the magnifying power of the telescope is produced by making the focal distance of the eye-glass less than that of the object-glass, it will easily be perceived, that the greater the difference of the focal lengths, the greater will be the magnifying power. In practice, however, it is found that they may be so disproportionate, that the increased magnifying power is overbalanced by the indistinctness which ensues. In order, therefore, to obtain a very great magnifying power, with the preservation of just proportion, these telescopes have sometimes been made one hundred feet or upwards in length; and as they were used for astronomical purposes, or mostly in the night-time, they were frequently used without a tube; viz. the object-lens was fixed on the top of a pole, in a frame capable of being moved by a cord or wire in any required direction, and the eye-glass, fixed in a short tube, was held in the hand, or fitted to another frame about the height of the observer, so as to be susceptible of a simultaneous movement.

A telescope of this description was called an *aerial* telescope. Its use is evidently incommodious; but such was the incredible pains taken by philosophers in exploring the wonders which even the imperfect telescopes at first

constructed, promised to lay open, that with such an instrument the five satellites of Saturn, and many other remarkable objects, were discovered. The length of common refracting telescopes must be increased in no less a proportion than the square of the increase of their magnifying power; so that in order to magnify twice as much as before, with the same light and distinctness, the telescope must be lengthened four times; and to magnify three times as much, nine times. On this account, their unwieldy length, when great powers are desired, is unavoidable.

The breadth of an object-glass adds nothing to the magnifying power; for whatever it may be, the image will be equally formed at the distance of its focal length; but the brilliancy of the image will be increased by the breadth, as a greater number of rays will then diverge from every point of the image.

The magnifying power, and the field of view, in this telescope may be increased by using two plano-convex lenses, combined so as to act like one glass; and such a combination is now generally employed. The disproportion above alluded to, which may subsist between an object-glass and an eye-glass, arises from this circumstance, that a lens does not converge the rays of the same radiant point, exactly to the same refracted focus, and the indistinctness, which is thus occasioned in the image, increases with the thickness of the lens, and the increase of its curvature. Hence arises the limitation to the use of highly magnifying eye-glasses. The field of view is enlarged by enlarging the eye-glass; but if a lens of very short focus were made large, the irregularity of its refraction would throw the view into confusion; if it were made sufficiently small to prevent this, it would be

equally useless from its contracted field of view, and the want of light. But if two plano-convex lenses be used, the curvature of both conjointly will be less than the curvature of a single lens of equally magnifying power; such a combination, therefore, will improve the eye-glass of a telescope, because the aberration of the rays passing through it will be less than through a single lens of the same focus.

The *astronomical telescope*, by the use of two additional eye-glasses, shows objects in their right position, and becomes a terrestrial telescope, that is, adapted for looking at objects on the earth. It is still more frequently called a perspective glass. This telescope is shown at fig. 2, plate 1. The rays of each pencil coming from the image L M of the object I K, emerge parallel from the lens A B, and having crossed at its focus, O, they continue in that direction to the lens E F, in consequence of which they form an image S T at the focus of the second lens, and again diverging, they fall upon the third lens, C D, in the same manner as they did upon the lens A B; therefore, after their emergence from this last lens, they fall parallel upon the eye at G. But as the last image, S T, is not inverted as at L M, but in the same position as the object I K, the eye sees a true or upright picture, as if the rays had come directly from the object.

Galileo's Telescope consists of a convex object-glass, and a concave eye-glass, as represented by fig. 3, plate 1. The distance between the two lenses is less than the focal distance of the object-glass; but the concave glass is situated so as to make the rays of each pencil fall parallel upon the eye, as is evident by conceiving the rays to go back again through the eye-glass, towards O; E O being the focal length of the eye-glass.

When the sphere of concavity in the eye-glass of a Galilean telescope is equal to the sphere of convexity in the eye-glass of another telescope, their magnifying power is the same; but the concave glass being placed between the object-glass and its focus, the Galilean telescope will be shorter than the other, by twice the focal length of the eye-glass. Hence, if the lengths of the telescopes be the same, the Galilean will have the greatest magnifying power.

Having already seen that the coloured rays forming the prismatic spectrum, differ in refrangibility, it will be quite evident that the nearer a lens approaches to the form of a prism, the more unequal must its refractive power be. It will, however, be apparent, by a reference to the figures shown in the prismatic spectrum, that every convex lens partakes of this defect, and it is on this account that the extremities of objects, viewed through them, are invariably found to be tinged with coloured rays; for the rays having different foci, will form their respective images at different distances from the glass. This defect in the construction of the telescope was at first considered as a necessary concomitant to all instruments in which great magnifying power was required; and Sir Isaac Newton, who first suggested the practicability of employing a compound lens, appears to have been too much absorbed by other pursuits to mature an arrangement of that description. The same result was attempted by Euler, who recommended a double object glass, consisting of two lenses, with water between them.

The published memoir of the Swiss philosopher excited the attention of Mr. Dollond, an optician of considerable celebrity; who, trying the refractive power of water, combined with glass, in the form of a prism, ascertained that a

series of glasses with different refractive powers would produce a similar effect.

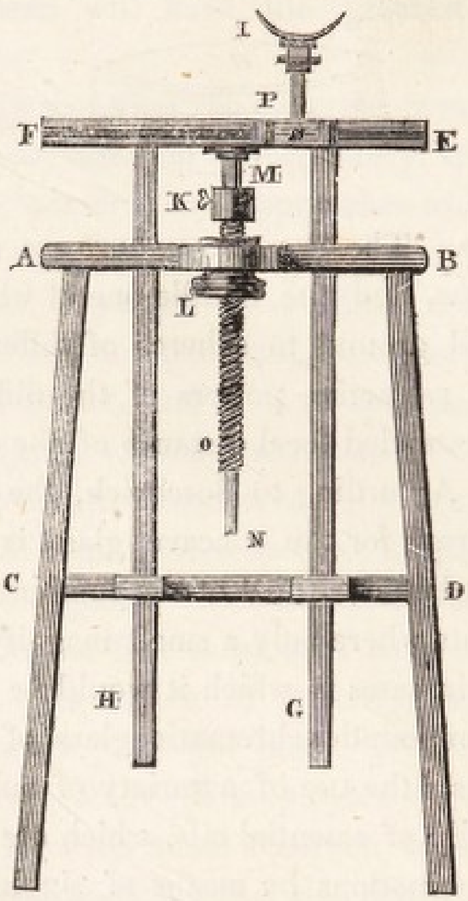
The object-glasses of Dollond's telescopes are composed of three distinct lenses, two of which are convex, and the other concave. The concave one is by British artists, placed in the middle, as represented in the accompanying figure, where *a* and *c* show the two convex lenses, and *b b*

the concave one. The two convex ones are made of London crown glass, and the middle one of white flint-glass, and they are all ground to spheres of different radii, according to the refractive powers of the different kinds of glass, and the intended focal distance of the object-glass of the telescope. According to Boscovich, the focal distance of the parallel rays for the concave glass is one-half, and for the convex-glass one-third of the combined focus.

In instruments where only a small magnifying power is required, and in cases in which it would be difficult to introduce the compound achromatic glass of Dollond, Dr. Brewster suggests the use of a variety of substances, consisting principally of essential oils, which are made to form achromatic combinations by means of single lenses, when employed as in the annexed list.

Substances fit for Eye Glasses.	Substances fit for Object Glasses.
Glass of lead.	Crown glass.
Oil of casia	Plate glass.
Oil of anise seeds.	Water.
Oil of cummin.	Alcohol.
Oil of cloves.	Sulphuric acid.
Oil of sassafras.	Oil of ambergrease.
Oil of sweet fennel seeds.	Rock crystal.
Oil of spearmint.	Topaz.

In supporting the large refracting telescope, some contrivance is necessary, to enable the observer to facilitate the motion of the instrument. Indeed, it requires to be supported at both ends, and then the nearer support must have adjustments for both altitude and azimuth, while the remote one may be a point of rest.



The accompanying diagram shows a support for the eye-end of a long telescope, which was originally contrived by Smeaton, and which is well calculated for its intended purpose. A B C D is a mahogany frame, four feet six inches high; the cross piece A B is fifteen inches long, and the piece C D seventeen, at the distance of eighteen from the other; another frame E F G H, with parallel sides, nine

inches apart, and more slender than the other frame, passes through the cross-bars of the former, in such a way as to have an easy motion; a cylinder or rod of brass is screwed by its head-piece to the cross-bar E F, and descends from M to N, through a wooden screw L O, which is hollow within, and cut into a screw round its circumference: this wooden screw terminates above with a brass socket and thumb-screw, which acts as a screw of pressure against the interior brass rod; the thick wooden piece L has a female screw, acting with the male screw of the hollow wooden cylinder L O, but is so made fast to the cross-bar A B, by a circular plate of brass above, that though it will turn round, it will neither ascend nor descend; consequently, will produce an ascending or descending motion in the wooden cylindrical piece L O, and also in the brass rod M N, held by the screw K, attached to it. The concave piece of brass I, has two motions in its stem, one horizontal, and the other vertical, like those in the stem of a small telescope, and receives the eye-end of a long telescope, to which it is screwed, while the remote end is supported by the branch of a tree, the block of a pulley, an opening in the roof of a house, or other elevated part of a building. The adjustments are thus managed: when the elevated end of the telescope is made to rest on its bearer, the eye-end adapts itself to the inclination by the joint in its stem under I; then the whole frame is turned to face the object, when the circular motion of the same small stem yields, and allows the long tube to remain quiet; and if the tube is not exactly pointed in azimuth to the object, the brass piece F, into which the stem I is made fast, slides along a groove made in the front face of the cross-bar E F, until the adjustment for azimuth is complete. This sliding motion, being manual, may be either quick or slow, as the observer desires;

therefore, when a body in motion is once in the field of view, it may be followed without difficulty, by pushing the sliding-piece P in a proper direction. The quick and slow motions for adjustment in altitude are separate, and are thus produced: first, the thumb-screw K is turned back, so as to let the rod M N ascend freely, till the altitude is nearly right, when it is fixed, and then the piece L is turned, backward or forward, as the case may require, with the right hand, while the left slowly slides the piece P, until the object is in the middle of the field; and when distinct vision has been properly obtained by the small tube at the eye-piece of the telescope, the pieces L and P, held respectively in each hand, will always afford the means of keeping the object in the proper part of the field; and though the support has but two legs, yet its connection with the support at the object end, through the heavy tube of the telescope, will always keep it in its place when the adjustments are settled.

We come now to the *reflecting telescope.* Mathematicians had demonstrated, that a pencil of rays could not be collected in a single point by a spherical lens; and also, that the image transmitted by such a lens would be in some degree incurvated. Gregory, a young man of great abilities, was induced to believe that these inconveniencies, and also the great length of the refracting telescopes, would be obviated by substituting for the object-glass of the common telescope, a metallic speculum, of a parabolic figure, to receive the image, and to reflect it towards a small speculum of the same metal. This again was to return the image to an eye-glass placed behind the great speculum, which, for that purpose, was to be perforated in its centre. These ideas were published by Gregory in 1663, but, as he possessed no mechanical dexterity himself, and could find no

workman capable of realizing his invention, it might have sunk into oblivion, had not Sir Isaac Newton, in the course of his discoveries, found that the errors arising from the different refrangibility of light were incomparably greater than those arising from reflection; and being himself as remarkable for manual skill, as mathematical knowledge, he was independent of others for the execution of his design. He therefore determined to try what could be done, and executed two reflecting telescopes in 1672, on a plan somewhat different to what Gregory had proposed. Although a good metal for the speculum was not then known, although he had to contrive for himself the method of polishing it, and although his telescopes were but six inches long, yet in power they were quite equal to a six-feet reflector, and were capable of showing Jupiter's satellites.

One great advantage of the reflecting telescope is, that it will admit of an eye-glass of a much shorter focal distance than a refracting telescope of the same length; consequently, it will magnify so much the more. This advantage arises principally from the rays of light not being dispersed by reflection as they are by refraction, and partly from the practicability of giving the large reflectors a form either parabolical, or at least, such as answers better than the spherical figure.

The theory of *Gregory's telescope* may be first examined. Plate I, fig. 4, represents a section of this instrument as it was originally made; fig. 5, being the improved form; in both which we may use the same letters of reference to the corresponding parts. A B C D, in each figure, denote the tube of wood or brass, in which two concave specula are contained; the large one, B D, is perforated at the centre, and placed contiguous to the interior end of the tube, but in such a way as to have a little play when pressed by a circular spring behind it; E F is the small speculum,

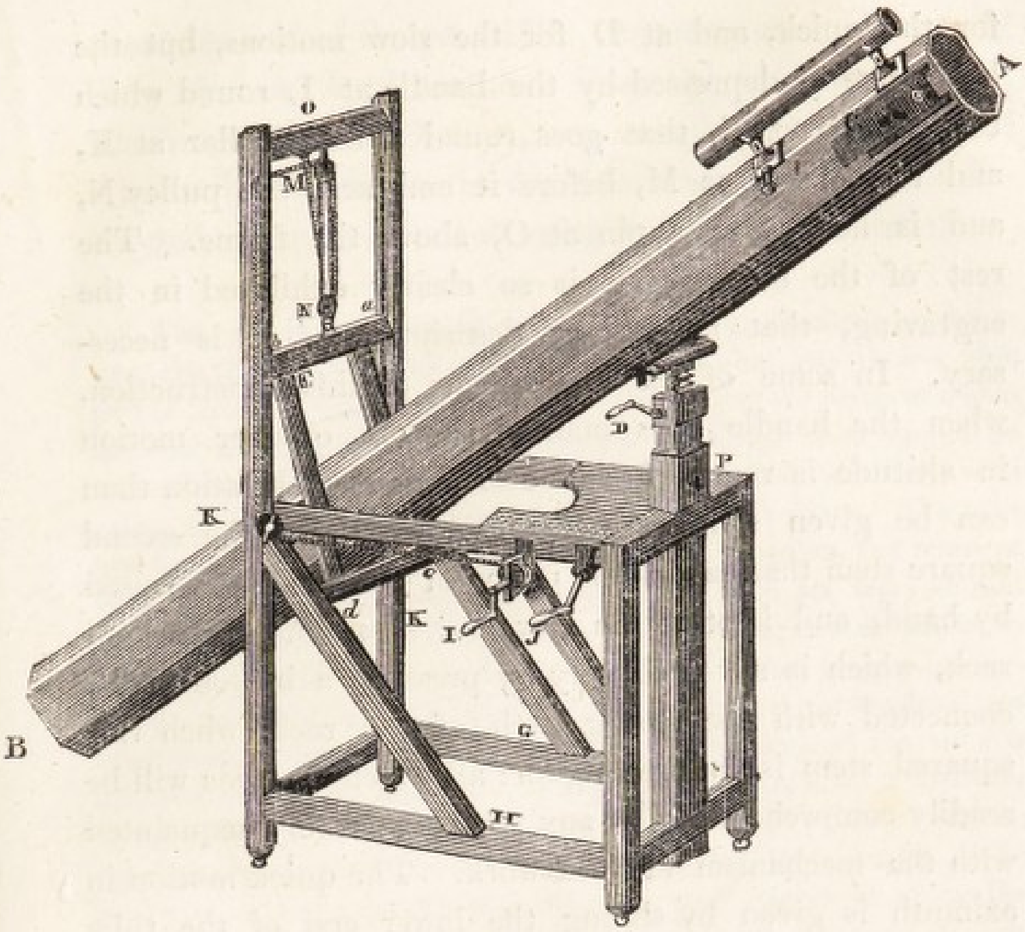
which is of shorter radius than the speculum B D, and has its centre placed exactly in the centre of the tube opposite the central aperture in the large speculum, and is so adjusted by the screws behind it, that the image of the large speculum forms a concentric circle on its reflecting surface, when viewed by an eye situated in the central hole of the large speculum. In this instrument, as in the refracting telescope, it will be most convenient to describe first the formation of the primary image of a distant object in the body of the tube, and then the microscopic means applied for rendering this image visible in an apparently magnified state; for in truth there is actually a compound reflecting microscope made use of as a constituent part of this instrument, in the same manner as the terrestrial tube of a refracting telescope of the best achromatic construction, is in itself a compound refracting microscope. In the first place, agreeably to the laws of catoptrics, if we consider *a b* and *c d* two rays of light coming from the centre of a distant arrow in a state of divergence approaching to parallelism, and impinging on the large speculum at the point *b* and *d*, near the remote edges of the speculum, and at equal distances from its axis, they will be reflected inwardly, so as to meet at the point *e*, in the common axis of both the specula, and will form the image of the central point of the arrow; and in like manner, any number of rays proceeding from the opposite ends of the said arrow, may be conceived to fall on the speculum, and to be reflected to the points *h* and *i*, and to all the intermediate points, so as to form a perfect image *h e i*, in an inverted position, because the rays which enter the tube from the right-hand end of the arrow, will, after reflection, cross the axis, and form the left-hand end of the image, and *vice versa*. When an image is thus formed, if it could be viewed,

under sufficiently favourable circumstances, by an eye placed in the vertex or central aperture of the large speculum, it would subtend the same angle as the object itself seen from the same situation, as we have already demonstrated; and, therefore, the length of the image will bear the same proportion to the length of the object which it represents, as its distance from the eye, or vertex, is to that of the object; so that the longer the radius of the speculum which forms the image, the more distant, and, consequently, the longer will this image be, as compared with the object; and for the same reason, the nearer the object, the longer will its image be, until the situation is at the centre of concavity of the speculum, where the object and image will coincide, and appear of like magnitude, but in contrary positions.

This formation of the primary image being understood, we must in the next place consider it as a real microscopic object, placed somewhere between the face of the large speculum and its centre of concavity: which situation will always depend on the distance of the real object itself, or, which is the same thing, on the degree of divergence of the incident rays coming from the object. Now, if the small speculum were so placed, as to have this primary image, or microscopic object, in its solar focal point, the rays coming from it would be reflected towards the large speculum in a parallel state; and passing through the central opening of the large speculum, would never converge so as to form a primary image, in which case the conjugate focus would be said to be *infinite*: and if the said primary image were nearer to the small speculum than its solar focus, the reflected rays would diverge, so as not to reach the central hole of the large speculum at all; but if the distance of the primary image *h e i*, exceeds the solar focus of the small

speculum E F, which is at the point f, then the reflected rays coming from the primary image, will converge to a conjugate focus somewhere in the axis, and form a *secondary* image, the magnitude of which will increase with its distance from the primary image, which we now consider as a real microscopic object. The place where this secondary image will fall, will depend on the distance of the primary image from the solar focus of the small speculum; and a small change of this distance will cause a great corresponding change in the place of the secondary image, or conjugate focus; so that an adjustment for a small forward and backward motion of the small speculum, by means of a screw at the end of a long rod placed parallel to the tube, and reaching to the eye-end, will suffice for regulating the place where the secondary image shall most conveniently fall to be viewed by an eye-glass. The secondary image has its position reversed, as it regards the primary one, and is therefore in the same position as the object itself, or what is usually called *erect*, in opposition to *inverted*. This secondary image was originally made to fall within the tube, as at $k\,l$ in the focus of the eye-glass G H, through which it may be viewed by a small hole at I, where the visual angle G I H is now considerably enlarged.

The best arrangement for the Newtonian reflecting telescope is shown on the next page. A telescope of this description forms part of the valuable apparatus in the London Institution. A, is the elevated mouth of the tube, and B, the place of the large speculum, that reflects the rays of light back to the small diagonal plane metal near C, which, by a second reflection, brings them to a focus at the eye-piece below C, as seen in the engraving. Above C, is the finder, the upper end of which has a small achromatic



object-glass, and the lower end the eye-glass. The upper end of the tube rests on a support D, that is capable of being raised or lowered slowly, by a pinion on the axis of the handle under D, while the lower end rests on the horizontal bar of the frame F, that is suspended by a pulley over F; the four pivots *a*, *b*, *c*, and *d*, of the said frame, sliding in the open grooves, seen near those letters, in the main frame, keep the small frame in any given situation, and allow a free motion, first down the vertical, and then down the inclined pieces, that compose the main frame, as low as to G and H; and when the lower end of the tube has been depressed into this situation, the tube may have an elevation approaching towards the zenith: for not only is the upper end elevated by the handle at J

for the quick, and at D for the slow motions, but the lower one is depressed by the handle at I, round which the cord is coiled, that goes round a fixed collar at K, and two others at M, before it embraces the pulley N, and is hooked to a pin at O, above the frame. The rest of the main frame is so clearly exhibited in the engraving, that no farther description of it is necessary. In some of the instruments of this construction, when the handle J is omitted, and a quicker motion in altitude is required, and also a greater elevation than can be given simply by the handle at D, the second square stem that carries the pinion of the handle is raised by hand, and kept to its elevation by means of a second rack, which is set at liberty by pressing a button at P, connected with the spring-catch of the rack, when this squared stem is lowered again: all which motions will be readily comprehended by any person tolerably acquainted with the mechanism of rack-work. The quick motion in azimuth is given by sliding the lower end of the tube gently along the bar on which it rests, or by moving the whole frame, which moves on castors; but the slow motion is produced by the screw at D. It is scarcely necessary to add, that the eye of the observer is applied to the side of the tube near its mouth, when the finder has pointed the tube properly to its object.

In 1781, Sir William (then Dr.) Herschel began a thirty-feet aërial reflector; but his mirror, thirty-six inches in diameter, having at one time cracked in the cooling, and at another period run into the fire, from a failure in the furnace, his project was partially abandoned. But the plan for forming a telescope of extraordinary size having been submitted by Sir Joseph Banks to the King, His Majesty offered to defray the expense of it, and, under his patronage, this distinguished optician began,

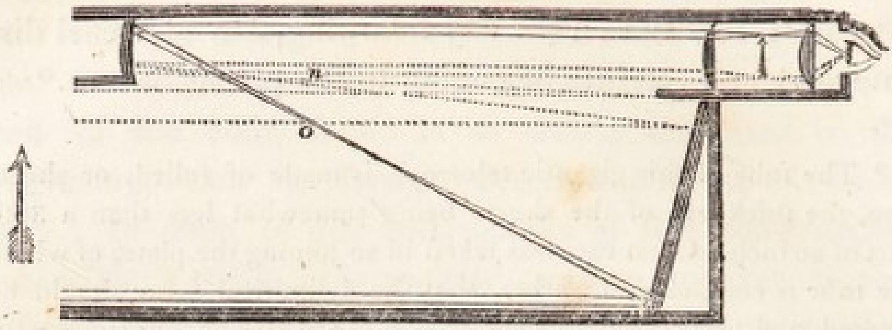
about the end of the year 1785, to construct a telescope of forty feet in focal length. This splendid instrument, which magnifies 6450 times, was completed on the 27th of August 1789; and on the day following, Dr. Herschel discovered a new satellite belonging to the planet Saturn.*

* The tube of this gigantic telescope is made of rolled, or sheet-iron, the thickness of the sheets being somewhat less than a 36th part of an inch. Great care was taken in so joining the plates of which the tube is composed, together, that the cylindrical form should be secured, and then the whole was coated over three or four times with paint, inside and outside, to secure it against the damp. The tube was formed at a short distance from its present situation, and removed with great ease by twenty-four men, divided into six sets; so that two men on each side, with a pole of five feet long in their hands, to which was affixed a piece of coarse cloth, seven feet long, going under the tube, and joined to a pole of five feet long, in the hands of two other men, assisted in carrying the tube. The length of the tube is 39 feet 4 inches, the diameter 4 feet 10 inches; and, upon a moderate computation, it is supposed that a wooden tube for the same purpose would have exceeded this in weight by at least 3000 pounds. The length of the iron plate forming the tube, and composed of smaller ones, 3 feet 10 inches long, and 23½ inches broad, is nearly 40 feet, and the breadth 15 feet 4 inches.

The great mirror is made of metal, 49½ inches in diameter; but the concave part, or polished surface, is only 48 inches in diameter. Its thickness is 3½ inches; and, when it came from the mould, its weight was 2118 pounds, of which a small quantity must have been lost in polishing. An iron ring, 49½ inches in diameter, within, 4 inches broad, and 1½ thick, with three strong handles to it, goes round the mirror, and a flat cover of tin is made to correspond to this ring, that the mirror may be preserved from damp; and, by an easy contrivance, it is taken off and fixed on at pleasure.

At the upper end, the tube is open, and directed to the part of the heavens intended for observation, to which the observer's back is turned, and he, standing on the foot-board, looks down the tube, and perceives the object, by rays reflected from the great mirror, through the eye-glass at the opening of the tube. Near the place of the eye-glass is the end of a tin pipe, into which a mouth-piece may be placed; so that, during an observation, a person may direct his voice into this pipe, whilst his eye is at the glass. This pipe is 1½ inch in diameter,

A new form of the telescope may here be briefly noticed; it is represented beneath.



The great mirror is, as usual, at the bottom of the principal tube, but instead of having its axis coincident with that of the tube, it is inclined, so as to throw the image upwards, through an aperture for that purpose, to *n o*,

runs down to the bottom of the tube, where it goes into a turning joint, thence into a drawing tube, and out of this into another turning joint, from whence it proceeds by a set of sliding tubes towards the front of the foundation timber. The use of this tube is to convey the voice of the observer to his assistants; for, at the last place, it divides itself into two branches, one going into the observatory, the other into the workman's room, ascending in both places through the floor, and being terminated in the usual shape of speaking-trumpets. Though the voice passes in this manner, through a tube with many inflections, and not less than 115 feet, it requires very little exertion to be well understood.

To direct so immense a body to any part of the heavens at pleasure, much ingenuity, and many mechanical contrivances are evidently necessary. The whole apparatus rests upon rollers, and care was previously taken of the foundation in the ground. This consists of concentrical circular brick walls, the outermost 42 feet, the innermost 21 feet in diameter; 2 feet 6 inches deep under ground, 2 feet 3 inches broad at the bottom, and 1 foot 2 inches at the top, capped with paving stones, about 3 inches thick, and $12\frac{3}{4}$ inches broad. In the centre is a large post of oak, framed together with braces under ground, and walled fast with brick-work, to make it steady. Round this centre, the whole frame is moved horizontally, by means of twenty rollers, twelve upon the outer, and eight upon the inner wall.

whence the rays diverge, and falling upon the small speculum, are reflected by it to the eye, as in the Gregorian telescope. Here we have supposed the small mirror to be concave, but that is not the form invariably resorted to, as it is clear, that the same principle is preserved, if the whole diameter of the mirror is employed to reflect light; and, therefore, it may have the small mirror convex, like Cassegrain's reflector, or plane, like Newton's.

The two mirrors of a telescope should not have precisely the same curve. Maskelyne has observed, that when the two specula are parabolas, they cause a very considerable aberration, which is negative, that is to say, the focus of the extreme ray is longer than those of the middle ones. If the large speculum is a parabola, the small one ought to be an ellipse; but when the small speculum is spherical, which is generally the case in practice, if concave, the figure of the large speculum ought to be an hyperbola; if convex, the large speculum ought to be an ellipse, to free the telescope from aberration. This will be easier understood, by attending to the positions of the first and second images; when a curve is of such a form, that lines drawn from each image, and meeting in any point of the curve, make equal angles with the tangent to the curve at that point, it is evident that such curve will be free from aberration.

The following observations on a very important adjustment, of which telescopes ought to be susceptible, are furnished by Mr. Nicholson. "Every attentive observer must have taken notice, that light is of as much consequence to artificial vision as magnifying power. It may therefore, afford matter of surprise, that the most variable of all adjustments of the eye, viz. that of aperture, should never be introduced into our artificial combinations. Dis-

tant woods, and other land objects, are invisible to a high magnifying power, for want of light; when the same object may be distinctly seen with a lower. By means of an artificial iris, which an ingenious artist will find little difficulty in contriving, this disadvantage in telescopes might be obviated. Suppose a brass ring to surround the object end of the telescope, and upon this, let eight or more triangular slips of brass be fixed, so as to revolve on equi-distant pins, passing through each triangle near one of its corners. If the triangles be slidden in upon each other, it may readily be apprehended, that they will close the aperture; and if they be all made to revolve or slide backwards alike, it is clear, that their edge will leave an octagonal aperture, greater or less according to circumstances. The equable motion of all the triangles may be produced either by pinions and one-toothed wheel, or by what is called snail-work. Another kind of iris, more compact, may be made by causing thin elastic slips of brass to slide along, parallel to the tube, and be conducted through a slit in a brass cap, which will lead them across the aperture in a radial direction.

The *micrometer* is an important part of the telescopic apparatus, and as such, must not be passed unnoticed.

Mr. Ramsden has described two valuable micrometers, which he contrived, with the view of remedying the defects of those that had been previously constructed. One of these is a catoptric micrometer, and can have no aberration, nor is it liable to any defect arising from the imperfection of its materials, or execution: as the extreme simplicity of its construction requires no additional mirrors or glasses to those required for the telescope; and the separation of the image being effected by the inclination of the two specula, and not depending on the focus of any lens or mirror, any

alteration in the eye of an observer cannot affect the angle measured. It has also the advantages of an adjustment, to make the images coincide in a direction perpendicular to that of their motion; and also of measuring the diameter of a planet on both sides of the zero, which is of no small advantage to observers, who know how much easier it is to ascertain the contact of the external edges of two images, than their perfect coincidence. A, Plate I, fig. 6, represents the small speculum of a reflecting telescope, of Cassegrain's construction, to which this micrometer is adapted, divided into two equal parts; one of which is fixed on the end of the arm B; the other end of the arm is fixed on a steel axis X, which crosses the end of the telescope C. The other half of the mirror A is fixed on the arm D, which arm at the other end terminates in a socket *y*, that turns on the axis X; both arms are prevented from bending by the braces a a. G represents a double screw, having one part, *e*, cut into double the number of threads in an inch to that of the part *g*; the part *e*, having a hundred threads in one inch, and the part *g* fifty only. The screw, *e*, works in a nut F, in the side of the telescope, while the part *g*, turns in a nut H, which is attached to the arm B; the ends of the arms B and D, to which the mirrors are fixed, are separated from each other by the point of the double screw pressing against the stud *h*, fixed to the arm D, and turning in the nut H on the arm B. The two arms B and D, are pressed against the direction of the double screw, *e g*, by a spiral spring within the part *n*, by which means all shake or play in the nut H, on which the measurement depends, is entirely prevented.

From the difference of the threads on the screw at *e* and *g*, it is evident that the progressive motion of the screw through the nut will be half the distance of the separation

of the two halves of the mirror, and, consequently, the half mirrors will be moved equally in contrary directions from the axis of the telescope C.

The wheel V, fixed on the end of the double screw, has its circumference divided into 100 equal parts, and numbered at every fifth division, with 5, 10, &c. to 100; and the index, I, shows the motion of the screw with the wheel round its axis, while the number of revolutions of the screw is shown by the divisions on the same index. The steel screw, R, may be turned by the key S, and serves to incline the small mirror at right angles to the direction of its motion.

The other micrometer, invented and described by Mr. Ramsden, is suited to the principle of refraction. This micrometer is applied to the erect eye-tube of a refracting telescope, and is placed in the conjugated focus of the first eye-glass; in which position, as the image is considerably magnified before it comes to the micrometer, any imperfection in its glass will be magnified only by the remaining eye-glasses, which in any telescope seldom exceeds five or six times; and besides, the size of the micrometer glass will not be the hundredth part of the area which would be required, if it were placed at the object-glass; and yet the same extent of scale is preserved, and the images are uniformly bright in every part of the field of the telescope. This micrometer is represented at fig. 7 in the same plate. A, is a convex or concave lens, divided into two equal parts by a plane across its centre; one of these semi-lenses is fixed in a frame B, and the other in the frame E, which two frames slide on a plate H, and are pressed against it by thin plates, *a a*; the frames B and E are moved in contrary directions by turning the button D; L is a scale of equal parts on the frame B; it is numbered from each end to-

wards the middle with 10, 20, &c. There are two verniers on the frame E, one at M, and the other at N, for the conveniency of measuring the diameter of a planet, &c. on both sides of the zero. The first division on both these verniers, coincides at the same time with the two zeros on the scale L; and, if the frame is moved towards the right, the relative motion of the two frames is shown on the scale L by the vernier M; but if the frame B be moved towards the left, the relative motion is shown by the vernier N.

This micrometer has a motion round the axis of vision, for the conveniency of measuring the diameter of a planet, &c. in any direction, by turning an endless screw F; and the inclination of the diameter measured with the horizon, is shown on the circle *g*, by a vernier on the plate V. The telescope may be adjusted to distinct vision by means of an adjusting screw, which moves the whole eye-tube with the micrometer, nearer or farther from the object-glass, as telescopes are generally made; or the same effect may be produced in a better manner, without moving the micrometer, by sliding the part of the eye-tube *m*, on the part *n*, by the help of a screw or pinion. The micrometer is made to take off occasionally from the eye-tube, that the telescope may be used without it.

Sir William Herschel applied a lamp-micrometer to Sir Isaac Newton's reflecting telescope. Two moveable lamps, the light of which is made to pass through two small holes, are placed at a convenient distance from the telescope, in the direction at which the observer looks at the image. These points of light are observed by the left eye, and brought to the opposite sides of a planet which comes within the sphere of vision of the right eye; and by measuring their distance from each other, and from the eye, the angle un-

der which the magnified diameter appears will be known, which, divided by the magnifying power of the telescope, gives the apparent diameter required. The construction of this micrometer is as follows: A B G C F E, fig. 8, Plate I. is a stand nine feet high, upon which a semicircular board, *q h o g p*, is moveable upwards or downwards, in the manner of some fire-screens, as occasion may require; and is held in its situation by a peg *p*, put into any one of the holes of the upright piece A B. This board is a segment of a circle, of fourteen inches radius, and is about three inches broader than a semicircle, to give room for the handles *r* D, *e* P, to work. The use of this board is to carry an arm L, thirty inches long, which is made to move upon a pivot at the centre of the circle by means of a string, which passes in a groove upon the edge of the semicircle *p g o h q*; the string is fastened to a hook at *o*, (not expressed in the figure, being at the back of the arm L,) and passing along the groove from *s h* to *q*, is turned over a pulley at *q*, and goes down to a small barrel *e*, within the plane of the circular board, where a double-jointed handle, *e* P, commands its motion. By this contrivance, we see the arm L may be lifted up to any altitude from the horizontal position to the perpendicular, or be suffered to descend by its own weight below the horizontal to the reverse perpendicular situation. The weight of the handle, P, is sufficient to keep the arm in any given position; but if the motion should be too easy, a friction-spring applied to the barrel will increase the friction at pleasure.

In front of the arm, L, a small slider, about three inches long, is moveable in a rabbet from the end L towards the centre, backwards and forwards. A string is fastened to the left side of the little slider, and goes towards L, where it passes round a pulley at *m*, and returns under the arm

from *m n*, towards the centre, where it is led in a groove on the edge of the arm, which is of a circular form, upwards to a barrel (raised above the plane of the circular board) at *r*, to which the handle, *r* D, is fastened. A second string is fastened to the slider, at the right side, and goes towards the centre, where it passes over a pulley *n*, and the weight *w*, which is suspended by the end of this string, returns the slider towards the centre, when a contrary turn of the handle permits it to act.

a and *b* are two small lamps, two inches high, one inch and a half in breadth by one inch and a quarter in depth. The sides, back, and top, are made so as to permit no light to be seen; and the front consists of a thin brass sliding door. The flame in the lamp, *a*, is placed three-tenths of an inch from the left side, three-tenths from the front, and half an inch from the bottom. In the lamp *b*, it is placed at the same height and distance, measuring from the right side. The wick of the flame consists only of a single very thin lamp-cotton thread; for the smallest flame being sufficient, it is easier to keep it burning in so confined a place. In the top of each lamp must be a little slit, lengthways, and also a small opening in one side near the upper part, to permit air enough to circulate to feed the flame. To prevent every reflection of light, the side opening of the lamp *a*, should be to the right, and that of the lamp *b*, to the left. In the sliding door of each lamp is made a small hole, with the point of a very fine needle, just opposite the place where the wicks are burning, so that when the sliders are shut down, and every thing dark, nothing shall be seen but two fine lucid points of the size of two stars of the third or fourth magnitude. The lamp *a*, is placed so that its lucid point may be in the centre of the circular board, where it remains fixed. The lamp *b*, is hung to the little

slider, which moves in the rabbet of the arm, so that its lucid point in a horizontal position of the arm, may be on a level with the lucid point in the centre. The moveable lamp is suspended upon a piece of brass, fastened to the slider by a pin, exactly behind the flame upon which it moves as a pivot. The lamp is balanced at the bottom by a leaden weight, so as always to remain upright, when the arm is either lifted above, or depressed below, the horizontal position. The double-jointed handles, *r* D, *e* P, consist of light deal rods, ten feet long, and the lowest of them may have divisions, marked upon it near the end P, expressing exactly the distance from the central lucid point, in feet, inches, and tenths.

From this construction we see, that a person at a distance of ten feet may govern the two lucid points, so as to bring them into any required position south or north, preceding or following from 0 to 90°, by using the handle P; and also to any distance from six-tenths of an inch, to five, or six and twenty inches, by means of the handle D. If any reflection or appearance of light should be left from the top or sides of the lamps, a temporary screen, consisting of a long piece of pasteboard, or a wire-frame covered with black cloth, of the length of the whole arm, and of any required breadth, with the slit of half an inch broad in the middle, may be affixed to the arm by four bent wires, projecting an inch or two before the lamps, situated so that the moveable lucid point may pass along the opening left for that purpose.

Fig. 9, represents part of the arm L, half the real size; S, the slider; *m*, the pulley over which the cord *x t y z*, is returned towards the centre; *v*, the other cord going to the pulley *n*, of fig. 10; R, the brass piece, moveable upon

the pin *c*, to keep the lamp upright. At R, is a wire rivetted to the brass piece, upon which is held the lamp, by a nut and screw. Figs. 11 and 12, represent the lamps *a*, *b*, with the sliding doors open, to show the situation of the wicks. W, is the leaden weight, with a hole, *d*, in it, through which the wire R, is to be passed, when the lamp is to be fastened to the slider S. Fig. 13, represents the lamp *a*, with the sliding door shut; *l*, the lucid point; and *i k*, the openings at the top, and *s*, at the sides, for the admission of air.

Cavallo's micrometer is simple and valuable. It consists of a small semi-transparent scale, or slip of mother-of-pearl, about the twentieth part of an inch broad, and of the thickness of common writing-paper. It is divided into a number of equal parts, by means of parallel lines, every fifth and tenth of which divisions is a little longer than the rest.

This micrometer, or divided scale, is situated within the tube, at the focus of the eye-lens of the telescope, where the image of the object is formed, and with its divided edge passing through the centre of the field of view, though this is not absolutely necessary. It is immaterial whether the telescope be a refractor or a reflector, provided the eye-lens be convex, and not concave, as in the Galilean telescope.

The simplest way of fixing it is to stick it upon the diaphragm, which generally stands within the tube, at the focal distance of the eye-lens. By looking through the telescope, the image of the object and the micrometer will appear to coincide; hence, the observer may easily see how many divisions of the latter measure the length or breadth of the former; and knowing the value of the divisions of

the micrometer, he may easily determine the angle which is subtended by the object.*

The mother-of-pearl micrometer may be applied to a microscope, and it will thus serve to measure the lineal dimensions of the object. The value of its divisions may be ascertained by placing an object of a known dimension before the microscope, and by observing how many divisions of the micrometer measure its magnified image. For instance, place a piece of paper, which is exactly one-tenth of an inch long before the microscope, and if it is found that 50 divisions of the micrometer measure its magnified image, the observer may conclude that each division denotes an extension of the 500th part of an inch in the object; for if 50 divisions measure 1-10th, 500 divisions must measure the whole inch.

Mother-of-pearl was found, by Cavallo, after many trials, to be a much more convenient substance than either glass, ivory, horn, or wood, as it is a very steady substance, the divisions are easily marked upon it, and when made as thin as common writing-paper, it has a very useful degree of transparency.

* There are several methods of ascertaining the value of the divisions of a micrometer in a given telescope. The following is one of the easiest: direct the telescope to the sun, and observe how many divisions of the micrometer measure its diameter exactly; then take out of the Nautical Almanack the diameter of the sun for the day in which the observation is made; divide it by the above-mentioned number of divisions, and the quotient is the value of one division of the micrometer. Thus, suppose that $26\frac{1}{2}$ divisions of the micrometer measure the diameter of the sun, and the Nautical Almanack gives for the measure of the angle which is subtended by the same diameter, $31'.22''$; or (by reducing the whole into seconds) 1882 seconds. Divide 1882 by 26.5, and the quotient neglecting a small remainder, is $71''$, or $1'.11''$; which is the value of one division of the micrometer; and, therefore, the value of any greater number of divisions is easily ascertained.

Scientific men have often had occasion to regret the difficulty of procuring fibres sufficiently elastic for micrometers. The difficulty of obtaining silver wire of a diameter small enough, induced Mr. Troughton to use the spider's web, which he has found so fine, opaque, and elastic, as to answer all the purposes of practical astronomy. But as it is only the stretcher, or long line, which supports the web, that possesses these valuable properties, the difficulty of procuring it has compelled many opticians and practical astronomers to employ the raw fibres of unwrought silk, or what is still worse, the coarse silver wire manufactured in this country. For these, Dr. Brewster has succeeded in obtaining a substitute, in a delicate fibre, which enables the observer to remove the error of inflection, while it possesses the requisite properties of opacity and elasticity. This fibre is made of glass, which is so exceedingly elastic, that it may be drawn to any degree of fineness, and can always be procured and prepared with facility. This vitreous fibre, when drawn from a hollow tube, will always be of a tubular structure, and its interior diameter may always be regulated by that of the original tube. When such a fibre is formed, and stretched across the diaphragm of the eyepiece of a telescope, it will appear perfectly opaque, with a delicate line of light extending along its axis. As this central transparency arises from the transmission of the incident light through the axis of the hollow tube, and this tube can be made of any calibre, the diameter of the luminous streak can be either increased or diminished. In a micrometer fitted up in this way by Dr. Brewster, the glass fibres are about 1-1200th of an inch in diameter; and the fringe of light is distinctly visible, though it does not exceed 1-3000th of an inch. In using these fibres for measuring the angle subtended by two luminous points,

the fibres may be separated, as hitherto done, till the luminous points are in contact with the inferior surfaces; but, in order to avoid the error arising from inflection, it is proposed to separate the fibres, till the rays of light issuing from the luminous points dart through the transparent axis of the fibres. The rays thus transmitted, evidently suffer no inflection in passing through the fibre to the eye; and, besides this advantage, the observer has the benefit of a delicate line, about one-third of the diameter of the fibre itself.*

The principle of the new micrometer invented by Dr. Brewster, is to have one or more pieces of wires absolutely fixed in the field of the telescope, and to separate them by an optical instead of a mechanical contrivance; for it is

* It may be proper to state, that Professor Wallace, of the Royal Military College, has suggested the employment of asbestos fibres in lieu of the fine wire or spider's web previously used for the *eye-piece micrometer*, and a filament about 1-3000th of an inch in diameter, having been applied to a telescope, was found to answer very perfectly the purpose for which it was intended.

The inventive genius of Dr. Wollaston has, however, far outstripped those who preceded him in the production of a micrometer fibre. The contrivance by which it is effected, is so ingenious, and promises to be productive of such valuable results, that it may be advisable to annex the account of the process employed by this philosopher.

"The extremity of a platinum wire having been fused into a globule nearly one-fourth of an inch in diameter, was next hammered out into a square rod, and then drawn again into a wire 1-253rd of an inch in diameter. One inch of this wire duly coated with silver, was drawn till its length was extended to one hundred and eighty two inches; consequently, the proportional diminution of the diameter of the platina will be expressed by the square root of 182, so that its measure had become $\frac{1}{253 \times 13{,}5} = \frac{1}{3415}$. The specific gravity of the coated wire was assumed to be 10.5, and since the weight of one hundred inches was one hundred and fourteen grains, its diameter was inferred to be 1-42,8th of an inch, or just eighty times that of the platina contained in it."

obviously the same thing, whether the wires are opened to embrace the sun's diameter, or the sun's diameter magnified till it fills the space between the wires. This change, however, in the magnitude of the object, must be effected in a part of the telescope anterior to the wires. In order to accomplish this, a second object-glass is made to move between the principal object-glass and its focus, by which means the magnifying power of the instrument, and consequently the angle subtended by the wires, may be constantly changed. When the object-glasses are in contact, the angle subtended by the wires is a maximum; and when they are at their greatest distance, the angle is a minimum, and every intermediate angle between these two is measured by a scale of equal parts, equal to the focal length of the principal object-glass. In this construction, the imperfections of the screw, the error arising from the uncertainty of the zero, from the bad centering of the lenses, from the want of parallelism in the wires, and from the minuteness of the scale, are completely removed.

The principle of the preceding micrometer applies most happily to the Gregorian and the Cassegrainian reflecting telescopes; and, what at first sight may appear paradoxical, these instruments may be converted into a very accurate micrometer, almost without the aid of any additional apparatus. A moveable object-glass is not necessary, as in the former case; for the magnifying power of these reflecting telescopes may be varied, merely by varying the distance between the eye-piece and the great speculum.

The same optical principle constitutes the foundation of the new divided object-glass micrometer. In the old micrometer of this construction, invented by Savery, two semi-lenses were made to separate from and approach to each other by a fine screw; and when the two images of

the object were in contact, the distance of the centres of the semi-lenses was a measure of the angle which it subtended. In Dr. Brewster's micrometer, however, the semi-lenses, fixed at an invariable distance, are made to move between the object-glass and its focus, so that the two images can easily be brought into contact, and the angle measured upon a scale of equal parts as large as the focal length of the object-glass.

SIMPLE ELECTRICAL PHENOMENA.

Excitation of Bodies.—Attraction and Repulsion.—Power of Conduction.—Construction of the Electrical Machine.—Improved Cylinder and Plate Machines.—Leyden Experiment.—Coated Electrics.—Battery.—Electrometers.

THE common phenomena of *electricity** were well known to the ancients, though they do not appear to have been aware of the connexion that subsists between atmospheric electricity, or lightning, and that which is produced by artificial means. Electrical phenomena are usually characterised by the attraction and recession of light substances; the consequent production of motion in them, and of sensation in living bodies, and by the evolution or production of light. There are various methods by which these effects may be produced, but the following are the most obvious sources of their production. Friction; change of form; change of temperature; contact of dissimilar bodies.

Of the first kind, viz. friction, the instances are most nu-

* This science appears to have derived its name from that of the first substance in which any of its properties were discovered. This was amber, the Greek name of which is ηλεκτρον, evidently derived from 'Ηλεκτωρ, a name by which Homer designates the sun. It has been said by some that the ancients, observing amber to possess the property of attracting light substances when rubbed, termed it electrum, and that hence arose the word electricity. Those who entertain this opinion, would derive the name from the Greek verb ελκω, to draw; though this appears to be a very forced derivation, as amber was called by the name of electron long before it was known to possess the magnetic property of attraction.

merous, and, under certain limitations, universal; they may indeed be obtained by rubbing any of an extensive list of resinous and siliceous substances: and of dry, vegetable, animal, and mineral productions. The electricity thus excited, is most readily rendered visible by its effects on the gold leaf electrometer.

Examples of the second kind are also very numerous. If a small quantity of sulphur be melted and poured into a conical wine glass, it will contract slightly, and become electrical in cooling. A silk thread with a small hook at the end of it, or a rod of glass should be inserted in the sulphur while in a fluid state, to serve as a handle for separating it from the glass when cold. On being separated from the glass, the sulphur will exhibit other signs of electricity; if kept in the glass, it will retain its electric virtue for years, and evince it very perceptibly on every attempt to separate the two substances.

Mr. Henly discovered that chocolate, fresh from the mill, becomes strongly electrical, as it cools in the tin pans. It soon loses this property, but recovers it once or twice, by being melted in an iron ladle and poured into the tin pans. When the mass becomes dry, the electricity cannot be restored by melting, unless olive oil be mixed with it in the ladle; in which case it completely recovers its electric power. M. Chaptal observed the same circumstance during the congelation of glacial phosphoric acid. The condensation of vapour, and the evaporation of fluids, though apparently opposite processes, are alike sources of electrical excitation.

Various crystallized gems, and a stone called the tourmalin, become electrical by the mere application of heat; and the effects of friction are generally increased, if it is preceded by a moderate elevation of temperature.

The contact of dissimilar bodies is probably in all cases the real primary cause of electrical excitement; but it is rarely employed alone, for electricity is known to us only by its effects, which are constantly the result of an artificial arrangement, and consequently may not immediately succeed the primary cause of electric powers, similar in their separate action on the electrometer, and other indifferent matter; but exerting a mutual influence on each other, destructive of their individual properties.

It was at first supposed that these phenomena were peculiar to the substances by which they were produced; hence the power excited by the friction of glass was termed vitreous electricity; and that by the friction of sealing-wax, resinous electricity. It has, however, long since been proved that both powers are produced in every case of electrical excitation; and, because their mutual counteraction of effect resembles that of an affirmative and negative power, they have been styled *positive* and *negative* electricity.

The determination of these two states of electricity in different excited bodies is of importance to the practical electrician, and may be thus effected:—Sealing-wax when rubbed on woollen cloth is negatively electrified. Glass, when rubbed with silk is positively electrified. Let an electrometer be made to diverge by its being approached by an excited stick of sealing-wax: while in this state, approach it with any excited body, the electricity of which is to be determined. If the divergence of the electrometer increase, the presented body is negative; if it be diminished, the presented body is positive. In other words, all those substances that lessen the divergence occasioned by excited wax, are positive; and such as increase it, negative: whilst those which lessen the divergence produced

by excited glass, are negative; and such as increase it, positive.

As an illustration of the doctrine here advanced, let the following simple and easily performed experiments be made. Roll up a warm and dry piece of flannel, so that it may be held by one extremity, while a stick of sealing-wax is rubbed with the other. After a slight friction, present the flannel to an electrometer, which will instantly diverge; while this divergence continues, bring the stick of sealing-wax near the cap, and the leaves of the electrometer will quickly collapse. Both these substances, it is obvious, are electrified by mutual friction, but their electricities are opposite; that of the wax being negative, and that of the flannel positive.

The electricities thus produced are equal to each other: for if the friction be repeated, and the two substances be both presented to the electrometer at the same time, no signs of electricity appear: the opposite electricities, when applied together, producing a reciprocal counteraction of effect.

If a black and a white silk riband be excited in contact, in the manner already described, the black riband will be found to be negatively and the white one positively electrified.

Take the sulphur cone already described, apply it and the glass separately to the electrometer; the cone will be found to be negatively, and the glass positively electrified.

From the above experiments it appears, that in all cases of excitation, positive and negative electricity are produced at the same time, and may be observed by the use of proper means. But it also appears that by friction with the same substance, different bodies are variously affected; for glass rubbed with silk evinces positive electricity: but

wax rubbed with silk is rendered negative. Again, polished glass, when rubbed with silk, skin-wool, or metal, becomes positive; but if it be excited by friction against the back of a living cat, it appears negative. Wool, silk, or fur, rubbed against sealing-wax, are rendered positive; but gold, silver, or tin, are by the same process rendered negative.

Electricians have drawn up tables for showing at one view what kind of electricity will be produced by rubbing various electrics with different substances; the following may be adduced on the authority of Mr. Cavallo.

	Is rendered	By friction with
Smooth Glass	Positive	Every substance hitherto tried, except the back of a cat.
Rough Glass	Positive	Dry oiled silk, sulphur, metals.
	Negative	Woollen cloth, quills, wood, paper, sealing-wax, white wax, the human hand.
Tourmalin	Positive	Amber, blast of air from bellows.
	Negative	Diamonds, the human hand.
Hare's skin	Positive	Metals, silk, loadstone, leather, hand, paper, baked wood.
	Negative	Other finer furs.
White Silk	Positive	Black silk, metals, black cloth.
	Negative	Paper, hand, hair, weasel's skin.
Black silk	Positive	Sealing wax.
	Negative	Hare's, weasel's, and ferret's skin, loadstone, brass, silver, iron, hand, white silk.
Sealing wax	Positive	Some metals.
	Negative	Hare's, weasel's, and ferret's skin, hand, leather, woollen cloth, paper, some metals.
Baked Wood	Positive	Silk.
	Negative	Flannel.

The effects of attraction and repulsion which result from the friction of these bodies, may be rendered apparent by a variety of contrivances. It may be advisable to select a few of the most simple.

If we take a small downy feather or a pith ball suspended by a thread, and, holding the thread, bring the ball near an electrified conductor, either positive or negative:

the ball will be attracted by the electrified conductor, and adhere to it, until its electricity is destroyed.

Such bodies as are positively electrified, tend to diffuse their superabundant fluid amongst surrounding substances; and those that are negative, endeavour to acquire the electric fluid: hence, either state of electricity will produce attraction; for if light bodies are to be moved, it is indifferent whether the electrified surface attracts their natural electric fluid, or the matter to which it is attached; for the attraction arises only from the different proportions of these in any two bodies, and will of course continue whilst that difference exists.

We may repeat the preceding experiment with a ball or feather supported by a silk thread: the light body will first be attracted to the electrified conductor, and will then recede from it; nor can it again be brought in contact until it has touched some conducting substance. The light body is here attracted for the same reason as before, but it is insulated, and consequently receives, by contact with the electrified surface, a similar electric state; it therefore recedes from that surface, being attracted by the ambient air, or other surrounding bodies; for they have their natural portion of electricity, and therefore differ from the light body, which has either more or less; but the electrified surface does not differ from the light body, and consequently cannot attract it, till, by touching some conductor, its natural electric state is restored.

We may add a very pleasing variety of the last-mentioned experiment.—Take a glass tube, whether smooth or rough is not material, and, after having rubbed it, let a small light feather be let out of your fingers at the distance of about eight or nine inches from it. This feather will be immediately attracted by the tube, and will adhere

very close to its surface for about two or three seconds, and sometimes longer; after which it will be repelled; and, if the tube be kept under it, the feather will continue floating in the air at a considerable distance from the tube, without coming near it again, except it first touch some conducting substance: and, if the tube be managed dexterously, the operator may drive the feather through the room at pleasure. This experiment may be varied as follows: a person may hold in his hand an excited tube of smooth glass, and another may hold an excited rough glass tube, a stick of sealing-wax, or any other electric negatively electrified, at about one foot and a half distance from the smooth glass tube; a feather now may be let go between these two differently excited electrics, and it will leap alternately from one electric to the other.

Some bodies possess the power of accumulating, others of transmitting this subtle fluid, and experiment shows that there is a gradation of effect from one class of bodies to the other. Those which transmit electricity with facility are called conductors; those whose transmitting powers are inferior, imperfect conductors: and such as have no power of transmission, non-conductors; but in general the various bodies in nature are divided into two classes only; the remote extremes of each forming the intermediate class.

In the following enumeration of the principal conductors, the substances are placed nearly in the order of their perfection; but the determination of this circumstance has not hitherto been accomplished with much precision.

All the known metals.
Well-burnt charcoal.
Plumbago.
Concentrated acids.
Powdered charcoal.
Diluted acids, and saline fluids.

Metallic ores.	Flame.
Animal fluids.	Smoke.
Sea water.	Steam.
Spring water.	Most saline substances.
River water.	Rarefied air.
Ice above 13° of Farenheit.	Vapour of alcohol.
Snow.	Vapour of ether.
Living vegetables.	Most of the earths.
Living animals.	Most stones.

To the above, Dr. Brewster adds powdered glass and powdered sulphur, which, he says, have been found to be conductors by the experiments of Van Swinden.

Many of the above-mentioned substances fail to conduct electricity when they are made perfectly dry ; hence it is concluded that their conducting power arises from the water they contain. Indeed, this faculty does not permanently exist in any of the bodies enumerated, but varies and disappears with their modifications of temperature, &c. Thus hot water is a much better conductor than cold water is ; the same is the case with charcoal and other substances.

The *non-conductors* are also called electrics ; they are as follows :

Shell-lac, amber, resins.	Some silicious and argillaceous stones.
Sulphur, wax, jet.	Camphor, elastic gum, lycopodium.
Glass, and all vitrifications, talc.	Native carbonate of barytes.
The diamond, and all transparent gems.	Dry chalk, lime, phosphorus.
Raw silk, bleached silk, dyed silk.	Ice at 13° of Fahrenheit.
Wool, hair, feathers.	Many transparent crystals when perfectly dry.
Dry paper, parchment, and leather.	Ashes of animal bodies.
Air, and all dry gases.	Ashes of vegetable bodies.
Baked wood, dry vegetable substances.	Oils, the heaviest are the best.
Porcelain, dry marble.	Dry metallic oxides.

Many substances in the preceding list lose their non-

conducting power, and become conductors, when intensely heated. Such is the case with red-hot glass, melted resin, wax, &c.; but the most intensely heated air, if unaccompanied by flame, is not a conductor. Many fibrous substances attract water so readily, that it is absolutely necessary to dry and warm them before their non-conducting property appears; this is particularly the case with paper, flannel, parchment, leather, &c. The influence of heat on this property is, indeed, very remarkable. It is well exemplified in the following instance: wood, in its natural state, is a conductor; if baked, its moisture is expelled, but its organisation is not altered: it is then a non-conductor. By exposure to a greater heat, its volatile elements are dissipated, and its indestructible base (charcoal replete with alkali) only remains; this is a conductor; but if exposed again to heat, with access of air, it suffers combustion, and is converted into ashes and gases, which are non-conductors.

When electricity is excited by friction, the quantity of effect is, within certain limits, proportioned to the extent of the rubbed surface; hence it appears that every part of that surface is concerned in the production of the general effect. Now, that this may be the case, it is essential that every part of such surface be insulating; for friction is a progressive process, a succession of contacts; and the effect produced by it in the first instant would otherwise be destroyed by conducting power, before a second operation could contribute to its increase. For this reason electricity is most usually excited by the friction of a conductor of limited size, against the extensive surface of a non-conductor.

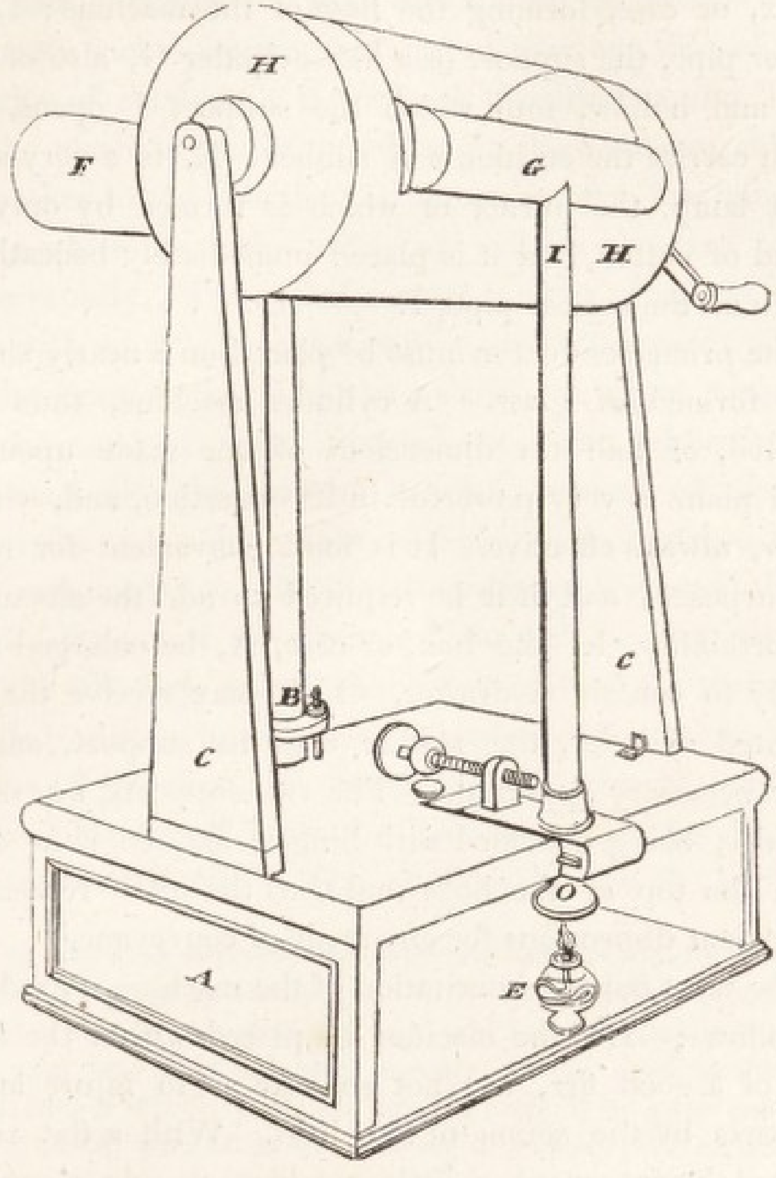
An apparatus, then, properly arranged for the excitation of electricity, is called an *electrical machine*. We have

seen that, to excite positive electricity, a glass tube may conveniently be used; the excitation is produced by rubbing it lengthwise by a piece of dry oiled silk, held in the hand, which is made to grasp the tube. In this way both the silk and the tube are electrified; but the electricity of the silk is destroyed by the conducting power of the hand, and that of the tube only appears. In a similar way negative electricity is procured by rubbing a large stick of sealing-wax with dry flannel or fur; the electrical power of the sealing-wax being all that results.

Thus, with the most simple machinery, two processes are employed to procure the opposite electricities, although they are at the same time both excited in each; but, to obtain them both, it would be necessary to insulate the silk, or flannel, used as rubbers, either by employing them in a very dry state, rolled up, so as to produce the friction with one extremity, at a distance from the hand, or by affixing them to a glass or other non-conducting support; but neither of these methods would be convenient where many experiments are to be made. This difficulty does not occur when large surfaces of glass are employed instead of tubes as sources of excitation; for these may be made circular, and proper friction be communicated to them from a fixed cushion, placed on an elastic support, against which they are made to revolve.

In examining the construction of the *cylinder electrical machine*, it may be advisable to select that form which combines portability with a high exciting power. A cylinder machine of this description, contrived by Mr. Ronalds, is represented in the accompanying figure, which possesses these advantages in a very eminent degree.

The cylinder H is excited by revolving on its axis, in



contact with the rubber or cushion, G. The prime-conductor F, forms a magazine for holding the electricity which has been separated from the rubber; and for which purpose it is provided with a series of metallic points, which readily draw electricity from the cylinder. A dove-tail joint and screw are placed at the bottom of the rubber, to ensure the right degree of pressure on the glass. A, is

a box, or case, forming the base of the machine; I, is a copper pipe, the support of a half-cylinder G, also of copper, and hollow, into which the support I opens, and which carries the cushion and rubber; E, is a very small spirit lamp, the burner of which is formed by only one thread of cotton, and it is placed immediately beneath the mouth of the copper pipe, I.

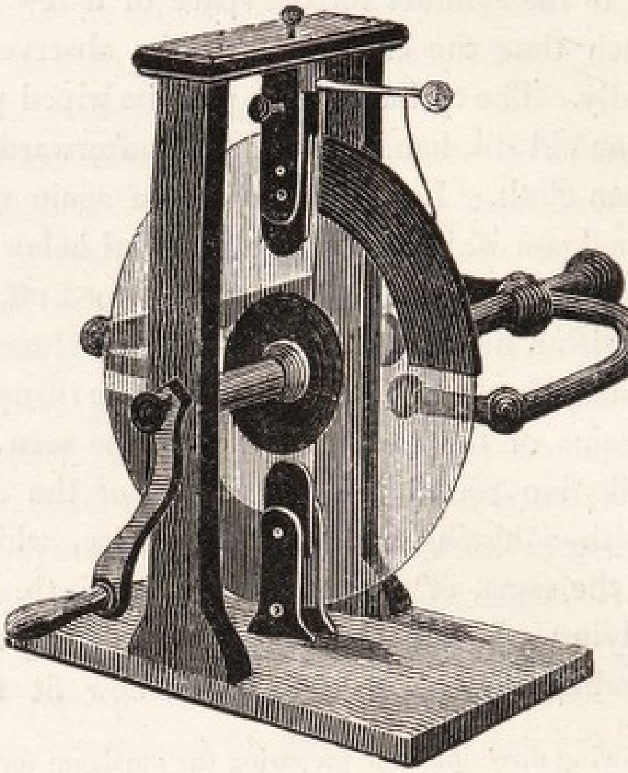
The prime-conductor must be placed on a nearly similar tube formed of glass. A cylinder machine, thus constructed, of half the dimensions of one made upon the usual plan, is very powerful in its operation, and, what is better, always effective. It is most convenient for medical purposes; and if it be required to add the advantage of portability, let the box, or case, A, be enlarged sufficiently to contain a drawer, which may receive the dismounted cylinder, the rubber with its support, and all other necessary apparatus. The two supports, *c c*, of the cylinder, being provided with hinges, may be shut down upon the top of the box, and thus the whole reduced to convenient dimensions for any mode of conveyance.

The most powerful excitation of the machine is produced as follows:—Let the machine be placed within the influence of a good fire, but not so near as to injure any of its parts by the action of the heat. With a flat round pointed knife spread a little amalgam evenly along the cushion, and return it to its place: turn the cylinder a few times round; then take off the cushion, and observe carefully those parts on its surface that have not been touched by the cylinder while revolving; on these parts put a little more amalgam, and repeat the process of turning the cylinder, and supplying the defective parts with amalgam, till every point of that part of the surface of the cushion which presses on the cylinder appears to be properly sup-

plied with amalgam.* Take now a piece of leather about five or six inches square, and spread over one side of it a quantity of amalgam; throw back the silk flap, and, turning the machine gently round, apply the amalgam side of the leather to the cylinder for the space of a few minutes, during which time the excitation will be observed to increase rapidly. The cylinder must next be wiped perfectly clean with an old silk handkerchief, and afterwards with a soft dry linen cloth. Let the cushion be again removed, and the amalgam which appears above and below the line of contact with the cylinder carefully scraped off, the silk flap wiped with a linen cloth, and the whole returned to its place and made fast. If now the cylinder be turned slowly round, streams of the electric fluid will be seen rushing from the silk flap round the lower part of the cylinder, attended with a hissing and snapping noise, while large brushes of the same, of several inches in length, may be observed flying off from the lower edge of the silk into the surrounding air. The machine is now fit for use,

* The following directions for preparing the amalgam for electrical machines are given by Mr. Singer. Melt in an iron ladle two ounces of zinc with one ounce of tin, and, while this mixture is in a fluid state, pour into it six ounces of mercury; let the whole be then put into an iron or wooden box, and agitated until it be quite cold. It must then be reduced to fine powder in a mortar, and mixed with sweet hogs' lard to the consistence of thick paste. This part of the process need not be performed till the amalgam is wanted for use. This amalgam, he remarks, answers exceedingly well; but, he afterwards adds, I have since made it with a still less proportion of mercury with equal effect. The proportions may be two ounces of tin, four ounces of zinc, and seven ounces of mercury. The mercury must be heated to about 300° of Fahrenheit, before the fused metals are added to it. When the amalgam has been agitated until cool, and finely powdered, it is to be mixed with hogs' lard by trituration in a mortar: and should it at any time become hard, more lard must be added, and the trituration be repeated.

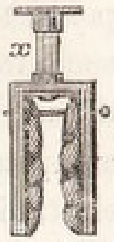
and may be fastened to the table; after which the whole of its parts are to be well wiped with a warm and dry linen cloth to free them from dust.



A *plate electrical machine* is represented in the above diagram. It consists of a circular plate of glass, turning on an axis that passes through its centre: it is rubbed by two pairs of cushions fixed at opposite points of its periphery by elastic frames of thin mahogany, which are made to press the glass plate between them with any required degree of force, by means of regulating screws. A brass conductor, supported by glass, is fixed to the frame of the machine, with its branched extremities opposite each other, and near the extreme diameter of the plate, in a direction at right angles to the vertical line of the opposite cushions. The branched extremities of the conductor are furnished with

pointed wires, that serve to collect the electricity from the surface of the excited plate.

If we wish to procure negative electricity from this machine, the rubbers may be insulated by attaching the frame to a glass tube *x*; but the usual mode of effecting this object is to place the whole apparatus on a glass-legged stool, and employ a glass handle to give motion to the cylinder.



The largest specimen of this instrument is that which was constructed by Mr. Cuthbertson, for Tyler's museum, at Haarlem. The following brief description will furnish some notion of the powers of this immense machine; and its construction will be readily understood by the description which we shall add of the most improved form of the instrument. It consists of two circular plates of glass, each sixty-five inches in diameter, and made to turn upon the same horizontal axis, at the distance of seven inches and a half from one another. These plates are excited by eight rubbers, each fifteen inches and a half long. Both sides of the plates are covered with a resinous substance to the distance of sixteen inches and a half from the centre, both to render the plates stronger, and likewise to prevent any of the electricity from being carried off by the axis. The prime conductor consists of several pieces, and is supported by three glass pillars fifty-seven inches in length. The conductor is divided into branches, which enter between the plates, but collect the fluid by points only from one side of the plate. The force of two men is required to work this machine; but when it is required to be put in action for any length of time, four are necessary. At its first construction nine batteries were applied to it, each having fifteen jars, every one of which contained about a foot square of coated glass; so that the grand bat-

tery, formed by the combination of all these, contained one hundred and thirty-five feet.

It is sometimes advisable, for medical and other purposes, to make a sort of living prime conductor, and, as such, to draw sparks from the body. This is effected by the use of a glass-legged stool. With an apparatus of this kind, the medical electrician is enabled to insulate his patient, and apply this powerful agent in the most advantageous way.

In the formation of the prime conductor, as well as in every other part of the machine that is intended to retain electricity, sharp angular points, or other asperities, should be particularly avoided.

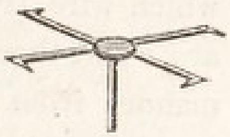
The action of bodies that are pointed or angular appears to consist in promoting the recession of the particles of electrified air, by protruding a part of the electrical atmosphere of the conductor into a situation more exposed to the action of the ambient unelectrified medium, and thereby producing a current of air from the electrified point to the nearest uninsulating body. On this account, the most prominent and the most pointed bodies are such as transmit electricity with the greatest facility; for with them this condition is most perfectly obtained.

A spherical surface is that which, considered with regard to its surrounding atmosphere, is most uniform; hence balls, or cylinders, with rounded ends, are naturally employed for insulated conductors, and their magnitude is proportioned to the intensity of the electrical state they are intended to retain; for a point is but a ball of indefinite diameter, and will act as such on very small quantities of electricity; and a ball of moderate size may also be made to act as a point, by electrifying it strongly.

If two spheres of equal size are connected together by a long wire and electrified, their atmospheres will extend to the same distance, and they will of course have respectively the same intensity ; but if the spheres be of unequal size, the atmosphere of the smallest will extend farthest, and it will necessarily have the greatest intensity; so that a longer spark can be drawn from a small ball annexed to the side of a conductor, than from the conductor itself, and longer in proportion as the ball projects farther from the side. Hence, the finer the point, and the more freely it projects beyond any part of the conductor to which it is annexed, the more rapidly will it receive or transmit electricity.

The facility with which pointed bodies transmit electricity has given rise to several very delicate and beautiful experiments to illustrate their operation : of these, the following are the most deserving of attention.

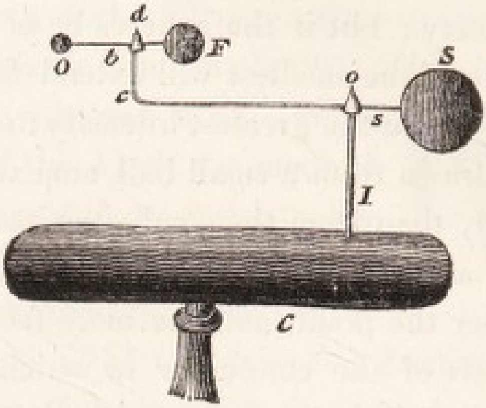
The *electrical fly* may first be noticed. It is shown beneath, and is composed of four small brass wires, fixed into a cap of the same material, easily movable upon a metal axis, and exactly balanced, so that they may turn with the smallest possible force. The ends, which



ought to be very sharp, should all be bent in one direction. With an apparatus of this kind, and a powerful machine, several flies may be made to turn either in the same, or in contrary directions; and, by their gradual increase or decrease in size, may represent a cone or other figure; for the course of each will be marked by a line of fire, and thus the whole will exhibit a beautiful appearance in the dark. The flies, in this experiment, turn the same way, whether the electricity be positive or negative.

The *electrical orrery* is another instrument frequently used for showing the effects of points in the transmission

of the electric fluid. Its construction is shown in the accompanying diagram; the ball S represents the sun, F



the earth, and *o* the moon, connected by wires *s c*, and *b*; *d*, is the centre of gravity between the earth and moon. These three balls and their connecting wires are supported by the sharp point of a wire, I, which is placed upright in the prime conductor of the electrical machine; the earth and moon hanging upon the sharp point of the wire *c*, in which wire is placed a short pin, projecting horizontally at *c*; and there is a similar pin at *o*, projecting in the same manner from the wire that connects the earth and the moon.

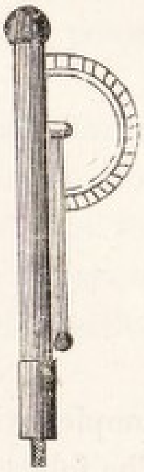
When the cylinder of the electrical machine is turned, these balls and wires are electrified; and the electrified air, flying off horizontally from the points, drives the balls round their common centre of gravity.

The *electrometer*, or *electroscope*, is a very valuable part of the electrical apparatus. By the use of this instrument, which has been variously modified and improved by Bennet, Singer, and Coulomb, we are enabled to ascertain the presence of electricity in cases where the quantity would be otherwise too small for observation.

The most simple apparatus for ascertaining the amount

of electrical repulsion, consists of two pith balls attached to threads, and connected with the prime conductor of the machine, so that their divergence serves as a measure of the electrical intensity.

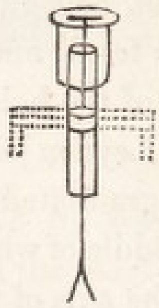
Another form of the pith-ball electrometer is that invented by Mr. Henley; it is simple in its construction, and extremely useful in numerous electrical experiments. It consists of a perpendicular stem formedat top like a ball, and furnished at its lower end with a brass ferule and pin, by which it may be fixed in one of the holes of the conductor, or at the top of a Leyden jar. To the upper part of the stem, a graduated ivory semicircle is fixed about the middle of which is a brass arm or cock, to support the axis of the index. The index consists of a very slender rod, which reaches from the centre of the graduated arch to the brass ferule; and to its lower extremity is fastened a small pith ball nicely turned in a lathe. When this electrometer is in a perpendicular position, and not electrified, the index hangs parallel to the pillar; but when it is electrified, the index recedes more or less, according to the quantity of electricity, from the stem. The scale in Mr. Henley's quadrant is divided into equal parts; but M. Achard has shown that, when this is the case, the angle at which the index is held suspended by the electrical repulsion is not a true measure of the repulsive force: to estimate this force truly, he demonstrates that the arc of the electrometer should be divided according to a scale of arcs, the tangents of which are in arithmetical progression.



The *gold-leaf electrometer* is a very valuable and delicate piece of apparatus. It consists of two thin leaves of metal suspended by a cap in a glass insulating cylinder. These,

when electrified, immediately repel each other, and show by their divergence the amount of repulsion.

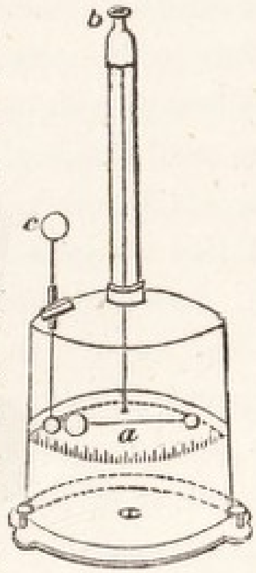
There have been some improvements proposed on this electrometer, one of which was by Mr. Singer, and chiefly respects the mode of insulation. This instrument is represented in the accompanying figures, in which a section and



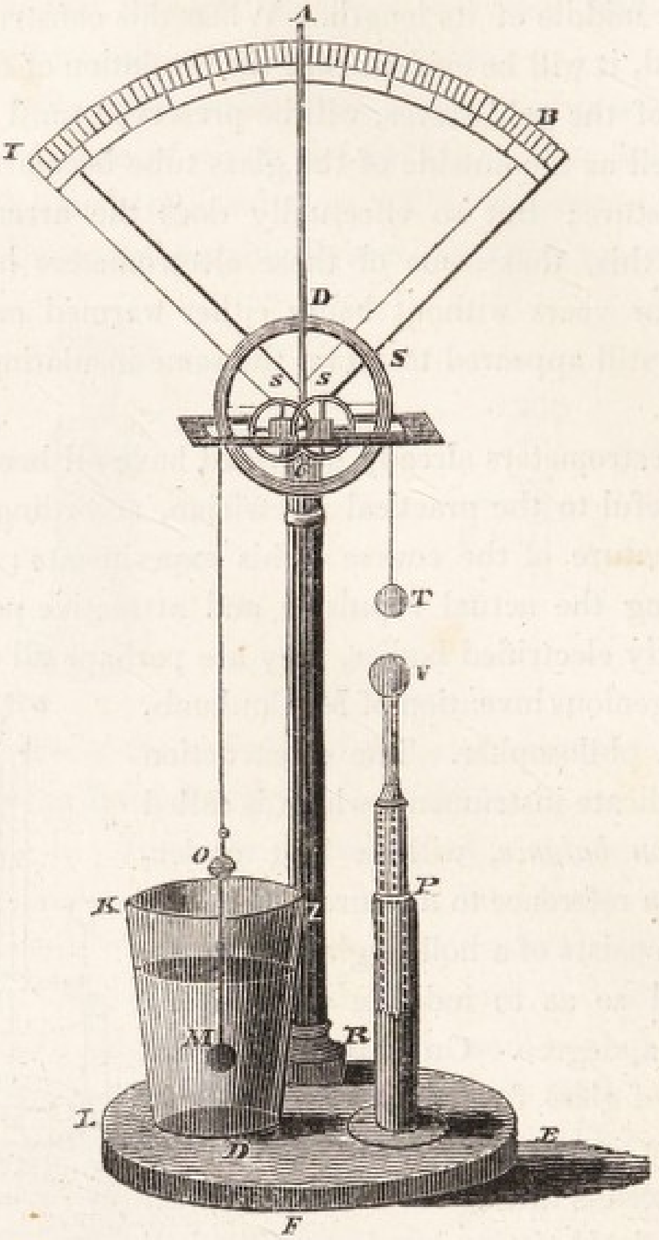
complete view of the exterior of the instrument is furnished. The following brief description will suffice to convey a correct idea of it. Like the preceding, it is constructed with a glass cylinder, surmounted by a broad cap of either wood or metal. The insulation depends on a glass tube of four inches long, and one-fourth of an inch in diameter, covered on both sides with sealing-wax, and having a brass wire of a sixteenth or twelfth of an inch thick, and five inches long, passing through its axis, so as to be perfectly free from contact with any part of the tube, in the middle of which it is fixed by a plug of silk, which keeps it in a concentric position with the internal diameter of the tube. A brass cap is screwed upon the upper part of this wire; it serves to limit the atmosphere from free contact with the outside of the tube, and at the same time to defend its inside from dust. To the lower part of the wire the gold leaves are fastened. The glass tube passes through the centre of the cap of the electrometer, and is cemented there

about the middle of its length. When this construction is considered, it will be evident that the insulation of the wire, and also of the gold leaves, will be preserved until the inside as well as the outside of the glass tube becomes coated with moisture; but so effectually does the arrangement preclude this, that some of these electrometers have remained for years without being either warmed or wiped, and have still appeared to retain the same insulating power as at first.

The electrometers already described have all been found highly useful to the practical electrician, according to the peculiar nature of the course of his experiments; but for ascertaining the actual repulsive and attractive powers of very faintly electrified bodies, they are perhaps all excelled by the ingenious invention of M. Coulomb, a French philosopher. The construction of this delicate instrument, which is called the *torsion balance*, will be best understood by a reference to a figure. The apparatus consists of a hollow glass cylinder, graduated so as to indicate degrees and parts of a degree. On this is placed a flat plate of glass, furnished with a tube in the centre, supporting a nut *b*. A silk string descends through the tube, to which is attached the index hand, *a*. The ball and wire *c* is insulated on the glass plate, and serves to communicate electricity from external objects, and the amount is indicated by the twisting of the string.



The action of *Harris's electrometer* depends on balancing the attractive force of accumulated electricity, by the increased weight which a body immersed in a fluid gains on rising out of it. It consists of a stand R, E, L, F; on

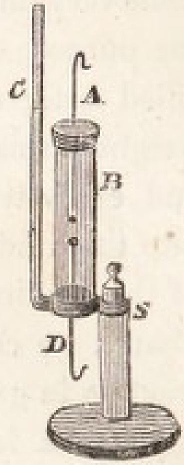


this is screwed the perpendicular column R; it supports a projecting plate of brass, S, and a large wheel, D; the axle of this wheel rests on four small friction wheels S, S, and its centre is that of the arc B I; this arc is a quadrant, divided into any number of equal parts on each side of its centre, marked Zero; the large wheel D, carries an index, formed of a fine strong straw, to indicate the attrac-

tive forces in the direction A, B, and the repulsive in the direction A, I; over the wheel passes a line S, to which is suspended a light ball of gilt wood T. The float, sustained, in great part, by the fluid in the vessel K, preserves an equilibrium when the index is at zero. The line passing over the pulley, if the attractive forces are to be estimated, is formed of two parts, the lower part being of silver thread, the remainder silk. When the repulsive forces are to be estimated, the whole is of silk. The float O M, is a small glass tube, about two-tenths of an inch diameter, terminating in a small bulb at its lower end, which contains some very fine shot, or mercury, occasionally put into it for the purpose of adjusting the instrument. The fluid is distilled water of a mean temperature. The difference of weight of this float, when in and out of the water, is known; and every tenth of an inch of it, which rises out or sinks into the fluid, is made to correspond, by employing a wheel of the required circumference, with five divisions of the arc above: we can hence readily estimate the force of the attraction in grains, and parts of a grain. Under the ball T, is placed a larger insulated ball V, in connexion with the prime conductor, or inner coating of the jar; it can be depressed or elevated by means of the sliding tube P, through divisions of one-tenth of an inch, which correspond, also, to every five divisions on this arc; and this enables us to obtain any multiple of the first force, and yet preserve the ultimate distance between the balls constant. Now it is evident, that the attractive or repulsive forces, operating in right lines between the balls, will cause the float to ascend or descend, until the weight gained or lost by its rising or sinking in the fluid furnishes a balance to the forces. The column is of baked wood, and has a wire through it, which, when the attractive force is alone measured, is connected at

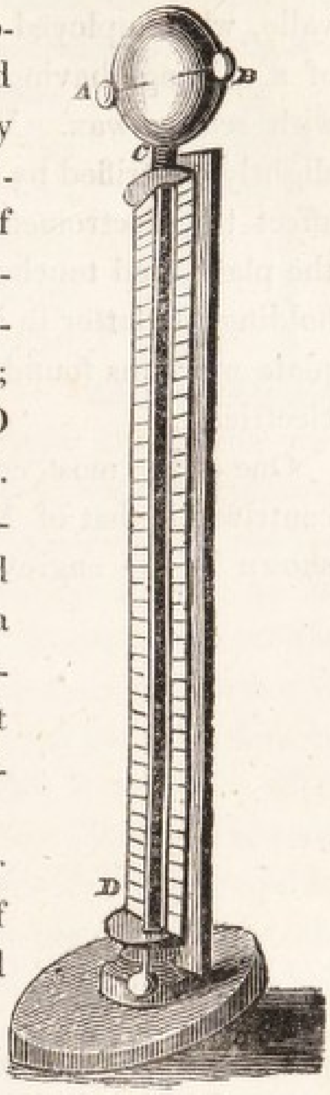
the base with the outside of the jar, or battery, and hence the interval between the inner and outer coating is that between the balls T and V; so that, when charging, the attraction between the balls will increase with the accumulation; hence the index moving over the arc I, B, is a true measure of it.

The *electrical air thermometer* was originally contrived by Mr. Kinnersley, of Philadelphia, and described by that gentleman in a letter to Dr. Franklin, early in 1761. The annexed diagram will represent the ordinary mode of constructing this instrument. A wire A is made to enter the glass tube B, by a metal cap, through which it passes, air-tight; a similar wire D passing up from the lower end. A glass tube C, forms the only communication with the atmosphere; so that if a small portion of any coloured fluid be placed in the large vessel, and the air above it be expanded, the coloured fluid must be driven up the tube. This is most readily effected by connecting the two coatings of a charged jar with the wires A and D.



The experiments which Mr. Kinnersley made with this instrument are as follows:—He placed the thermometer on a stand S, and connected the wire A with the prime conductor of an electrical machine in action. He, by this means, kept the air electrified for a considerable time, without producing any peculiar effects; from whence he inferred, that the electrical fluid, when in a state of rest, had no more heat than the air in which it might reside. When the two wires were in contact also, and a powerful shock passed through the apparatus, little or no effect was produced: but when the wires were placed about two inches asunder, the charge of a small jar rarefied the air

very considerably. The charge of a jar containing about five gallons produced a prodigious rarefaction in the air, frequently raising the fluid to the top of the tube.



Another air-thermometer may be noticed. Its construction was suggested by Lieut. Harris, and it consists merely of a glass bulb furnished with a capillary tube, containing a small portion of any coloured fluid. The stem, D, is inserted in a mahogany stand, which preserves it in a perpendicular position; and a graduated index, passing from D to C, indicates the height of the fluid. Two rings at A and D, form the communication between the internal and external coatings; so that, on making a communication between them, a portion of air is displaced, and the amount is found to differ very materially in different gaseous bodies.

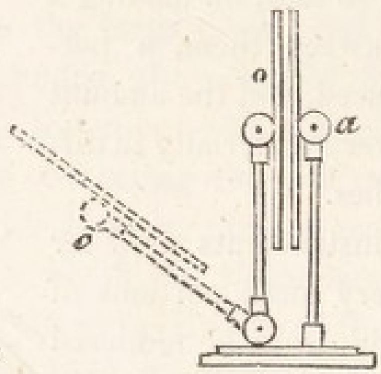
Condensers are instruments used for the detection of very small portions of electricity, too minute to be rendered sensible by the electrometer.

Volta appears to have been the first electrician who constructed an apparatus of this description. His condenser of electricity consisted of a flat and smooth metal plate, furnished with an insulating handle, and a semi-conducting, or imperfectly insulating plane. The principle on which the action of this apparatus depends, says Mr. Cavallo, " is, that the metal plate, whilst standing contiguous to the semi-conducting plane, will both absorb and retain a much greater quantity of electricity than it can

either absorb or retain when separate; its capacity being increased in the former, and diminished in the latter case."

This condenser was afterwards improved by Mr. Cavallo, who employed a small metallic plate, about the size of a shilling, having affixed to it a glass handle covered with sealing-wax. When the larger plate appeared so slightly electrified by the communicated electricity as not to affect the electrometer, he then placed the small plate on the plane, and touched it with the edge of the large one, holding the latter in an almost vertical position; the small plate was thus found to indicate a very sensible degree of electricity.

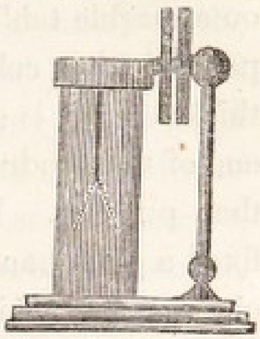
One of the most convenient and elegant condensers yet contrived is that of Mr. Cuthbertson. This instrument is shown in the engraving, and is composed of two metallic



plates, *a* and *c*, about six inches in diameter, tightly screwed to two brass balls, but so as that one of them be fixed immovably to a glass pillar, as *a*, while the other is fastened to a brass pillar, having a hinge at its lower extremity, by which it can be moved backwards from the position *o*. When the instrument is used, the electricity to be examined is communicated to the insulated plate *c*, while it is parallel to the uninsulated plate *a*; and after remaining for some time in this position, the uninsulated plate is

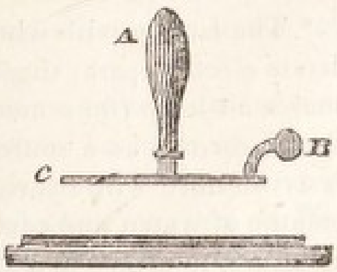
drawn back, and the intensity of the insulated plate *c* is shown by being presented to an electrometer in the usual way.

A modification of this instrument, called the condensing electrometer, is represented in the accompanying figure. In this construction the plates are smaller, and the insulated plate is attached to the cap of a gold-leaf electrometer; by this means very small degrees of electricity are discovered, and their intensity shown by the divergence of the gold leaves within the cylinder.



A condenser of a remarkably simple description was proposed by Mr. Singer, and is constructed by placing three small spots of sealing-wax, at equal distances, on the lower face of the cover of an electrophorus, to serve as insulating feet, by which the cover may be supported at the distance of about the twelfth of an inch from the surface of a smooth and even table. If a Leyden jar, he adds, be now charged, and afterwards discharged, so as not to affect an electrometer, and its knob be then placed in contact with the condenser resting on the table for a few seconds, the small residuum of electricity in the jar will be absorbed by the condensing plate; and when this is raised from the table, it will affect the electrometer with the same electricity as that with which the jar was charged.

The *electrophorus* is sometimes employed as a substitute for the electrical machine. The accompanying figure furnishes a view of this useful piece of apparatus, which is easily constructed by a reference to the following directions. Procure two circular plates of metal, or of



wood covered with tin-foil, and well rounded at the edges; these are the conductors: between them is placed a resinous plate, formed by melting together equal parts of shell-lac, resin, and Venice turpentine, and pouring this mixture, whilst fluid, into a tin hoop of the required size, placed on a marble table, from which the plate may be readily separated when cold. This plate should be half an inch in thickness; it is sometimes made by pouring the mixture on one of the conductors, which is then formed with a rim for that purpose. In the centre of the upper conductor is fixed a glass handle A, for the purpose of lifting it without drawing off its electricity; and, when the electric state of the lower conductor is to be examined, the whole apparatus must be placed on an insulating stand. To use the electrophorus, rub the upper surface of the resinous plate with a piece of dry fur; cat's skin is reckoned the best, and it will be excited negatively. Place the upper conductor *c* upon it, and then raise the same by its insulating handle; it will be found to exhibit very faint, if any, electrical signs. Replace the conductor, and, whilst it lies on the surface of the excited plate, touch it with a finger or any other uninsulated conductor, and then raise it again by its handle. It will now be positively electrified, and afford a spark at B: if it be then placed on the resinous plate, touched, and again raised, another spark will be procured; and this process may be repeated for a considerable time without any perceptible diminution of effect.*

* The facility with which inflammable air is lighted by even a moderate electric spark, suggested to Volta the construction of an inflammable air-lamp (for a modification of which a patent was some time since procured as a source of instantaneous light). It consists of a reservoir filled with hydrogen gas, subject to the constant pressure of a column of water, and confined by a stop-cock, which, when opened, permits it to escape in a slender stream from a small aperture. In a

In the year 1746, some very singular phenomena were exhibited by two or three ingenious professors in the University of Leyden; which depended on a newly discovered power of accumulating electricity. Their mode of exhibiting these effects consisted in enclosing some water in a glass vessel, and electrifying it; if then the outside of the glass vessel was grasped with one hand, and the enclosed conductor, or any substance connected with it, touched with the other, a bright spark ensued, and a violent convulsive motion was felt in the arms and across the breast.

Professor Muschenbroeck, Messrs. Cuneus, Alemand, and Winkler, made the experiment with water in glass jars or bottles; and M. Von Kliest (who it is said first made the discovery) employed a phial, in which a blunt piece of wire was loosely placed. This experiment soon became popular; the apparatus received the name of a Leyden jar, or Leyden phial; and the sensation it produced, the electric shock.*

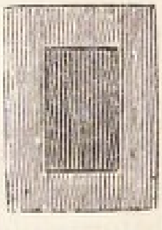
Dr. Franklin, in accounting for these phenomena, suggested that a charged phial or jar contained no more electricity than before; that as much was taken from one side, as the other had above its natural portion; and that, to discharge it, nothing more was necessary than to make a com-

box beneath the vessel of gas an electrophorus is placed, and a wire passes through a glass tube from the upper part of this box to the opening of the stop-cock. The cover of the electrophorus is connected by a silk string with the handle of the stop-cock; so that the same motion that opens the cock, raises the cover of the electrophorus, and the spark that passes from it is conveyed by the insulated wire to the stream of gas, which it inflames.

* The first experimenters gave ludicrous and exaggerated accounts of its effects, and to this circumstance, may perhaps be partly attributed the public curiosity it so promptly and highly excited. In the same year it was shown by itinerant exhibitors in almost every part of Europe; and the experiment was repeated and varied by the electricians of every country.

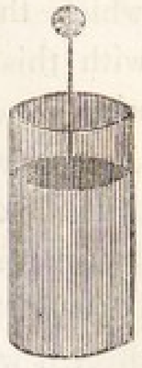
munication between the two sides; the electricity being by this means enabled to regain its equilibrium, that equilibrium was instantly restored, and no signs of electricity remained. He also demonstrated by experiments, that the electricity did not reside in the coating, as had been supposed, but in or upon the glass itself. After a phial was charged, he removed the coating, and found, that upon applying a new coating, the shock might be received. When, to any body or surface, was attributed the property, according to this theory, of having more than its usual portion of electricity, the Doctor proposed to distinguish its state by the term *plus*, or positive; when the body or surface had less than its usual share of electricity, its state was distinguished by the term *minus*, or negative. These terms answered the same end, and expressed the same things, as those of vitreous and resinous, proposed by Du Fay, but they were supposed to be so much more appropriate, that their admission into the language of the science soon became general both in England and America.

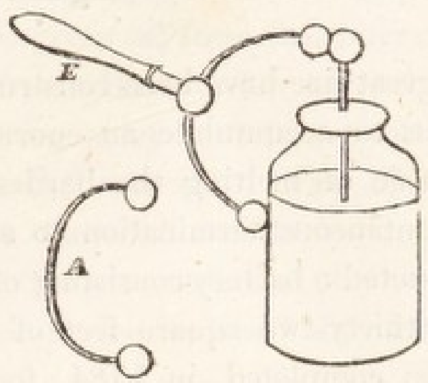
Having thus briefly explained the usually received theory of the Leyden experiment, it may now be advisable to examine the form of the apparatus best calculated to exhibit the effects of accumulated electricity. A plate of common window-glass, coated on both sides with tin-foil, is occasionally used for this purpose; though it will be evident that the metallic coating must not reach the extremity of the glass, as a conducting communication would then be formed between the two surfaces.



If we wish to increase the electrified surface, a glass cylinder or jar is employed, and a wire, projecting from the centre, is furnished with a ball which connects the

interior of the jar with the prime conductor of the machine. But the most convenient form of the jar is shown in the accompanying diagram. It is coated on the inside, and also on the outside, with tin-foil to within two inches and a half of the top. With the inside coating a wire is connected, which rises through a lid of baked wood neatly fitted into the mouth of the jar,





and terminating in a smooth brass ball. The uncoated part of the jar must be kept perfectly clean and dry, otherwise the action will be very incomplete. The coating is best fastened on with very strong gum water, but some electricians use common paste; and in some instances the tin-foil is first pasted upon paper, and afterwards on the glass: this is considered an improvement, both as it respects the facility of drying the gum or paste, and also the strengthening of the jar.

When it is wished to discharge the jar without allowing the charge to pass through the body, an instrument is used, called the discharging rod, which is composed of a bent wire A, or two branches, connected by a joint, and furnished with a glass handle E. The extremities of the rod or branches are pointed, but have screws, by means of

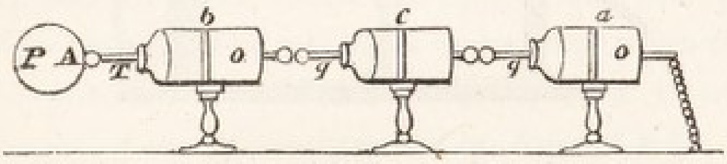
which they are fitted with balls. In discharging a jar with this instrument, it is held by the glass handle, and, while one end is applied to the outer coating of the jar, the other is made to approach the ball of its wire, and thus the electricity passes through the metallic part of the discharger from the one coating to the other of the jar. If the extremities be without their balls, the discharge is effected without noise; but otherwise there takes place an explosion, more or less loud according as the jar is more or less charged.

Batteries of great size have been constructed by different electricians, so as to accumulate an enormous quantity of electricity, capable of melting the hardest metals, and of putting an instantaneous termination to animal life. Dr. Priestley constructed a battery consisting of sixty-four jars, and containing thirty-two square feet of coated surface. Mr. Cuthbertson completed, in 1784, for the Teylerian Museum at Haarlem, a battery of one hundred and thirty-five jars and one hundred and thirty-two feet of coated surface; and in 1789 he completed another battery for the same institution, consisting of one hundred jars, and containing five hundred and fifty feet of coated surface.

We have already noticed that the uncoated interval of the Leyden jar should be clean and dry; but this must be understood with some limitation, as, if it be perfectly clean, and so dry as to approach to warmness, an explosion will take place between the coatings over the glass, and thus occasion a loss of the charge, with a great waste of time. These effects may be prevented by breathing on the glass through a piece of barometer tube, but much more effectually by pasting a slip of writing paper, an inch broad, on the inner surface of the jar, close to the upper edge of the coating. By this means the intensity of the charge is

diminished at the very spot where its tendency to explode is the greatest.

If we suspend a globular jar by its knob from the positive conductor of the electrical machine, the outer coating being insulated, no charge can be communicated to it, as the glass has only an attraction for a certain quantity of electricity, and the coatings can only be considered as conductors for its two surfaces; but if a communication be made with the ground by means of any conducting body, sparks will then be given off from the outer coating in rapid succession. Professor Brande has suggested a mode of applying this arrangement to the construction of a powerful battery; instead, however, of supporting them by the prime conductor, they are attached to glass insulating stands. This ingenious contrivance may be readily understood by reference to the annexed diagram, in which the

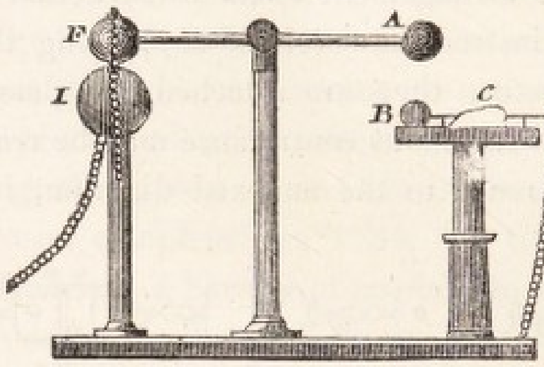


jar *b* is connected by its ball T, with the prime conductor P A, while the outer coating *o*, communicates with the internal surface of the jar *c*; this is again connected in a similar way with the third jar *a*,—the latter jar having its outer coating *o* connected with the ground. On connecting this series in the ordinary way, after it is charged, it will be evident that a very powerful effect must be produced.

Upon this principle, several jars may be charged at once by attaching them to the prime conductor, so that the outer coating of one of the suspended jars invariably communicates with that which precedes it. Thus the ball of the first jar is attached to the prime conductor by a hook;

and a similar contrivance may then be employed to connect the internal coating of the second with the external side of the jar above it; and as the electric fluid is driven off from the first jar, it is received by the second, and so on through the entire series.

An electrometer has been constructed by Mr. Cuthbertson, which, for discharging accumulated electricity, is superior to any that has yet been described. Those only who have to go through the operation of melting wires before a public audience, can duly appreciate the value of this incomparable instrument.



The accompanying figure will best illustrate the form of the apparatus. The base consists of an oblong square piece of mahogany of about eighteen inches long, and six in breadth: in this are three glass supports, mounted with brass balls. The ball I, has a brass tube fixed to it, about three inches long, cemented to the top of the glass stand, and a hole at the top, of about half an inch in diameter, corresponding with the inside of the tube. A F, is a straight brass wire, with a knife-edged centre in the middle, placed a little below the centre of gravity, and equally balanced with a hollow brass ball at each end; the centre, or axis, resting upon the inside of the central ball, a light balance weight being fitted to the wire.

It is obvious, from the construction of the apparatus, that if the foot stand horizontally, and the ball F be made to touch I, it will remain in that position without the help of the weight; and if it should receive a low charge, the two balls will repel each other; F will begin to ascend, and, on account of the centre of gravity being above the centre of motion, the ascension will continue till A rest upon B. If the balance be again set horizontally, and the sliding weight be brought towards F, it will bring F back to I, with a pressure equal to that weight, so that more electricity must be communicated than formerly, before the balls will separate; and, as the weight at F is increased or diminished, a greater or less quantity of electricity will be required to effect a separation.

When this instrument is to be used with a jar, or battery, one end of a wire or chain must be inserted into the ball L, and the other end into a hole of any ball proceeding from the inside of a battery or jar, and when the electrical repulsion becomes sufficiently energetic to overcome the weight, a communication will be formed with the ball at B, and the inflammable body *c* inflamed. The communication between the ball F and the prime conductor being kept up after the ball F, leaves I, by means of a small loose wire within.

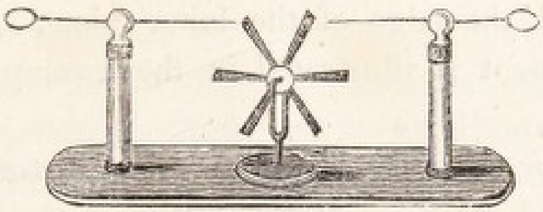
A variety of attempts have been made to mark the precise direction of the electrical current which results from destroying the equilibrium of any two bodies. If we take a Leyden jar that has been rendered slightly damp by being breathed upon, and place it with its knob in contact with the positive conductor of an electrical machine in a darkened room, when the jar is charged, and the action of the machine continued, the electricity will appear to pass from the internal to the external coating over the uncoated

interval in luminous streams, like water overflowing from the top of a vessel kept constantly supplied. If the jar be removed, and its knob placed against the negative conductor, the stream will obviously change its direction. A degree of dampness on the uncoated part of the glass is necessary in this experiment, to prevent the discharge of the jar by a spontaneous explosion, in which case the fluid passes too rapidly from one surface to the other to allow the observer to ascertain its direction. If the moisture be not sufficient, diverging brushes of light will occasionally pass from the positive surface, instead of the continuous streams abovementioned.

If a light wheel, the vanes of which are made of fine card-paper, be made to turn freely on its axis, a stream of electricity from a pointed wire fixed in the conductor will give it motion; and it will move from the electrified point, whether its electricity be positive or negative. In this experiment, the current seems to be produced by the recession of the similarly electrified air in contact with the point; and, therefore, the circumstance of the wheel turning in the same direction when the electricity is negative, cannot be considered as a proof of the existence of a double current of the electric fluid.

But the most satisfactory exhibition of the course of the electric fluid, or air, from the positive to the negative conductor, is afforded by an experiment contrived by Mr. Singer, and which he considered as removing all difficulties on the subject. "It has," observes he, "been long known that a light float-wheel, made by inserting several vanes of card in the periphery of a cork that is made to turn freely on a pin or centre, will be put in motion by presenting it to an electrified point; and the motion of the wheel being always from the point, whether that point was positive or

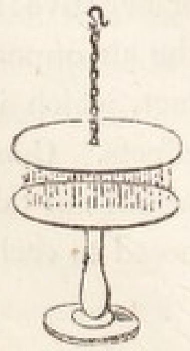
negative, has been occasionally urged as an argument for a double current of the fluid; although it is evident, from what has been already stated, that a point either positive or negative must produce a current, by the recession of the air opposed to it, when similarly electrified by its contact, which is fully adequate to the production of these effects. Conjecturing that the currents of electrified air would not take place in this manner if the points were opposed to each other, the following arrangement was made."



A light float-wheel is shown above, which being mounted so as to turn freely between two upright wires, was placed on an insulated stem, and introduced between the pointed wires of Henley's discharger, which was placed accurately opposite to each other, and at the distance of rather more than an inch from the upper vanes of their respective sides. On connecting one of the wires with the positive conductor of the machine, and the other with the negative conductor, and turning the machine, the wheel will move in a direction from the positive to the negative wire. On reversing the connexions, so that the wire which was negative may become positive, and that which was positive be made negative, the motion of the wheel will be reversed; for it will still move from the positive to the negative wire.

The attraction and repulsion of air that has been electrified by contact with the prime conductor of the electrical machine may readily be exhibited by the following simple

apparatus. Suspend from the conductor, by a brass chain, a circular plate of copper, reaching to within an inch and a half or two inches of the table. Directly under this plate place another of the same form, and a little larger, on the table. Turn the machine, and the fluid will pass from the upper to the lower plate. If small figures cut out of pasteboard, or pith of elder, be introduced between the plates, they will dance about with apparent vivacity, and sometimes appear to course round the edge of the lower plate,



This experiment is illustrated in the accompanying diagram.

The *electrical bells* furnish a pleasing illustration of the attraction and repulsion of the electric matter. They are usually three in number. The two outer bells are suspended by brass chains; the middle bell and the two clappers by fine silk threads. When the bells are attached to the conductor, and the machine is turned very gently, the fluid will pass along the chains to the two outer bells, but will not pass along the silk to the clappers and middle bell. Thus the outer bells, being charged with an extra quantity of fluid, will attract the clappers; but the moment they touch the bells they become charged, and are repelled with such force as to cause them to strike against the middle bell, on which they deposit their electricity, and are again attracted. By this means a constant ringing is kept up while the machine is turned. From the inside of the middle bell, a brass chain passes to the table, for the purpose of conveying away the fluid deposited on it by the clappers.

When a powerful electric charge is passed through a slender iron wire, the wire is ignited or dispersed in red-

hot balls. Very large batteries were formerly considered essential to the production of this effect; but if the wire be sufficiently thin, a single jar, exposing a coated surface of about one hundred and ninety square inches, will sufficiently exemplify it. The finest flat steel wire is best calculated for the purpose. Cuthbertson's balance electrometer should always be employed to regulate the charge: the circuit from the inner to the outer surface of the jar should be as short as possible; and the wire intended to be melted, placed in a right line, and confined at the ends between small wire forceps.

Dr. Franklin performed some pleasing experiments on the fusing of metals, which may be thus imitated:—Take three pieces of window-glass, each one inch wide, and three inches long, and place them contiguous to each other, with two narrow strips of gold-leaf between them, so that the middle glass may have, on each side of it, a strip of gold, with its ends projecting a little beyond the glass. Let the whole be properly secured within the press of the universal discharger; pass the charge of a large jar through the strips of gold, they will be melted and driven into the glass. The outer pieces of glass are generally broken, but the middle piece is often left entire, and is marked with an indelible metallic stain on each of its surfaces.

The colours produced when metals are thus fused, either on glass or paper, are sometimes exceedingly beautiful, and have been in some cases employed in impressing letters, and ornaments of various kinds, on silk and paper. The process observed in such cases, Mr. Singer thus describes in his Elements:—" The outline of the required figure is first traced on thick drawing-paper, and afterwards cut out in the manner of stencil plates. The drawing-paper is then placed on the silk or paper intended to be marked; a leaf

of gold is laid upon it, and a card over that; the whole is then placed in a press, or under a weight, and a charge from a battery sent through the gold leaf. The stain is confined, by the interposition of the drawing paper, to the limit of the design; and in this way, a profile, a flower, or any other outline figure, may be very neatly impressed."

A single spark may be made to perforate a strong glass tube by the following simple process: fill a small phial with olive oil, and insert into it a pointed wire bent at right angles, so that by sliding through a cork fixed in the neck of the phial, the point of the wire may rest against any part of the inside beneath the oil: attach the phial by its wire to the conductor of the machine, and bring the knuckle or a brass ball near the outside of the phial, opposite to the point of the wire within it; a spark will pass from the point to the knuckle, and make a small hole in the glass.

Almost all inflammable substances may be kindled by means of electricity. The common method of kindling resin by the electric spark, is to pulverise it, and sprinkle the powder on some dry cotton wool. Thus, if a small quantity of flax, or of cotton wool, be loosely tied on one of the knobs of the discharging rod, and a little finely-powdered resin sprinkled on it, and a jar be discharged by bringing the end of the rod thus prepared in contact with the knob of the jar, the charge will pass through the flax, or wool, and in so doing will melt and ignite the resin, and set the whole on fire.

The decomposition of water by electricity was first effected by Van Troostwyk and Deiman, assisted by Mr. Cuthbertson; this they effected by means of a complicated apparatus, and a very tedious process. Their method of procedure was improved on by Dr. Pearson, and after him by Mr. Cuthbertson: but the most simple form of an ap-

paratus for this purpose is that of Dr. Wollaston. This apparatus is thus constructed:—Two finely pointed wires of gold or platina are inserted into capillary tubes; each wire is thrust into the tube till it nearly reaches the end of it, and the glass is softened by heat until it adheres to the wire and covers its point. The glass is then carefully ground away, till the point of the wire can be seen by the help of a magnifying glass. One of these wires is made to communicate with the ground, or with the negative conductor of the machine, and the other with an insulated ball placed near the positive conductor; the two points are placed near each other in a vessel of water: when a current of sparks is discharged through the wires, a series of minute bubbles of gas will rise from the points of the gold wires, and, when collected in an inverted receiver, will explode on the application of a lighted taper. Dr. Wollaston found by experiment, that a point 1-700th of an inch in diameter, decomposed the water, when the spark which passed from the conductor to the insulated ball was 1-8th of an inch in length; and that a point 1-1500th of an inch in diameter produced the same effect, when the sparks were only 1-20th of an inch in length. Hence the rapidity of the decomposition was in proportion to the limited size of the point of the wire.

To show the passage of the electric light, we may employ an instrument composed of a glass tube closed with two brass caps. This tube has a spiral row of small round pieces of tin-foil attached to its outer surface, and lying at about 1-13th of an inch from each other. If this instrument be held by one of its extremities, and its other extremity be presented to the prime conductor, every spark that it receives from the prime conductor will cause small sparks to appear between all the round pieces of tin-foil,

and this in the dark affords a pleasing spectacle, the instrument appearing encompassed by a spiral line of fire. The small round pieces of tin-foil are at other times attached to a flat piece of glass, so as to represent curve lines, flowers, letters, &c. and they may be illuminated in the same manner as the spiral tube.

The colour of the electric spark seems to depend on the density of the medium through which it is made to pass. This is proved by the following experiments :—Fix with cement a short iron or platina wire at one end of a glass tube thirty inches long, so that the wire may project a little way within the tube, and fix a small brass ball on the outer extremity of the wire. Fill the tube with mercury, and at the open end place a drop of ether, which may be secured by the point of the finger while the tube is inverted in a vessel of mercury, so as to form a Torricellian vacuum in the upper part. The ether will rise to the top; and upon the removal of the finger, and the fall of the mercury, will expand into vapour. If now electricity be transmitted through this vapour, it will be rendered luminous, and assume various hues according to its strength. When the spark is strong, and has to pass through some inches of the expanded vapour, the light is usually of a beautiful green colour. Take an air-pump receiver twelve or fourteen inches high, and six or seven inches in diameter; adapt a wire, pointed at its lower extremity, to the top of the receiver, letting the point project about two inches into its inside; place the receiver on the plate of the air-pump, and electrify the wire at its top positively; whilst the air remains in the receiver, a brush of light of very limited size only will be seen, but in proportion as the air is withdrawn by the action of the pump it will enlarge, varying its appearance, and becoming more

diffused as the air becomes more rarefied; until at length the whole of the receiver is filled by beautiful coruscations of light, changing their colour with the intensity of the transmitted electricity. Another pleasing experiment may be noticed:—Into a piece of soft deal about three inches long and an inch and a half square, insert two pointed wires obliquely at nearly an inch and a half distance from each other, and to the depth of an eighth of an inch; the wires should incline in opposite directions, and the track between the points be in that of the fibres; a spark, in passing from one point to another through the wood, will assume different colours, in proportion as it passes more or less below the surface; and by inserting one point lower than the other, so that the spark may pass obliquely through different depths, all the prismatic colours may be made to appear at once. Sparks taken through balls of wood or ivory appear of a crimson colour; those from the surface of silvered leather are of a bright green; a long spark taken over powdered charcoal is yellow; and the sparks from imperfect conductors have a purple hue. The quantity of air through which these sparks are seen also influences their appearance; for the green spark in the vapour of ether appears white when the eye is placed close to the tube, and reddish when it is viewed from a considerable distance.

ATMOSPHERIC ELECTRICITY.

Identity between Lightning and Artificial Electricity.—Experiments by Franklin, Monnier, and Mazeas.—Electric Kite.—Results by Cavallo.—Phenomena of a Thunder-Storm. — Atmospheric Electrometer. — Best Mode of Protecting Buildings.—Thunder and Powder Houses. — Electric Light in Rarefied Air. — Aurora Borealis.—Shooting Star.

We have now to notice the analogy that subsists between atmospheric electricity, or lightning, and that produced by artificial means. The following may be considered as an outline of Dr. Franklin's observations on this important branch of the science. He commences by observing that " The zig-zag appearance of the natural lightning is exactly the same as that of a strong electric spark when it passes through a considerable interval of air. Lightning generally strikes such bodies as are high and exposed, as the summits of hills, the tops of lofty trees, high towers, and spires; while the electric fluid is always received by the most prominent parts, when striking from one body to another. Lightning is observed to strike most frequently into those substances that are good conductors of electricity, such as metals, water, and moist substances; and to avoid those that are non-conductors. Lightning inflames combustible bodies. The same is effected by electricity. Metals are melted by a powerful charge of electricity: this phenomenon is one of the most common effects of a stroke of lightning. Lightning destroys animal life. The magnetic needle is effected in the

same manner by lightning and by electricity, and iron may be rendered magnetic by both causes. The phenomena are, therefore, strictly analogous, and differ only in degree; and if an electrified gun-barrel will give a spark, and produce a loud report at two inches distance, what effect may not be expected from perhaps 10,000 acres of electrified cloud?"

Reasoning from these facts, Franklin formed the design of erecting a conducting-rod by which the lightning might be drawn from the clouds, and thus afford an opportunity of ascertaining its identity with the electric fluid. "The electric fluid," said he, "is attracted by points; we do not know whether this property be in lightning; but since they agree in all the particulars in which we can already compare them, it is not improbable that in this they likewise agree. Let the experiment be made." While the American philosopher was waiting for the erection of a spire in Philadelphia, his opinions became known, and he was anticipated by D'Alibard and De Loe, who erected a rod such as Franklin had suggested, in France, and succeeded in the experiment.

The earliest useful observations that were made on the electrical state of the atmosphere in Europe, appear to have been those of Monnier; his experiments were performed with an apparatus, which consisted of a pole thirty-two feet in height insulated in a piece of turf, having at its top a strong glass tube, to which a tube of tinned iron was attached, and which terminated in a point. About the middle of this tube there was fastened a fine iron wire about fifty lines long, which, without touching any other body, was connected with a silk cord stretched horizontally. He found that, although the atmosphere was constantly electrified more or less, yet that in dry weather

the electricity increased from sunrise, when it was weakest, till about four o'clock in the afternoon, at which time it was strongest, gradually diminishing from that time till the dew began to fall, after which it diminished till midnight.

The Abbé Mazeas made several observations with an atmospherical apparatus, consisting of an iron wire three hundred and seventy feet long, raised about ninety feet from the ground, and properly insulated. The results of his experiments with this instrument were the following:—In very dry weather the wire readily attracted light bodies, if brought within three or four lines of it; and, if the weather was not stormy, the electricity of the air was about half as great as that of a stick of sealing-wax two inches long. When he grasped the wire in his hand, the signs of electricity disappeared entirely, and did not return till after an interval of three or four minutes. He also found that the electricity of the atmosphere was not increased with storms and hurricanes unattended with rain; for during a violent storm of wind, which continued uninterruptedly for three days, in the month of July, he found it necessary to place the dust within four or five lines of the conductor, before it exhibited a sensible attraction. No change was produced by the different directions of the winds. In the driest nights of summer he never could observe any electricity in the air, but it began to appear in the morning at sunrise, and vanished in the evening at about half an hour after sunset. In the month of July, on a very dry day, when the sky was serene, and the heat intense, he found the electricity stronger than he had ever observed it. The dust was then attracted at the distance of ten or twelve lines from the conductor.*

* Experiments connected with atmospheric electricity, were now performed by the philosophers in nearly every part of Europe, and the

Having thus briefly noticed the effects of metallic rods for conveying the electricity of the atmosphere to the earth's surface, it may now be advisable to advert to another agent, which, although somewhat more complicated than the conducting wire, was yet found, in the hands of Dr. Franklin, a most efficient piece of apparatus. It consists in the elevation of a long conducting string by means of a windsail or kite.

An *electrical kite* should be constructed in the most simple manner, as it is an apparatus very liable to be injured or lost. In dimensions it should not exceed four feet in height, by two feet wide. This will be found the most manageable size, and it is necessary to varnish it with drying oil to defend it from the rain. The string must be furnished with a thin copper or silver thread interwoven through its whole length; that which is employed in the fabrication of gilt lace appears best adapted to the purpose.

When the kite is raised, the string is insulated by attaching to it a silk cord, whose opposite extremity may be

following unfortunate catastrophe will show that they were not always unattended with danger. On the 6th of August, 1753, Professor Richman, of Petersburgh, was making experiments on lightning drawn down a metal rod into his own room. He had provided himself with an instrument for measuring the quantity of electricity communicated to his apparatus, and as he stood with his head inclined to it, Solokou, an engraver, who was near him, observed a globe of blue fire, as large as his hand, pass from the instrument towards his head. The Professor was struck lifeless, and his assistant was also much hurt. The latter could give no very minute account of the way in which he was affected; for at the time the Professor was struck, he stated there arose a sort of vapour which entirely benumbed him, and made him sink down to the ground, so that he could not even remember to have heard the clap of thunder which followed. The globe of fire was attended with an explosion like that of a pistol; the instrument for measuring the electricity was broken to pieces, and the fragments thrown about the room.

fastened to a rail, or any other fixed place. The end of the metallic string may then be connected with a prime conductor similar to that employed in the common electrical machine; and with this the experiments may be performed.

To ensure the safety of the operator, which is a very important consideration in this otherwise dangerous experiment, it will only be necessary to connect a brass rod with the earth, and bring the other end within about two inches of the prime conductor, so that in the event of the kite coming in contact with a large electrical cloud, a ready passage will thus be found for the electric fluid to the earth. In raising or lowering the kite, shocks are frequently taken: this, however, may be effectually prevented, by suffering a part of the string between the operator and the kite, to bear constantly against the brass ball that is connected with the ground; and this precaution is more particularly essential when thunder-clouds are over-head.

Mr. Cavallo, from a variety of experiments made with electrical kites, furnishes the following results, which will be found correct in the generality of cases. "The air appears to be electrified at all times: its electricity is constantly positive, and much stronger in frosty than in warm weather; but it is by no means less in the night than in the daytime. When it rains, the electricity of the kite is generally negative, and very seldom positive. The aurora borealis seems not to affect the electricity of the kite. The electric spark taken from the string of the kite, or from any insulated conductor connected with it, especially when it does not rain, is very seldom longer than a quarter of an inch; but it is exceedingly pungent. When the index of the electrometer is not higher than 20°, the person who takes

the spark will feel the effect of it in his legs; as it appears more like the discharge of an electric jar, than the spark taken from the prime conductor of an electrical machine The electricity of the kite is generally stronger or weaker, according as the string is longer or shorter; but it does not keep any exact proportion to it. The electricity, for instance, brought down by a string of one hundred yards, may raise the index of the electrometer to twenty; when, with double that length, the index of the electrometer will not go higher than twenty-five."

The phenomena incident to a thunder-storm are always beheld with the most intense interest by the student in this science; and although many very poetical descriptions of its effects are on record, the facts furnished by the Italian philosopher Beccaria are as illustrative as any.

"Thunder-storms," says Beccaria, "generally happen when there is little or no wind; and their first appearance is marked by one dense cloud, or more, increasing very fast in size, and rising into the higher regions of the air; the lower surface black, and nearly level, but the upper finely arched, and well defined. Many of these clouds seem frequently piled one upon another, all arched in the same manner; but they keep continually uniting, swelling, and extending their arches.

"At the time of the rising of this cloud, the atmosphere is generally full of a great number of separate clouds, motionless, and of odd and whimsical shapes. All these, upon the appearance of the thunder-cloud, begin to move towards it, and become more uniform in their shapes as they approach; till, coming very near the thunder-cloud, they mutually stretch towards one another, immediately coa-

lesce, and together make one uniform mass. But sometimes the thunder-cloud will swell, and increase very fast, without the conjunction of these adventitious clouds, the vapours of the atmosphere forming themselves into clouds wherever it passes. Some of the adventitious clouds appear like white fringes at the skirts of the thunder-cloud, but these are continually growing darker and darker as they approach or unite with it.

"When the thunder-cloud is grown to a great size, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into various large protuberances, bending uniformly towards the earth. When the eye is under the thunder-cloud, after it is grown larger, and well formed, it is seen to sink lower, and to darken prodigiously; at the same time that a number of adventitious clouds (the origin of which can never be perceived) are seen in rapid motion, driving about in every direction under it. While these clouds are agitated with the most rapid motions, the rain generally falls in the greatest plenty; and, if the agitation is exceedingly great, it commonly hails."

While the thunder-cloud is swelling, and extending its branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired a sufficient extent, the lightning strikes between the cloud and the earth, in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches.

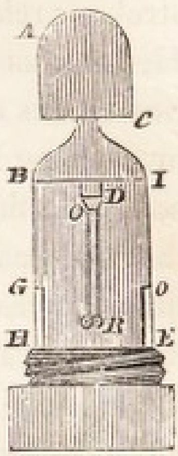
The electrical explosion generally takes place in the air, and at a considerable height; but in many instances it happens between the clouds and the earth. In most instances, perhaps, the lightning descends from the clouds to

the earth, and the explosion is then called the descending stroke; but in some cases it is known to pass from the earth to the clouds, and is then termed the ascending stroke: of the latter kind appears to have been the explosion which took place on the Malvern Hills, in the summer of 1826, and which was attended with such melancholy consequences. A very curious instance of the ascending stroke is related by G. F. Richter, in his work on thunder. He informs us, that in the cellar belonging to the Benedictine monks of Fontigno, while the servants were employed in pouring into a cask some wine which had been just boiled, a fine light flame appeared round the funnel, and they had scarcely finished their operation, when a noise like thunder was heard: the cellar was instantly filled with fire; the cask was burst open, although hooped with iron; the staves were thrown with prodigious violence against the wall; and, on examination, a hole of three inches diameter was found in the bottom of the cask.

A portable electrometer is essential for observing the electrical state of the atmosphere, for meteorological purposes. Electrometers constructed of pith of elder were employed by Mr. Cavallo in many of his experiments. The case, or handle, of one of these instruments must be formed of a glass tube, about three inches in length, and three-tenths of an inch in diameter, one half of which is coated with wax on the outside. From one extremity of this tube a small loop of silk proceeds, which occasionally serves to support the electrometer. To the other extremity of the tube a cork is adapted, which, being cut tapering on both ends, can fit the mouth of the tube with either end. From one extremity of this cork two linen threads proceed, a little shorter than the length of the tube, each of which support a little cone of pith. When this electrome-

ter is to be used, that end of the cork which is opposite to the threads is pushed into the mouth of the tube; the tube then forms the insulated handle of the instrument. But when the electrometer is to be carried in the pocket, the threads are put into the tube, and the cork stops it.

Mr. Cavallo also constructed another portable electrometer for atmospherical purposes, which deserves particucular notice. Its principal part consists of a glass tube B I O G, as represented in the accompanying figure, cemented at the bottom into the brass piece H E, by which part the instrument is to be held when used for the atmosphere. The upper part of the tube is tapered, and entirely covered with sealing-wax; to this tapering part a small tube is cemented; the lower extremity, being also covered with sealing-wax, projects a short way within the large tube.



Into this smaller tube a wire is cemented, which with its under extremity touches the flat piece of ivory D, fastened to the tube by means of a cork; the upper extremity of the wire projects about a quarter of an inch above the tube, and screws into the brass cap A C, which cap is open at the bottom, and serves to defend the waxed part of the instrument from moisture.

The conical corks, or balls, B, which show the electricity by their repulsion, are made very small, and suspended by very fine silver wires, shaped like rings at the top, by which they hang very loosely on the flat piece of ivory, which has two holes in it. By this method of suspension, which is applicable to every sort of electrometer, the friction is reduced to almost nothing, and the instrument is thus rendered sensible to a very small degree of electricity. O E

and G H are two narrow slips of tin-foil, fixed on the inside of the glass, and communicating with the brass bottom H E. They serve to convey that electricity which, when the balls touch the glass, is communicated to it, and, being accumulated, might disturb the free motion of the balls.

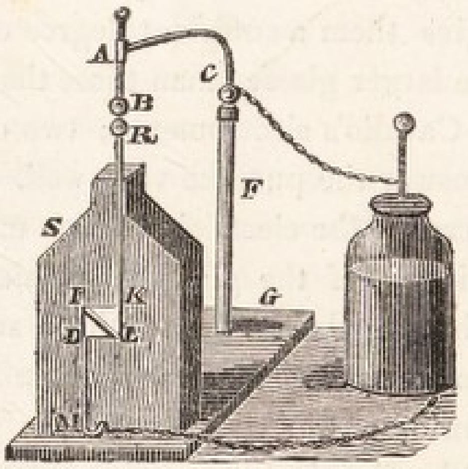
To try the electricity of the atmosphere by this electrometer, the electrician must unscrew it from its case, and hold it by the bottom H E; thus presenting it to the air a little above his head, so that he may conveniently see the balls, which will immediately diverge if there is any electricity; whether this be positive or negative, may be ascertained by bringing an excited piece of sealing-wax, or other electric, towards the cap.

M. Saussure has made an improvement in this electrometer. The principal circumstances in which his electrometer differs from Mr. Cavallo's are: The fine wires, by which the balls are suspended, should not be so long as to reach the tin-foil which is pasted on the inside of the glass; because the electricity, when strong, will cause them to touch this tin-foil twice consecutively, and thus deprive them in a moment of their electricity. To prevent this defect, and yet give them a sufficient degree of motion, it is necessary to use larger glasses than those that are generally applied to Mr. Cavallo's electrometer; two or three inches diameter will answer the purpose very well. But, as it is necessary to carry off the electricity which may be communicated to the inside of the glass, and which may be confounded with that which belongs to those substances that are under examination, four pieces of tin-foil should be pasted on the inside of the glass; the balls should not be more than 1-20th of an inch diameter, suspended by silver wires, moving freely in holes nicely rounded. The bot-

tom of the electrometer should be of brass; for this renders it more easy to deprive them of any acquired electricity, by touching the bottom and top at the same time.

For common purposes, and occasional observations, very simple contrivances may be employed. A common jointed fishing-rod, having a glass stick covered with sealing-wax substituted for the smallest joint, may be occasionally projected from the upper window of a house. A pair of pith-balls must be attached to a cork, in which the end of the glass stick is thrust; and this part of the apparatus is to be occasionally uninsulated, by placing a pin in the cork, connected with a thin wire held in the hand. In this uninsulated state, the fishing rod and its attached electrometer are to be held for a few seconds projecting from the window, and, whilst in this position, the pin is to be withdrawn by pulling the thin wire; this insulates the electrometer, which may be then drawn in and examined. Its electricity will be found to be contrary to that of the atmosphere.

The best mode of protecting buildings by reference to experimental data may now be examined.



The simplest form in which these experiments are made,

is that known by the name of the *thunder-house.* This is represented in the preceding page, where S is a board about three quarters of an inch thick, and shaped like the gable-end of a house. It is fixed perpendicularly upon the base G, from which rises the perpendicular glass F. A square hole, I L D K, about a quarter of an inch deep, and nearly one inch wide, is made in the board S, and fitted with a square piece of wood, nearly of the same dimensions. This board must fit in rather easily, so that the slightest shaking may throw it out. A wire, L I, is fastened diagonally to this square piece of wood. Another wire, R K, of the same thickness, having a brass ball R, screwed on its pointed extremity, is fastened upon the board ; so also is the wire D M, which is formed into a hook at M. From the upper extremity of the glass pillar, F, a crooked wire proceeds, having a spring socket A, through which a double-knobbed wire slides perpendicularly, the lower knob B of which falls just above the knob R. The glass pillar must not be fixed very tightly into the bottom board ; but so as to be easily moved round its own axis, by which means the brass ball B may be brought nearer or farther from the ball R. When the square piece of wood is fixed into the hole so that the wire stands from K D, then the metallic communication is continuous, and the instrument represents a house furnished with a proper metallic conductor ; but if the square piece of wood is fixed so that the wire stands in the direction I L, as represented in the figure, then the metallic conductor from the top of the house to its bottom, is interrupted, and mischief may result.

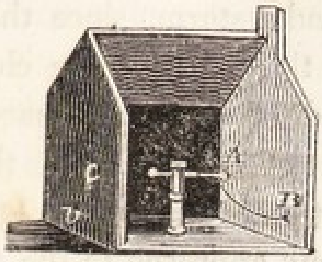
Fix the piece of wood, so that its wire may be as represented in the figure, in which case the metallic conductor is discontinued. Let the ball B be fixed at about half an

inch perpendicular distance from the ball R; by means of a chain connect the wire *e* with the wire of the jar, and let another chain, fastened to the hook M, touch the outside coating of the jar. Connect the wire C with the prime conductor, and charge the jar; then, by turning the glass pillar, let the ball B come gradually towards the ball R, and when they are arrived sufficiently near one another, the jar will explode, and the piece of wood be driven out of the hole to a considerable distance from the thunder-house. In this experiment the ball B represents an electrified cloud; which, when it is arrived sufficiently near the top of the house, the electricity strikes; and, as this house is not secured with a proper conductor, the explosion breaks part of it, as is seen by the violent removal of the piece of wood.

Unscrew the brass ball B from the wire, so that it may remain pointed. With this difference only in the apparatus, repeat the above experiments, and it will be found that the piece of wood is not in neither case moved from its place, nor will any explosion be heard; which not only demonstrates the preference of the conductors with pointed terminations to those with obtuse ends; but also shows that a house furnished with sharp terminations, although not furnished with a regular conductor, is almost sufficiently guarded against the effects of lightning.

In the same way, a model of a powder-mill may be blown up, or a house be set on fire, by making an interrupted circuit within them, and placing gunpowder, or other combustible matter in its interval, as is shown in the model on the next page.

The house is supported by a mahogany base *v*, and one side is removed to show the internal construction. The wire and ball A enters the central pillar, which is furnish-



ed with a cavity to contain the gunpowder. The chain passing through the end of the house at B, communicates with the external surface of a charged jar, while a similar chain may be made to pass through a hole at C, and form a conducting line with another wire and ball entering the central stem opposite A. On passing the spark through the edifice, the gunpowder is ignited, and the walls thrown down.

The following precautionary hints may be offered, as they comprise the best modes of ensuring safety during a thunder-storm.

Shelter should not be taken under trees or hedges, for, should they be struck, such situations are particularly dangerous; at the same time a person is much safer at about thirty or forty feet from such objects than at a greater distance, as they are likely to operate as conductors. Large portions of water also ought to be carefully avoided, and even smaller streams that may have reulted from recent rain, as these are good conductors, and the height of a human being connected with them, may sometimes determine the course of the lightning. In a house the safest situation is considered to be the middle of the room; and this situation may be rendered still more secure by standing on a glass-legged stool: but, as such an article is not in the possession of many people, a hair mattress, or a thick woollen hearth rug makes a very good substitute. It is very injudicious to take refuge, as some persons do, in the

cellar during a thunder-storm, since the discharge is often found to be from the earth to the clouds, and many instances are recorded of buildings that were struck having sustained the greatest injury about the basement story. But whatever situation is chosen, the greatest care should be taken to avoid any approach to the fire-place, since the chimneys are most likely to attract the fluid, and even if there be no fire in the grate at the time, it should be remembered that soot is a powerful conductor. The same caution is necessary with respect to all large metallic surfaces; as gilt furniture, or bell wires.

The distance of the thunder-cloud may readily be determined, as the interval between the flash and the commencement of the report furnishes the data necessary for the calculation. According to Flamstead, sound travels at the rate of 1142 feet in a second: consequently, by a watch which points the seconds, the distance of the cloud is easily ascertained, for the flash and the sound are really contemporaneous; and the former requires hardly any perceptible lapse of time to travel through any ordinary distance. Thus, for example, suppose the flash to occur five seconds before the sound is heard, then $1142 \times 5 = 5710 = 1$ mile 430 feet, the distance of the explosion from the place of the observer. So far this calculation is very gratifying, but it is no criterion of safety, for it only indicates the distance of a discharge that has taken place: the next may render the observer incapable of observation.

The *aurora borealis*, or northern lights, are generally considered to arise from the passage of electricity through highly rarefied air, and the mode of producing these diffused luminous streams has already been pointed out; it may however be advisable to notice Mr. Dalton's account

of this splendid phenomenon. It occurs in his Meteorological Essays.

"Attention," says Mr. Dalton, "was first excited by a remarkably red appearance of the clouds to the south, which afforded sufficient light to read by, at eight o'clock in the evening, though there was no moon, nor light in the north. Some remarkable appearance being expected, a theodolite was placed to observe its altitude, bearing, &c.

"From half past nine to ten o'clock P. M., there was a large, luminous, horizontal arch to the southward, almost exactly like those which we see in the north; and there were some faint concentric arches northward. It was particularly noticed that all the arches seemed exactly bisected by the plane of the magnetic meridian. At half past ten o'clock streamers appeared very low in the south-east, running to and fro from west to east; they increased in number, and began to approach the zenith apparently with an accelerated velocity; when all on a sudden the whole hemisphere was covered with them, and exhibited such an appearance as surpasses all description. The intensity of the light, the prodigious number and volatility of the beams, the grand intermixture of all the prismatic colours in their utmost splendour, variegating the glowing canopy with the most luxuriant and enchanting scenery, afforded an awful, but at the same time a most pleasing and sublime spectacle. Every one gazed with astonishment; but the uncommon grandeur of the scene only lasted about one minute; the variety of colours disappeared, and the beams lost their lateral motion, and were converted into the usual flashing radiations; but even then it surpassed all other appearances of the aurora, in that the whole hemisphere was covered with it.

"Notwithstanding the suddenness of the effulgence at the breaking out of the aurora, there was a remarkable regularity in the manner. Apparently a ball of fire ran along from east to west, and the contrary, with a velocity so great as to be barely distinguishable from one continued train, which kindled up the several rows of beams one after another: these rows were situated before each other with the most exact order, so that the bases of each row formed a circle crossing the magnetic meridian at right angles; and the several circles rose one above another in such sort, that those near the zenith appeared more distant from each other than those near the horizon, a certain indication that the real distances of the rows were either nearly or exactly the same."

The aurora borealis, or, as the same appearance is commonly termed, streamers, and in the Shetland Isles, the merry dancers, can seldom be seen in the southern parts of the kingdom; and, even when seen there, the appearance is far less brilliant than in northern latitudes, where this wonderful phenomenon is the constant attendant of clear evenings, affording a great relief to the inhabitants, amid the gloom that would otherwise attend their dreary winter nights.

Now between these appearances and those of electricity, under certain circumstances, there are several points of close resemblance. For it is found by a simple experiment that, when the electric fluid is made to pass through rarefied air, it exhibits a diffused luminous stream, which has all the characteristic appearances of the northern lights. There are to be seen the same varieties of colour and intensity, the same undulating motion and occasional coruscations; the streams exhibit the same diversity of character, at one moment minutely divided into ramifications,

and at another beaming forth in one body of light, or passing in well-defined flashes; and, when the rarefaction is high, various parts of the stream assume that peculiar glowing colour which occasionally appears, and which, on the whole, leaves but little room to doubt that the phenomena are produced by the passage of electricity through the upper regions of the atmosphere.

The next form of atmospherical electricity that claims our attention is that which it assumes in those meteors, to which the vulgar name of falling, or shooting stars, has been given. The aurora borealis, we have said, is caused by streams of the electric fluid passing rapidly through the higher regions of the air; and these phenomena of which we are now speaking, are, in all probability, portions of the same matter moving through a more resisting medium, since they are always observed to be at comparatively small altitudes.

These meteors vary considerably in their size and colour, and also in the rapidity of their motion; they move in various directions, but chiefly incline towards the earth. They occur in different states of the atmosphere, but prevail most in clear frosty nights, and at other times when the winds are easterly, and the sky clear; in the intervals also of showery weather they are frequent, and on summer evenings, when well defined clouds are seen floating in a clear atmosphere.

A tall glass tube connected with the air-pump is well calculated to exhibit this phenomenon; instead, however, of employing the mere spark as in the aurora borealis, it is in this case necessary to employ a Leyden jar, and transmit the charge through the vacuous tube. Large masses of fire varying in colour, and dependent on the state of the vacuum may thus be made to dart along a tube more than five feet in length.

VOLTAIC ELECTRICITY.

Discoveries by Galvani.—Muscular Motion produced by Electricity.—Invention of the Voltaic Pile.—Method of exhibiting the Electricities of Metals.—Combination of Plates.—Phenomena of Decomposition.—Medical application of Electricity.

This science may be said to owe its origin to the discoveries of an ingenious Italian philosopher, named Galvani, who published a Latin treatise on the subject at the close of the last century.

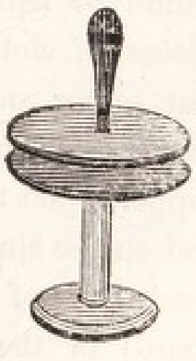
In the preceding sections, the various phenomena resulting from the friction of dry bodies have been examined, which, by their mutual action on each other, tend to destroy their electrical equilibrium; and it may now be advisable to examine that branch of electricity which has led to some of the most important discoveries and splendid triumphs connected with the progress of chemical science.

In the year 1790, Galvani, professor of anatomy at Bologna, accidentally discovered that the passage of a small quantity of electricity, through the nerve of a frog that had been recently killed, had the property of exciting distinct muscular contractions. He produced the same effect with atmospherical electricity; and afterwards by the mere contact of two different metals. His discoveries were published in 1791: he proved the phenomena to be electrical, and says, "If you lay bare the sciatic nerve of a frog, and remove the integuments, then place the nerve on a piece of zinc, and a muscle on a plate of gold, and connect these metals by any conducting substance, contractions are pro-

duced; but, if non-conductors are used to connect the metals, contractions are not excited." The experiments of Galvani received considerable attention; and they were varied and extended with the greatest perseverance by Professor Volta, Dr. Valli, Humboldt, Fowler, Monro, and Robison.

The effects obtained in the experiments of these naturalists may be illustrated by very simple apparatus. The most important facts they establish are, first, that the passage of a small quantity of electricity through the nerve or nerves of any animal, occasions a tremulous motion or contraction of the contiguous muscles, and sometimes an extension of the limbs. This effect takes place both in living animals and such as have been recently killed, and even in the detached limbs of these last. It is produced when the transmitted electricity is too weak to affect the most delicate electrometers, and obtains in all animals for some time after death; their susceptibility being greatest at first, and gradually diminishing as the limbs stiffen. Animals with cold blood, as frogs and fishes, retain the power of action after death longer than others, sometimes for many hours, or even days.

When an insulated plate of zinc is brought into contact with one of copper or silver, it is found, after removal, to be positively electrical, and the silver or copper is left in the opposite state. With the accompanying simple apparatus, the above fact may be experimentally illustrated. If we take any other series of metals, the same law will be found to hold good; and if we take platinum, gold, silver, mercury, copper, iron, tin, lead, and zinc, placing them in the order in which they have been enume-



rated, each will be negative by comparison with the one that precedes it.

When several pairs of plates with discs of moistened cloth placed between each series, are placed on each other, the power of the apparatus is materially increased.

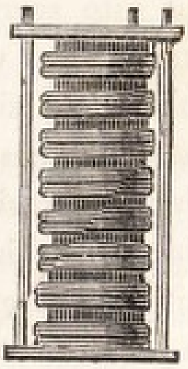
The important discovery of accumulating the effects of this species of electricity was made by Volta in 1800, and thence has been denominated the Voltaic pile. The apparatus, as first made by Volta, consisted of a certain number of pairs of zinc and silver plates, separated from each other by pieces of wet cloth. Hence the arrangement was as follows: zinc, silver, wet cloth; zinc, silver, wet cloth, and so on. The silver plates were chiefly silver coins, the plates of zinc and the pieces of cloth being of the same size. He found this pile much more powerful when the pieces of cloth were moistened with a solution of common salt instead of pure water. A pile, consisting of forty pairs of plates, he found to possess the power of giving a very sharp shock, similar to that of a small electric jar; and that this effect took place as often as a communication was made between each end of the pile, and as long as the pieces of cloth remained moist.

To construct an apparatus of this kind, procure a number of plates of zinc and copper, or zinc and silver, either round or square, of any size; and an equal number of pieces of cloth, leather, or pasteboard, of the same form, but rather smaller. Soak these last in salt water, until they are thoroughly moistened; place a plate of silver, or copper, upon the table, then upon that place a piece of zinc, and on the zinc one of the moistened discs; upon this a second series of silver, zinc, and moistened cloth (or pasteboard) in the same order; and thus consecutively until a series of fifty or sixty repetitions have been arranged.

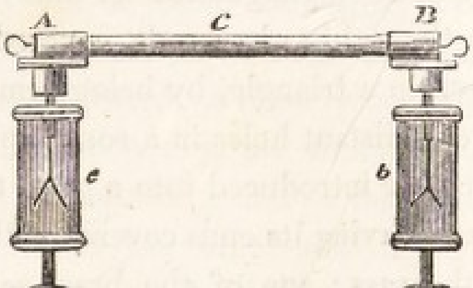
Particular care must be taken to place the plates in regular order; if in the first group silver is placed lowest, zinc next, and then the moistened disc, the same disposition must be observed throughout.

The Voltaic pile being thus formed, let the operator moisten both his hands with brine, and grasp a silver spoon in each. If the top of the pile be then touched with one spoon, and the bottom with the other, a distinct but slight shock will be felt at every repetition of the contact. This shock resembles very nearly the sensation produced by a very large electrical battery weakly charged; it is greater in proportion to the number of groups of which the pile is composed. If the communication is made with any part of the face near the eyes, or with a silver spoon held in the mouth, a vivid flash of light is perceived at the moment of contact, and that whether the eyes be open or shut.

A pile furnished with three rods to preserve the plates in a perpendicular direction, is shown in the accompanying diagram.



Another form of the pile must now be noticed. If a number of alternations be made of copper or silver-leaf, zinc-leaf, and thin paper, the electricity excited by the contact of the metals will be rendered evident to the common electrometer. C represents a glass tube, in which are



regularly arranged a number of alternating plates of silver,

zinc, and thin paper, forming De Luc's electrical column. The metallic cap A is in contact with the silver plate, and B with the zinc plate, at the respective extremities of the pile. Upon examining the electrometers, it will be found that *c* is negatively diverged, and *b* positively.

To distinguish this instrument from the usual Voltaic apparatus, from which it differs in many respects, M. De Luc proposed to call it "the Electric Column," an appellation sufficiently appropriate, since the effects it produces are purely electrical.

Mr. Singer made very numerous experiments on the construction of such columns, and varied their combinations most extensively. The materials he preferred, are thin plates of flatted zinc alternated with writing or smooth cartridge paper, and silver-leaf. The silver-leaf is first laid on paper, so as to form silvered paper, which is afterwards cut into small round plates by means of a hollow punch. In the same way an equal number of plates are cut from thin flatted zinc, and from common writing or cartridge paper. These plates are then arranged in the order of zinc, paper, silvered paper with the silvered side upwards; zinc upon this silver, then paper, and again silvered paper, with the silver side upwards; and so on, the silver being in contact with zinc throughout, and each pair of zinc and silver plates separated by two discs of paper from the next pair. An extensive arrangement of this kind may be placed between three thin glass rods, covered with sealing-wax, and secured in a triangle, by being cemented at each end into three equidistant holes in a round piece of wood; or the plates may be introduced into a glass tube previously well dried, and having its ends covered with sealing-wax, and capped with brass; one of the brass caps may be cemented on before the plates are introduced into the tube,

and the other afterwards; each cap should have a screw pass through its centre, which terminates in a hook outside. This screw serves to press the plates closer together, and to secure a perfect metallic contact with the extremities of the column.

There appears every reason to believe, that the action of a well-constructed column would be very durable. There is, however, a precaution necessary to their constant and immediate action; the two ends of a column should never be connected by a conducting substance for any length of time; for if, after such continued communication, it be applied to an electrometer, it will scarcely affect it for some time. It is, therefore, necessary, when a column is laid by, that it be placed upon two sticks of sealing-wax so as to keep its brass caps at the distance of about half an inch from the table, or other conducting surface on which it is laid. And if a column, which appears to have lost its action by laying by, be insulated in this way for a few days, it will usually recover its full power.

There is another cause of deterioration which is more fatal; it is the presence of too much moisture. If the paper be perfectly dry, it is a non-conductor, and will not therefore produce any action in the column; but this perfect dryness can only be obtained by exposing the paper to a heat nearly sufficient to scorch it, and in its dryest natural state the paper will be found sufficiently a conductor, even when, by exposing the paper discs to the heat of the sun, they have been so dried as to warp considerably. When the paper is sufficiently dry, the action of the column continues without diminution; and on taking such an apparatus to pieces after it had been constructed thirty months, no trace of oxidation was evident on the zinc plates.

Soon after the invention of the column, Mr. B. M. Fors-

ter discovered that, when a sufficiently extensive series was put together, its electric power was sufficient to produce a sort of chime by the motion of a small brass ball between two bells, insulated, and connected with the opposite extremities of the column. He constructed a series of 1500 groups, and by its agency kept a little bell-ringing apparatus in constant activity for a considerable length of time.

Mr. Singer contrived an arrangement which is well calculated to form a perpetual motion, by excluding, to a very considerable extent, the operation of extraneous causes of interruption, and it at the same time renders the disposition of the apparatus rather elegant. A series of from 1200 to 1600 groups are arranged in two columns of equal length, which are separately insulated in a vertical position by glass pillars constructed on his principle of insulation; the positive end of one column is placed lowest, and the negative end of the other; and, their upper extremities being connected by a wire, they may be considered as one continuous column. A small bell is situated between each extremity of the column, and its insulating support, and a brass ball is suspended by a thin thread of raw silk, so as to hang midway between the bells, and at a very small distance from each of them. For this purpose the bells are connected, during the adjustment of the pendulum, by a wire, that their attraction may not interfere with it; and, when this wire is removed, the motion of the pendulum commences. The apparatus is placed upon a circular mahogany base, in which a groove is turned to receive the lower edge of a glass shade with which the whole is covered.

There is some cause, not yet perfectly developed, that appears to influence the power of the column to produce the motion of light metallic pendula. In the bell-ringing

apparatus, for instance, though the motion always continues, it is much more rapid at one period than another, and the oscillations of the pendulum, though usually as uniform as that produced by mechanism, is on some occasions singularly wild and irregular. The frequency with which the gold leaves of an electrometer strike the sides of the glass, when connected with an electric column, is also different at different times; the variations observed in some experiments of M. De Luc are much more considerable than we have yet noticed with the more powerful columns of Mr. Singer's construction.

It has been stated that the power of the moist galvanic pile gradually diminishes, the zinc surfaces becoming oxidated by the action of the moisture; it therefore requires to be taken to pieces and cleaned, an operation that is very troublesome when the number of plates is considerable. This inconvenience was diminished by soldering each pair of zinc and copper plates together, instead of simply laying them on each other; and a further improvement was devised by Mr. Cruickshanks, which consisted in cementing the pairs of plates in regular order, in grooves made in the side of a mahogany trough, so as to form water-tight cells between each pair. These cells being filled with water, or any conducting fluid, served as a substitute for the moistened discs used in the pile; and, as the fluid could be easily poured out and replaced, it required considerably less time to keep it in proper order. The form of the apparatus, which is called the Voltaic trough, or battery, has been much used in this country; it is perhaps, one of the best arrangements hitherto devised, and its construction is sufficiently simple.*

* The plates need only be soldered together at their upper edges,

When the trough is prepared, the kind of fluid with which it is to be filled, must next be considered. Distilled

because the other edges are secured by the cement. At the soldered edge, the copper is doubled over the zinc, in a degree equal to the thickness of the latter, and the solder is then applied with more ease, as a groove to contain it may be left between the two metals.

The plates should not be quite equal to the depth of the trough, for the convenience of filling; as when they do not reach the top, by leaning the trough on one side, each cell will receive an equal quantity of fluid.

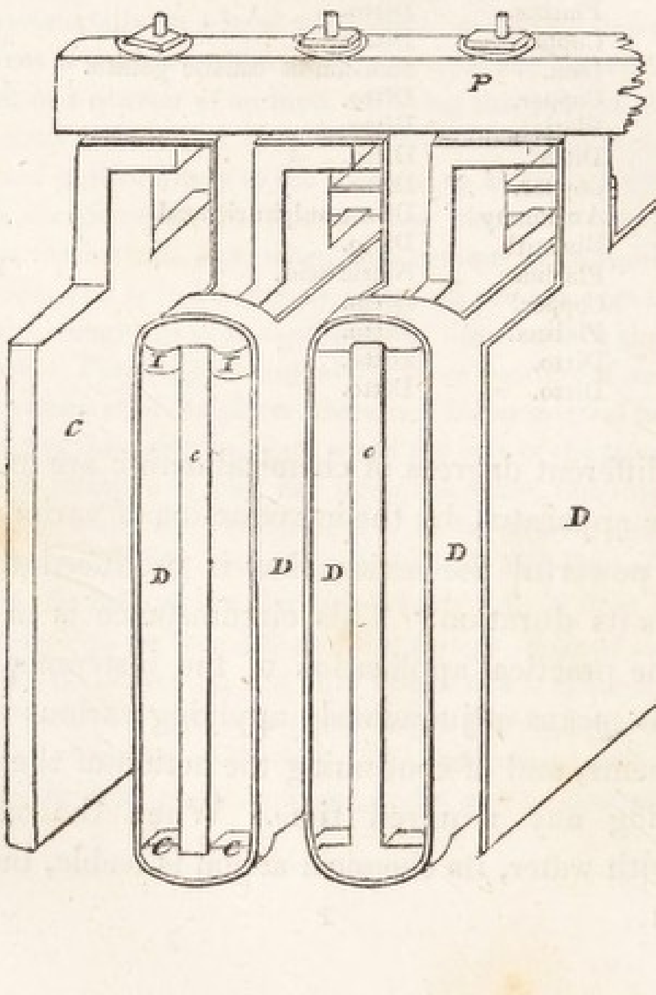
The trough must have as many grooves in its sides as the number of plates it is intended to contain, which should be fewer in proportion to their size, otherwise the apparatus will be inconvenient from its weight. When the plates are not more than three inches square, their number in one trough may be fifty, and the distance of the grooves from three-eighths to half an inch. The trough must be made of very dry wood, and put together with white lead or cement. The plates being placed to the fire, the trough is to be well warmed, and placed horizontally on a level table, with its bottom downwards, very hot cement is then to be poured into it, until the bottom is covered to the depth of a quarter of an inch. During this process the plates will have become warm, and they are then to be quickly slided into the grooves and pushed firmly to the bottom, so as to bed themselves securely in the cement. In this way the plates are very perfectly cemented at the bottom, and, when this cement is sufficiently cool, a slip of thin deal is to be slightly nailed on the top edge of one of the sides of the trough, so as to overhang the inner surface about a quarter of an inch. The trough being about three quarters of an inch deeper than the diameter of the plates, there will be an interval between their top edges and the deal slip; and, when the side of the trough to which the slip is attached is laid flat upon the table, this interval forms a channel into which very hot cement is to be poured, and it will flow between each pair of plates, so as to cement one side of all the cells perfectly. As soon as the channel is quite full of fluid cement, the strip of deal is to be torn off, and the trough inclined so as to admit the superfluous cement to run out. When this is effected, and the cement cool, a slip of deal is to be nailed on the opposite side and the same process pursued with that. The instrument will then be cemented in the most perfect manner, and it may be cleaned off and varnished.

water will produce but a very slight effect, and it has been found that the power of the trough is greatly increased by the use of liquids which are capable of oxidizing, or exerting a chemical action on at least one of the metals; the water is therefore acidulated,—or some common salt, as muriate of ammonia. The series of fluids best calculated for this purpose will, however, be best understood by reference to a tabular view.

Positive Metal.	Negative Metal.	Interposed fluid.	Effect produced.
Zinc.	Platina.	Dilute sulphuric acid.	10
Ditto.	Gold.	Ditto.	10
Ditto.	Silver.	Ditto.	10
Ditto.	Palladium.	Ditto.	10
Ditto.	Copper.	Ditto.	8
Ditto.	Iron.	Ditto.	7
Iron.	Platina.	Ditto.	3
Ditto.	Ditto.	Dilute nitric acid.	3
Ditto.	Copper.	Dilute sulphuric acid.	0
Tin.	Platina.	Ditto.	4
Ditto.	Copper.	Ditto	0
Ditto.	Iron.	Solution of caustic potash.	1
Ditto.	Copper.	Ditto.	$\frac{1}{2}$
Ditto.	Platina.	Ditto.	2
Zinc.	Ditto.	Ditto.	3
Ditto.	Copper.	Ditto.	2
Ditto.	Antimony	Dilute sulphuric acid.	2
Ditto.	Bismuth.	Ditto.	4
Ditto.	Platina.	Nitric acid.	10
Ditto.	Copper.	Ditto.	8
Tin.	Platina.	Ditto.	3
Copper	Ditto.	Ditto.	1
Silver.	Ditto.	Ditto.	$\frac{1}{4}$

When different degrees of chemical action are excited in the Voltaic apparatus, by the introduction of various fluids, the more powerful the action that is produced the more transient is its duration. This circumstance is of importance in the practical application of the instrument, since it offers the means of judiciously applying various methods of experiments, and of continuing the action of the apparatus during any required time. When the battery is charged with water, its chemical action is feeble, but it ap-

pears to continue without diminution for an indefinite length of time; by the addition of a minute quantity of muriatic acid, 1-500th part for instance, its chemical action is greatly augmented, and still continues for a considerable period. When the proportion of acid is increased to a thirtieth or twentieth part, the action is considerable, but comparatively of short duration. Mr. Singer says, he has found no solutions so advantageous as those of acids, and he prefers the muriatic acid to all others; the nitric is indeed rather more powerful in the same proportion, but its cost is four times as great, and it is found that it destroys the copper plates as well as the zinc. The nitrous gas evolved by its action is also much more offensive than hydrogen, which results from the employment of muriatic acid.



Dr. Wollaston's arrangement of the plates materially increases the power of the apparatus. It consists in extending the copper plate, so as to oppose it to every surface of the zinc, as seen in the previous page. P is the rod of wood to which the plates are screwed ; *c c* the zinc plates connected as usual with the copper plates D D, which are doubled over the zinc plates, and opposed to them upon all sides, contact of the surfaces being prevented by pieces of wood or cork placed at I I C C.

The Wedgwood ware battery is now generally employed when an extended series of plates are put into operation. These troughs contain compartments about half an inch broad, and they are about the same depth and length as the plates of ordinary troughs. Single plates of zinc and copper are united by a metallic arch at the top, so that they are parallel to each other, and at such a distance that the two plates can be placed in two adjoining compartments. When the battery is completed, each compartment is filled with fluid, and contains a plate of copper and a plate of zinc. This apparatus, in fact, combines the principle of the battery with glasses, and that of the common trough. As both surfaces of the metals are exposed to the action of the fluid, plates of the same size as those of the common trough expose twice the surface to oxidation ; the galvanic effect is not, however, duplicated, although rather greater than with a single surface. The principal advantage consists in the facility with which the battery can be constructed, and the plates cleaned after having been used : it also admits of another adjustment, which is occasionally convenient ; the plates are sometimes all united by a bar along the top of them ; and they may then be raised or lowered by a rack work at pleasure, so

that the charge can be reduced in any required proportion, and again increased to its full quantity.*

Mr. Pepys has contrived a single coil of copper and zinc plate, consisting of two sheets of the metals, each fifty feet long, by two feet broad, having, therefore, a surface of two hundred square feet; they are wound round a wooden centre, and kept apart by hair lines, interposed at intervals between the plates. This voltaic coil is suspended by a rope, and counterpoised over a tub of dilute acid, into which it is plunged when used.

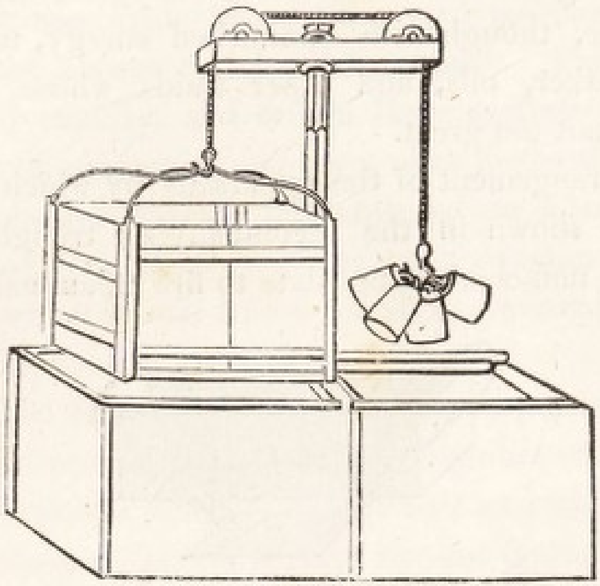
It gives not the slightest electrical indications to the electrometer; indeed, its electricity is of such low intensity, that well-burned charcoal acts as an insulator to it; nor does the quantity of electricity appear considerable, for it with difficulty ignites one inch of platinum wire of 1-30th of an inch diameter. When, however, the poles are connected by a copper wire 1-8th of an inch diameter, and

* Dr. Hare states, that having had occasion to remark the surprising increase in the deflagrating power of a series of galvanic pairs, when, after due repose, they were simultaneously exposed to the acid; he was induced to devise means of accomplishing this object in various ways, and that ultimately the following method occurred to him as the best: two troughs are joined lengthwise edge to edge so that when the sides of the one are vertical, those of the other are horizontal. Then by a partial revolution of the two troughs, thus united upon pivots which support them at the ends, any fluid which may be in one trough must flow into the other, and on reversing the motion, must flow back again. The galvanic series being placed in one of the troughs, the acid in the other, by a movement such as above described, the plates may all be instantaneously subjected to the acid, or relieved from it.

The pivots are made of iron, coated with brass or copper, as less liable to oxidizement; they are connected within with the galvanic series, and move on pieces of sheet-copper, which are easily made the extremities of connecting pieces, and thus the whole can be arranged in any way that is found convenient.

eight inches long, it becomes hot, and is rendered most powerfully magnetic, and the instrument is admirably adapted for all electro-magnetic experiments.

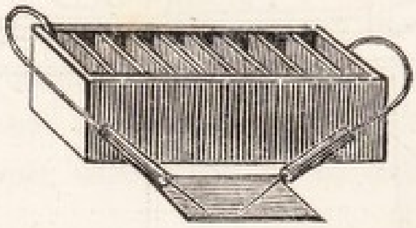
A modification of this apparatus will be seen in the accompanying diagram.



When the opposite extremities of a powerful Voltaic apparatus are connected by a wire, at the moment of contact a distinct spark is perceived, which occurs every time the contact is alternately broken and renewed. If the contact is made with a wire terminated at the end by a piece of well-burnt charcoal, the spark is considerably more vivid. And if the two wires proceeding from the opposite ends of the battery are armed with charcoal points, and brought in contact with each other, the light evolved is more brilliant and intense than any that has been procured by other artificial arrangements. When the battery is powerful, the emission of light may be kept up for a considerable time; it is so dazzling as to fatigue the eye even by a temporary glance, and, when it ceases, leaves the most brilliantly illuminated room in apparent darkness.

This light appears to be principally derived from the immediate action of the Voltaic apparatus, and not from the combustion of the charcoal; for, though that is partly ignited, it suffers but comparatively little waste, and the light is evolved with equal splendour when the experiment is made in gases which contain no oxygen; and will even take place, though with diminished energy, under water, alcohol, ether, oils, and other fluids whose conducting power is not too great.

The arrangement of the apparatus by which this is effected, is shown in the accompanying trough, with its wires and non-conducting plate to fire inflammable bodies.



With the most powerful Voltaic batteries the striking distance of the spark, or interval at which it passes from one conductor to another, is very considerable. Mr. Children measured this effect by means of a micrometer, attached to two polished points of platina, which were inserted in a receiver containing very dry air. With 1250 pairs of plates the points were brought within one-fifteenth of an inch of each other before the spark took place. With a large apparatus employed at the London Institution, which extends to 2000 pairs of four-inch plates, points of charcoal were brought within a thirtieth or fortieth of an inch of each other before any light was evolved; but, when the points of charcoal had become intensely ignited, a stream of light continued to play between them when they were gradually withdrawn even to

the distance of nearly four inches. The stream of light was in the form of an arch, broad in the middle and tapering towards the charcoal points; it was accompanied by intense heat, and immediately ignited any substance introduced into it; fragments of diamond, and points of plumbago disappeared, and seemed to evaporate, even when the experiment was made in an exhausted receiver; though they did not appear to have been fused. Thick platina wire melted rapidly, and fell in large globules; the sapphire, quartz, magnesia, and lime, were distinctly fused.

These phenomena may be exhibited on a smaller scale by means of 100 pairs of plates, of six inches square, an apparatus which is well suited for all experiments of fusion and ignition.

The arched form of the stream of light, passing between two charcoal points, is often very perceptible when the distance of the points does not exceed half an inch.

As the charcoal points usually become ignited when the battery has moderate power, almost any combustible substance may be inflamed, if placed between them. Oils, alcohol, ether, and naptha, are decomposed when the points are plunged into them, and inflamed when they are brought near each other upon the surface.

Some of the most pleasing effects of the Voltaic apparatus result from its action on metals; if these substances, in thin leaves, are made the medium of communication between the opposite ends of a powerful battery, they inflame, and by continuing the contact may be made to burn with great brilliance. The best method of performing these experiments, is to suspend the metallic leaves to a bent wire proceeding from one extremity of the battery, and to bring in contact with them a broad metal plate connected with the opposite extremity; the brilliancy of the effect may be

increased by covering the plate with gilt foil. Gold-leaf burns with a vivid white light tinged with blue, and produces a dark brown oxide. Silver-leaf emits a brilliant emerald green light, and leaves an oxide of a dark grey colour. Copper produces a bluish-white light attended by red sparks; its oxide is dark brown. Tin exhibits nearly similar phenomena, its oxide is of a lighter colour. Lead burns with a beautiful purple light; and zinc with a brilliant white light, inclining to blue, and fringed with red. For the distinct appearance of these colours it is essential to make the contacts with the metal; for, if charcoal be used, the brilliant white light it evolves absorbs the colours produced by the combustion of the metals.

If a fine iron wire be connected with one extremity of a powerful battery, and its end be brought to touch the surface of some quicksilver connected with the other extremity, a vivid combustion both of the wire and the quicksilver results, and a very brilliant effect is produced.

If a fine iron wire of moderate length be made the medium of connexion between the extremities of the battery, it becomes ignited, and may be fused into balls; or if a platina wire is employed, it may be kept at a red, or even white, heat, for a considerable length of time; which seems to prove that some power is continually circulating through it; but however powerful the battery, wires are never dispersed by it, as they are by the action of a charged surface.

If a slender wire be inserted in any fluid, and then introduced into the Voltaic circuit, the fluid may be made to boil.

The contact of either surface of the battery with the ground increases the electrical state of the opposite extremity, and as experiment proves this to be the case, the

same circumstance may be presumed to take place with every pair of associated metals, when their surfaces are in contact with a conducting fluid. Whilst the apparatus is insulated, the first zinc plate can only act on the electricity of its associate, the first copper plate; but the second zinc plate, through the conducting interposed fluid, can act on both these, besides its companion, the copper, and may therefore become more highly positive; and it is easy to conceive that such a repetition of action would be attended with an increase of effect, proportioned to the number of plates; and that the electrical tension of either end must be increased by connecting the other with the ground.

To ascertain if this principle really operated with a single combination, Mr. Singer took a pair of circular plates of six inches diameter, very clean and smooth, one being formed of zinc and the other of copper, and each provided with an insulating handle. When both plates were held by their insulating handles, and the zinc was successively applied to the flat surface of the copper, and after each contact made to touch the insulated plate of a condenser of six inches diameter; twenty contacts were required to communicate such a charge to the condenser as would occasion the leaves of a very delicate electrometer to separate to a quarter of an inch. But when the copper plate, instead of being held by its insulating handle, was simply laid on the hand, or on any similar conducting body, ten successive contacts of the insulated zinc plate, communicated a charge to the condenser, which occasioned the gold leaves to separate to the distance of more than half an inch. On repeating these experiments, with the variation of touching the condenser with the copper plate, held by its insulating handle, and brought in contact with the zinc plate, first insulated,

and then uninsulated, similar results were obtained, but with the contrary electrical state. Hence the similarity of action in a single pair of metals, and a combined series, is sufficiently proved; and the preceding statement of the manner in which the electrical power is supposed to increase with the number of associated plates, is rendered highly probable.

The first experiments made upon the moist pile in this country appear to have been performed by Messrs. Nicholson and Carlisle. After observing the effects then ascribed to the piles on bringing the wires from each end of the column in contact with a drop of water, they observed a disengagement of bubbles of some elastic fluid.

On closer examination they found the gas to be hydrogen. They then took a glass tube, about half an inch in diameter, into each end of which a cork was inserted, the tube being filled with water. Through each cork was introduced a brass wire, so that the ends of the wires in the glass were about an inch and three-quarters of an inch. The pile employed consisted of thirty-six half-crowns, and as many similar pieces of zinc, and wet pasteboard. The zinc end of the pile was then connected with one of the wires in the tube, and the silver end with the other, so that the circuit formed by the pile was separated by the water in the tube placed between them. A stream of bubbles was observed at the end of the wire, in the tube connected with the silver end of the pile. No gas was disengaged from the opposite wire, but it speedily became tarnished, first of an orange colour, and ultimately black. The tube was then reversed, when it was observed that the wire, which in the first experiment became tarnished, gave out bubbles, while that which had before given out gas, in its turn became tarnished.

The emission of gas from the wire connected with the silver end of the pile was constant and uniform, except when a metallic circuit was formed between the ends of the pile, during which no gas whatever appeared. It was observed that, when this metallic conductor was removed, the appearance of the gas was not immediate, since there was an interval of about two seconds between the removal of the wire and the appearance of bubbles. After the process had continued two hours and a half, a bulk of gas was produced equal to two-thirds of a cubic inch. This gas was mixed with an equal bulk of common air, and exploded on the application of a lighted taper.

These ingenious experimenters, supposing the phenomena in question to arise from the decomposition of the water, thought it surprising that the hydrogen should make its appearance at a distance of an inch and three quarters from the point where the oxygen was disposed of. They then made the same experiment with a tube thirty-six inches in length, but no gas was observed. When they introduced an infusion of litmus instead of pure water, they observed that the fluid in the vicinity of the wire connected with the zinc end of the pile became red, and hence were led to suppose that an acid had been produced. The fluid at the other wire was not changed, but gas, as usual, was evolved.

In Sir H. Davy's Bakerian lecture on the chemical agencies of electricity, published in the Philosophical Transactions for 1807, he amply proved that acids, which are electrically negative, with respect to alkalies, metals, and earths, are separated from these bodies in the Voltaic circuit at the positive pole; and that alkalies, metals, and earths, are separated from acids, at the negative surface. He showed further, that such are the attracting powers of

these surfaces, that acids are transferred through alkaline solutions, and alkalies through acid solutions, to the poles where they have their points of repose. This was exhibited by making a combination of three agate cups, one containing sulphate of potash, one weak nitric acid, and the third distilled water. The three were connected by asbestos moistened in pure water, in such a manner, that the surface of the acid was lower than the surface of the fluid in the other two cups. When two wires of platina from a powerful Voltaic apparatus, are introduced into the two extreme cups, the solution of the salt being positively electrified, a decomposition took place, and in a short time, a portion of potash was found dissolved in the cup, in contact with the negative wire, though the fluid in the middle cup was still sensibly acid.

As the current of electricity excited by the Voltaic apparatus, acts on the bodies through which it passes, and often attacks and decomposes them; it must also, by the same power, act upon all the decomposible bodies which enter into the construction of its own system; so that it becomes indispensable to examine, by experiment, the nature, the extent, and the consequences of this action.

Among the phenomena which it produces, the first to be examined, because it is the most general, is a rapid absorption of the oxygen of the air around the apparatus. This may be rendered apparent in a very simple manner, by placing a vertical pile upon a support surrounded with water, and covering it with a cylindrical jar of glass, which also dips into the water at its base. In a few instants, the water will be seen to rise in the interior of the jar, especially if we form the communication between the two poles of the pile by metal wires, so as to direct through them the circulation of the electricity: when no communication is

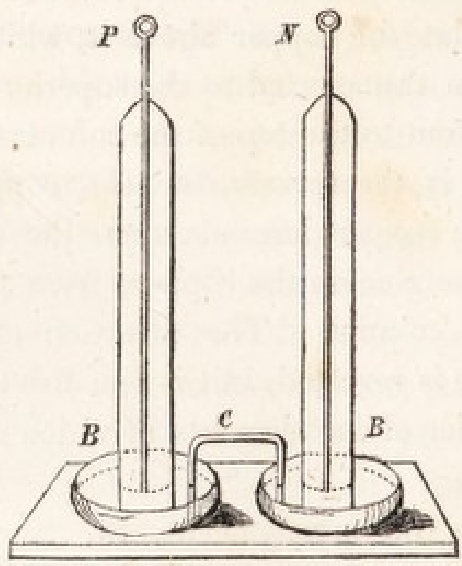
formed, the absorption still goes on, but with much greater slowness. In every case, in more or less time, according to the volume of the pile, and the quantity of air which surrounds it, the absorption ceases, and the air remaining under the jar presents no more traces of oxygen.

When we separate the elements of the piles which have been thus kept in action during several hours, or even days, under a cover which prevents the renewal of the atmospheric air, and having a constant communication kept up between their poles, we find that the metallic plates which compose them adhere to each other, and to the intermediate moistened cloths, with so great a force, that it is difficult to separate them. When this is done, we observe that the chemical action of the pile appears to have reacted on it, and produced remarkable alterations in its own elements. If the pile has been raised, according to the order, zinc, moisture, copper, zinc, and placed on its zinc base, we observe invariably that particles detached from the inferior zinc plate have been carried to, and have fixed themselves on the plate of copper above it, while particles of copper have been transported to the superior zinc, and so on from the bottom to the top of the columns. If the situation of the pile is the reverse, namely, copper, moisture, zinc, copper, the copper descends upon the zinc, which is below it, and the zinc on the copper, from the bottom to the top of the column. The direction of the passage through the pile is reversed, but it remains the same relatively to the order of the elements of which the apparatus is composed.

According to this arrangement, the zinc, in order to reach the copper, must necessarily pass through the small piece of moistened cloth which separates them. In piles where the communication between the two poles is not

formed, this transmission does not sensibly take place; the surface of the copper remains smooth, and that of the zinc, which is opposite to it, is only covered with minute black lines, which follow the direction of the threads of the cloth. When the communication has been established for a short time, some particles of oxide begin to pass, and attach themselves to the copper; and, if the action of the pile is strong, the surface of the copper is at last entirely covered; then the chemical and physiological action of the pile ceases, either because the oxide of zinc deposited on the copper exerts on it an electromotive action, which balances that of the metallic zinc, touching it on its other side; or because the interposition of this stratum of oxide presents too great an obstacle to the transmission of the electricity; or lastly, what is most probable, because these two effects combine their influence at the same time.

A beautiful illustration of the effects resulting from electrical transfer may readily be adduced.



Fill the glass tubes represented in the above diagram, which are closed at top and open at bottom, with infusion

of violets, or red cabbage, and invert them in the basins B B, containing a solution of Glauber's salt, and connected by the glass tube C, also containing the blue infusion. P and N are platinum wires, which pass into the tubes nearly to the bottom, and which are to be connected with the positive and negative extremities of the Voltaic apparatus. It will be found that oxygen is evolved at the wire P, and hydrogen at N, derived from the decomposition of the water. The Glauber's salt, which consists of sulphuric acid and soda, will also be decomposed, and the blue liquor will be rendered red in the positive vessel, by the accumulation of sulphuric acid, and green in the negative, by the soda, while the acid and alkali will each traverse the tube C without uniting, in consequence of being under the influence of electrical attraction.

Procure four glass tubes, one-fourth of an inch internal diameter, and about four inches long, bent in the form of the letter U. Fill these tubes with blue cabbage liquor, the interrupted metallic circuit being formed through them by connecting arcs of platina wire. When the extremities of this apparatus are connected with the opposite wires of a Voltaic battery, after a short time, the liquor in that leg of each syphon which inclines towards the copper extremity of the battery will become green, and that in the opposite leg red; and by reversing the connections, those legs which were green, may be rendered red, and those that were red converted to green.

That these phenomena depend on the transmission of electricity, from metal to water, and from water to metal, is demonstrated by the following variation of the experiment.

Remove all the platina wires but the two end ones, and connect the four syphons (filled with blue test liquor as be-

fore) by three arcs of moistened cotton. When the end wires have been some time connected with the opposite ends of the battery, the liquor in the two syphons next the copper side will be wholly changed to green, and that in the two syphons next the zinc extremity will be wholly changed to red. Hence it is probable, that when the electric fluid passes from metal to water, it separates oxygen, or acid; and when it passes from water to metal, it separates hydrogen, alkali, or inflammable matter.

The most difficult feature of all the Voltaic decompositions, is the invisible form in which the separated elements of various compounds appear to traverse the fluid, and arrange themselves at the opposite wires. The oxygen and hydrogen that appear in some of our experiments, at the distance of three feet from each other, are necessarily supposed to result from the same particle of water; and if this be situated at either wire, one of its elements (either the oxygen or hydrogen) must pass through the whole length of the tube to reach the other, and that in an invisible state, for the gases are separated at the opposite extremities without any apparent alteration of the interposed fluid.

Let the wires of a galvanic battery be made to terminate in a flat-bottomed vessel, containing pure water, about an inch and a half from each other; if then another wire, of an inch in length, be laid longitudinally between them, but not to touch them, each end of the intermediate wire, if of gold or platina, will afford gas. That end opposite the negative wire will give oxygen, and the other end of the same will furnish hydrogen; and if any number of bits of wire be placed between the principal wires, at the same time they do not touch each other, oxygen and hydrogen will be alternately furnished by the ends of the wires.

When the principal wires are brought nearer together, and a platina wire placed transversely between them, one side of the intermediate wire will furnish oxygen, and the other hydrogen. This fact is put in a more striking point of view, by placing a plate of platina in a vessel of water edgeways, and bringing the wires of the battery opposite to each other, and perpendicular to the sides of the plate. If the battery employed consist of fifty plates, three inches square, a circular spot will be observed on each side the plate opposite the wires. This appearance is caused by the evolution of gas from those parts of the plate only.

If a plate of glass be coated over with a solution of nitrate of silver, and a brass pin or a piece of zinc wire be laid in the middle of the plate, beautiful ramifications of silver will soon appear as if growing out of the pin, very much resembling vegetation. By observing the process with a magnifying glass, each branch of this arborescence may be seen to grow from the end or side of another; which proves that the silver forming the vegetative appearance is not reduced by the oxydable metal laid on the plate, but by something at the successive points of the silver branches. With a view to ascertain this fact, one half of the plate may be covered with nitrate of silver, and the other half with dilute muriatic acid. If a piece of zinc wire be tied to a piece of platina wire, and the compound wire so bent that the zinc may touch the dilute acid, and the platina the nitrate of silver, the ramifications of silver will soon appear upon the platina wire. That the silver is reduced by the hydrogen carried in the galvanic current, is probable, from varying the experiment as follows: if, instead of coating the plate with nitrate of silver, the whole be covered with dilute acid, and the same compound arc be laid upon it, the platina will give out bubbles of hydro-

gen. In the common way of making this experiment with the pin, as well as the variation above stated, it appears that the process is kept up by the galvanic current, which furnishes the hydrogen. The pin first reduces a small portion of silver, which forms a galvanic combination with the pin. The hydrogen which, but for the presence of the remaining nitrate of silver, would appear in the gaseous form, is employed in depriving the silver of its oxygen. With the compound arc, the zinc does not require to touch the nitrate of silver, because the platina with zinc is already a galvanic combination. The theory of whitening common pins can be explained on this principle. The tin, in a small proportion, is dissolved in the tartrate of potash; pieces of metallic tin, with the pins, are also present. The two latter form the galvanic combination, and a portion of tin is reduced from the solution upon the pins, to which they owe their whiteness.

The phenomena that have been described as the consequences of Voltaic decomposition obtain in every variety of experiment. Sulphuric acid introduced into the Voltaic circuit gives off oxygen gas, and sulphur is deposited. Phosphoric acid evolves oxygen gas, and phosphorus combines with the negative wire. Ammonia separates into hydrogen and nitrogen with a small proportion of oxygen. Oils, alcohol, and ether, when acted on by a powerful battery deposit charcoal, and give off hydrogen. And Professor Brande has shown, that when animal fluids containing albumen, are placed in the Voltaic circuit, the albumen is separated in combination with alkali at the negative wire, and in combination with acid at the positive wire. And that, with a powerful battery, it separates at the negative wire in the solid form; and with a less power, in the fluid

form, so that it is probable animal secretion may depend on some such power.

The decomposition of the alkalies may, by care and attention, be effected with a battery of fifty pairs of plates of three or four inches square; but the results are rather uncertain: two hundred plates form a very efficient arrangement; they should be excited by a weak acid mixture (about one part strong muriatic or nitrous acid, to thirty parts of water). A plate of silver or platina being connected with the negative side of the battery, a thin piece of pure potash or soda is to be placed upon it, and a platina or silver conductor, proceeding from the positive side of the battery, is to be brought in contact with the upper surface of the alkali, which soon fuses at the points of contact: metallic globules shortly appear near the negative surface, and gradually increase in size, until a crust of alkali begins to form on their surface; at this moment they should be removed by the point of a knife, and instantly plunged under naptha; or, if the experiment be merely intended to demonstrate their production, they may be brought in contact with the surface of water or nitric acid. It sometimes happens that no globules appear, but if the contact be preserved for some time, and the alkali be afterwards raised, several will be found imbedded in its under surface. If the action of the battery be strong, it also sometimes happens that the globules inflame, and even detonate at the moment of their production; it is therefore advisable not to bring the eyes too near during the experiment, or else to cover them with glasses. These experiments always require great care to insure their success, which a trifling variation in the power of the battery, purity of the potash, or moisture of the atmosphere, may prevent.—Soda is

rather more difficult to decompose than potash, and therefore requires to be employed in thinner pieces; the pieces of potash should rarely exceed a quarter of an inch in thickness, and those of soda one-eighth of an inch.

To prevent the loss of the alkaline bases during their separation, by the powerful action of the air upon them, it has been proposed to effect the decomposition under naptha: the moist potassa being placed between two plates of platina in a proper vessel, which is to be filled with naptha as soon as the contact with the battery is established; in this way the action of the air is prevented, but the naptha decomposes, and hydrogen and charcoal are liberated, which renders the result less satisfactory than in the more simple form of the experiment. The most essential precautions are to preserve the alkali as dry as is consistent with a sufficient degree of conducting power, and to employ the battery in a moderate state of action, in which it does not produce a very intense heat, for that would destroy the metallic base at the moment of its production.

The amalgam of potassium, or sodium, with mercury, is easily procured; and may be obtained by a very moderate power. A glass tube, one-fourth of an inch diameter and three inches long, having a short platina wire sealed in one end, is to have mercury poured into it until the end of the platina wire is covered; the rest of the tube is to be filled with a concentrated solution of alkali, either pure or carbonated. The platina wire, surrounded by mercury, is then to be connected with the negative end of a Voltaic battery, and the circuit completed by bringing a platina wire from the positive end, in contact with the solution of alkali. Gas will be evolved from this wire, and the surface of the mercury will be greatly agitated; when the action

grows weaker, the mercury may be poured into a glass of water, and the presence of the alkaline metal will be immediately indicated by the evolution of a cloud of minute bubbles of hydrogen gas, which may be collected by inverting over the mercury a small closed glass tube filled with water. This result has been frequently obtained with a battery of thirty pairs of plates of only two inches square. The amalgam may be obtained more highly charged with the alkaline metal by employing a solid piece of alkali, with a small cavity on its surface, in which a globule of mercury is to be placed. The alkali is to be connected with the zinc surface of a battery, and the mercury with the copper surface; the mercury soon becomes more tenacious, and sometimes is converted into a soft solid mass, and in this state, if thrown into water, it produces a rapid decomposition.

Mr. Hare has observed, that the charcoal points, when ignited by the instrument, "assumed a pasty consistence, and appeared as if in a state of fusion." This most important fact seems to have been placed beyond a doubt by Professor Silliman, who has obtained some very curious and valuable results with a powerful galvanic apparatus. When the charcoal points were brought into contact, and then withdrawn a little, the most intense ignition took place. The charcoal part of the positive pole shot out and increased from the tenth to the eighth, and sometimes to the fourth of an inch in length. The charcoal of the negative pole, on the contrary, was diminished, and a circle-shaped cavity was formed at the end of it, as if the matter had been actually transferred to the positive pole, by a current flowing from the negative to the positive pole. From various experiments Professor Silliman concludes, "that

there is a current from the negative to the positive pole, and carbon is actually transferred by it in that direction," probably in the state of vapour.

Upon examining with a microscope the projecting point of the positive pole, it exhibited decisive indications of having undergone a real fusion. It presented a mamillated appearance, and its form was that of an aggregation of small spheres. Its surface was smooth and glossy, as if covered with a varnish. Its lustre was metallic, and it had entirely lost the fibrous appearance it previously possessed.

The power possessed by certain animals of destroying the electrical equilibrium, and of rendering this apparent by the transmission of shocks to other bodies, is too important to be passed without notice.

In the *gymnotus* or *electric eel*, and in the *torpedo* or *electric ray*, are arrangements given to those remarkable animals for the purposes of defence, which nearly resemble Voltaic apparatus, for they consist of many alternations of different substances. These electrical organs are much more abundantly supplied with nerves than any other part of the animal, and the too frequent use of them is succeeded by debility and death. We may, however, notice them somewhat more in detail.

The *torpedo*, which belongs to the order of *rays*, is a flat fish, very seldom twenty inches in length, weighing but a few pounds when full grown, and commonly caught in various parts of the sea-coast of Europe. The electric organs of this animal are two in number, and placed one on each side of the cranium and gills, reaching from thence to the semicircular cartilages of each great fin, and extending longitudinally from the anterior extremity of the animal to the transverse cartilage which divides the thorax

from the abdomen. In those places they fill up the whole thickness of the animal from the lower to the upper surface, and are covered by the common skin of the body, under which, however, are two thin membranes or fasciæ. The length of each organ is somewhat less than one-third part of the length of the whole animal. Each organ consists of perpendicular columns, reaching from the under to the upper surface of the body, and varying in length according to the various thickness of the fish in various parts. The number of those columns is not constant, being not only different in different torpedos, but likewise in different ages of the animal, new ones seeming to be produced as the animal grows. In a very large torpedo, one electric organ was found to consist of 1182 columns. The greatest number of those columns are either irregular hexagons, or irregular pentagons, but their figure is far from being constant. Their diameters are generally one-fifth part of an inch. "Their coats are very thin, and seem transparent, closely connected with each other, having a kind of loose net-work of tendinous fibres passing transversely and obliquely between the columns, and uniting them more firmly together: these are mostly observable where the large trunks of the nerves pass. The columns are also attached by strong inelastic fibres, passing directly from the one to the other."

Each column is divided by horizontal partitions, placed over each other at very small distances, and forming numerous interstices, which appear to contain a fluid. These partitions consist of a very thin membrane, considerably transparent. Their edges appear to be attached to one another, and the whole is attached by a fine cellular membrane to the inside of the columns.

The above-mentioned electric organs seem to be the only

parts employed to produce the shock; the rest of the animal appearing to be only the conductor of that shock, as parts adjacent to the electric organs; and, in fact, by artificial electricity, it has been found that the animal is a conductor of the electric fluid. The two great lateral fins which bound the electric organ laterally, are the best conductors.

The *gymnotus electricus* has been frequently called the *electric eel*, on account of its superficial resemblance to the common eel; though, when accurately examined, it is found to have few of the specific properties of that animal. The gymnotus is found pretty frequently in the great rivers of South America.

M. Humboldt, in his "Personal Narrative," furnishes a very interesting account of the mode of catching the gymnoti, which inhabit some of the rivers and pools of South America. M. H. would not employ the roots of the Piscidea erithryna and Jacquinia armillaris, which, when thrown into the pool, would intoxicate or benumb the animals; as these means would have enfeebled them: the Indians therefore said they would fish with horses, and the guides were soon seen returning from the savannah, which they had been scouring for wild horses and mules. They brought about thirty with them, which they forced to enter the pool. The extraordinary noise caused by the horses' hoofs, made the fish issue from the mud, and excited them to combat. The yellow and livid eels, which resembled large aquatic serpents, swam on the surface of the water, and crowded under the bellies of the horses and mules.

This singular contest between animals so different in their organization, appears to have furnished a very striking spectacle. The Indians, provided with harpoons and

long slender reeds, surrounded the pool closely, while others climbed the trees which hung over its banks, and by their wild cries prevented the horses from running away. The eels, stunned by the noise, attempted to defend themselves by the repeated discharge of their electric batteries, and for a time appeared victorious, as several horses sunk beneath the violence of the invisible strokes; while others, panting, with mane erect, and haggard eyes, raised themselves and endeavoured to fly from the storm by which they were overtaken. But few, however, succeeded in gaining the shore, and these stumbling at every step, stretched themselves on the sand, exhausted with fatigue, and their limbs benumbed by the electric shocks of the gymnoti.

In less than five minutes the *humane* conductors of this exhibition had succeeded in drowning two horses, and M. Humboldt imagined that the fishing would terminate by killing successively all the animals engaged; but by degrees, the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. On the fish approaching the edge of the marsh, they were readily taken by means of a small harpoon, and when the cord to which the instrument was attached was free from moisture, the Indians felt no shock in raising the fish from the water. The temperature of the pool was about 86° of Fahrenheit, and the electric energy of the fish was supposed to diminish in colder water.

Some of the gymnoti measured by M. Humboldt exceeded five feet in length, and the Indians asserted that they had seen them still longer. The transverse diameter of the body was more than three inches, and a fish of three feet ten inches in length weighed twelve pounds.

The gymnoti of Cano de Bera are of a fine olive-green

colour; the under part of the head being yellow mingled with red. Two rows of small yellow spots are placed symmetrically along the back, from the head to the end of the tail; each of which contains an excretory aperture, so that the skin of the animal is constantly covered with a mucous matter, which it appears conducts electricity more than twenty times as well as pure water.

We may now notice some of the electric effects which resulted from a variety of experiments with these fish. First shocks from large and strongly irritated gymnoti were as much as possible avoided; and if by chance a stroke was received, the pain and numbness was so violent as to exceed all description. M. H. says he never received so severe a shock from common electricity as he experienced from having incautiously placed both his feet on the body of a fish just taken from the water, and he adds that he was afflicted for the rest of the day by a violent pain in almost every joint. The gymnotus, when in a state of extreme weakness, merely causes a twitching sensation, which is propagated from the part that rests on the electric organs, as far as the elbow, every stroke producing an internal vibration, that lasted two or three seconds, and accompanied by a painful numbness. The electric action of the fish appeared to depend entirely on its will, each shock being accompanied by a depression of the eyes.

The electric organ of the gymnoti acts only under the immediate influence of the brain and heart, for on cutting a very vigorous fish through the middle of the body, the fore part alone gave shocks; but these in a live fish are equally strong in every part of the body. Resinous substances, glass, very dry wood, horn, and even bones prevent the action of the gymnoti from being transmitted to man,

but M. Bonpland received shocks when carrying an eel on two cords formed of the fibres of the palm-tree.

Although it has been seen that the shock from this fish is at least as powerful as any that can be produced by artificial electricity; and the electric spark has even been elicited by Messrs. Walsh and Ingenhousz, yet in no case has it exhibited the phenomena of attraction or repulsion, both of which can be produced by the Voltaic pile.

The third fish which is known to have the power of giving the shock, is found in the rivers of Africa, but we have a very imperfect account of its properties. This animal belongs to the order which the naturalists call *silurus;* hence it is commonly called *silurus electricus.* Some of those fishes have been seen even above twenty inches long.

The body of the silurus electricus is oblong, smooth, and without scales; being rather large, and flattened towards its anterior part. The eyes are of a middle size, and are covered by the skin which envelopes the whole head; each jaw is armed with a great number of small teeth. About the mouth it has six filamentous appendices. The colour of the body is greyish, and towards the tail it has some blackish spots.

The electric organ seems to be towards the tail, where the skin is thicker than on the rest of the body, and a whitish fibrous substance, which is probably the electric organ, has been distinguished under it.

It is said that the silurus electricus has the property of giving a shock or benumbing sensation like the torpedo, and that this shock is communicated through substances that are conductors of electricity; but no other particular about it is known with any considerable degree of certainty.

For a knowledge of the *medical* use of the galvanic agency, we are mainly indebted to Professors Galvani and Aldini, on the Continent, and Dr. Wilson Philip, in England. Numerous experiments made on dead animals, as well as on human subjects, had previously proved, that galvanism had a peculiar effect on the nervous and muscular system, and led to the conclusion, that this singular agent must possess some sanative as well as energetic influence on the actions of diseased living beings, and would effect cures or afford relief in nervous disorders. This supposition was verified by several trials, and numerous instances have, subsequently, confirmed its efficacy in those disorders, as well as in many other complaints. Galvanism has not only been used to cure the afflicted living, but also to resuscitate the apparently dead; and in suspended animation it has been found to be a test of vitality, and the surest criterion of recent death. Dr. Grapengiesser, of Berlin, one of the principal writers on medical galvanism, who strongly recommends its use in palsies, rheumatism, debility of sight, nervous deafness, hoarseness, white swellings of the joints, tumours in the glands of the neck, &c. concludes by observing, that galvanism not only possesses a stimulating power over the nerves and muscles, but also over the vital forces; and that it moreover possesses resolutive and derivative qualities. M. Sprenger, of Jenna, an able administrator of galvanism, gives an account of his having restored the sense of hearing to forty-five persons, to four of whom he also restored the sense of smelling. Dr. Wilkinson, in his "Elements of Galvanism," has related a variety of cases in which it was applied with the greatest advantage by Continental practitioners; and he also describes the beneficial effects which were produced by its use under his own immediate direction in paralytic and spasmodic affections.

Experience has proved that the medical effect of electricity is not confined to the Voltaic apparatus, but that the ordinary electrical machine may be made most effective in producing sanative effects. The auxiliary apparatus requisite for medical purposes are the following:—A jar fitted up with Lane's electrometer, by which shocks may be given of any required force. A pair of directors, each consisting of a glass handle, surmounted by a brass cap with a wire of a few inches in length, having a ball screwed on its extremity, which may be occasionally unscrewed and a wooden point substituted for it.

When shocks are given by means of these directors, they must be applied at the opposite extremities of the part through which the charge is required to pass; and being respectively connected by conducting wires, the one with the outside of the jar, and the other with the receiving ball of the electrometer previously placed at the requisite distance, the jar may be set to the machine, which is then put in motion until any required number of shocks has been given.

The insulated director is also employed to give sparks, being held by its glass handle, and its ball previously connected with the conductor by a fine chain being brought near the patient, or rubbed lightly over a piece of flannel or woollen cloth laid on the affected part. When the eye or any delicate organ is electrified, the ball of the insulated director is unscrewed and the wooden point applied, at the distance of about half an inch from the part. The stream of electricity which passes from the point, in such cases, produces rather a pleasant sensation than otherwise.

An insulated stool is sometimes employed; it should be of sufficient size to receive a chair upon it, with a resting-

place in front of the chair for the feet. The patient being placed on the insulated chair, and connected with the conductor of the machine by means of a chain, sparks may be drawn from any part of the body by a person who stands on the ground and presents a brass ball to it.

MAGNETISM.

Nature of Ferruginous Bodies.—Loadstone.—Artificial Magnets.—Magnetising Power of the Prismatic Spectrum.—Magnetism applied to Nautical Purposes.—Construction of the Compass.—Attempted Insulation.—Barlow's Apparatus.—Dipping Needle.

This science may justly be considered as yet but in its infancy, although the facts elicited since the commencement of the nineteenth century, by Barlow, Morichini, and Davy, bid fair to throw considerable light on some of its more recondite principles.

The theory of magnetism bears a very strong resemblance to that of electricity, and it must therefore be placed near it in a system of natural philosophy. We have seen the electric fluid not only exerting attractions and repulsions, and causing a peculiar distribution of neighbouring portions of a fluid similar to itself, but also excited in one body, and transferred to another, in such a manner as to be perceptible to the senses, or at least to cause sensible effects, in its passage. The attraction and repulsion, and the peculiar distribution of the neighbouring fluid, are found in the phenomena of magnetism; but we do not perceive any actual excitation, or perceptible transfer of the magnetic fluid from one body to another; and it has also this striking peculiarity, that metallic iron is very nearly the only substance capable of exhibiting any strong indications of its presence.

The most simple experimental illustration of the effects of magnetic attraction may be thus illustrated. If the

north pole of a magnetised bar be presented to a similar pole of another bar, it will be repelled, or driven away from it; but if, on the contrary, two opposite poles be presented towards each other, they will be attracted.

From this it will be seen, that a north pole always repels a north pole, and attracts a south pole. And in a neutral piece of soft iron, near to the north pole of a magnet, the fluid becomes so distributed by induction, as to form a temporary south pole next to the magnet, and the whole piece is of course attracted, from the greater proximity of the attracting pole. If the bar is sufficiently soft, and not too long, the remoter end becomes a north pole, and the whole bar a perfect temporary magnet. But when the bar is of hard steel, the state of induction is imperfect, from the resistance opposed to the motion of the fluid; hence the attraction is less powerful, and an opposite pole is formed at a certain distance within the bar; and beyond this another pole, similar to the first; the alternation being sometimes repeated more than once. The distribution of the fluid within the magnet is also affected by the neighbourhood of a piece of soft iron, the north pole becoming more powerful by the vicinity of the new south pole, and the south pole being consequently strengthened in a certain degree; so that the attractive power of the whole magnet is increased by the proximity of the iron. A weak magnet is capable of receiving a temporary induction of a contrary magnetism from the action of a more powerful one, its north pole becoming a south pole on the approach of a stronger north pole; but the original south pole still retains its situation at the opposite end, and restores the magnet nearly to its original condition, after the removal of the disturbing cause.

To explain the phenomena of magnetism, Æpinus suggested the following hypothesis. He imagined that there must exist a fluid capable of producing all the phenomena of attraction and repulsion, and with a subtilty so great, as to penetrate the pores of all bodies; and also of an elastic nature, its particles being repulsive of each other. At the same time he imagined a mutual attraction between the magnetic fluid and iron, or other ferruginous bodies. According to this hypothesis, iron and all ferruginous substances contain a quantity of magnetic fluid, which is equally dispersed through their substance, when those bodies are not magnetic; in which state they show no attraction or repulsion towards each other, because the repulsion between the particles of the magnetic fluid is balanced by the attraction between the matter of those bodies and the said fluid, in which case, those bodies are said to be in a natural state; but, when in a ferruginous body, the quantity of magnetic fluid belonging to it is driven to one end, then the body becomes magnetic, one extremity of it being now overcharged with magnetism, and the other extremity undercharged. Bodies thus modified, or rendered magnetic, exert a repulsion between their overcharged extremities, in virtue of the repulsion between the particles of that excess of magnetic fluid, which is more than overbalanced by the attraction of their matter. There is an attraction exerted between the overcharged extremity of one magnetic body, and the undercharged extremity of the other, on account of the attraction between that fluid and the matter of the body; but to explain the repulsion which takes place between their undercharged extremities, we must either imagine that the matter of ferruginous bodies, deprived of its mag-

netic fluid, must be repulsive of its own particles, or that the undercharged extremities appear to repel each other, only because either of them attracts the opposite over-charged extremities; both which suppositions are embarrassed with difficulties. A ferruginous body, therefore, is rendered magnetic by having the equable diffusion of magnetic fluid throughout its substance disturbed, so as to have an overplus of it in one or more parts, and a deficiency of it in the remainder, and it remains magnetic as long as its impermeability prevents the restoration of the balance between the overcharged and undercharged parts.

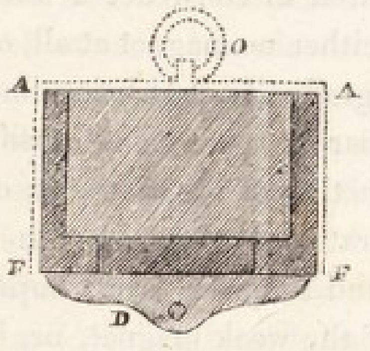
The distinction between conductors and non-conductors is with respect to the electric fluid, irregular and intricate: but in magnetism, the softness or hardness of a ferruginous body constitutes the main distinction. And it is well known that magnetic effects are produced by quantities of iron, incapable of being detected either by their weight or the most delicate chemical tests. M. Cavallo found that a few particles of steel, adhering to a hone, on which the point of a needle was slightly rubbed, imparted to it magnetic properties; and M. Coulomb has observed that there are scarcely any bodies in nature which do not exhibit some marks of being subjected to the influence of magnetism, although its force is always proportional to the quantity of iron which they contain, as far as that quantity can be ascertained. Dr. Young considers a single grain sufficient to make twenty pounds of another metal sensibly magnetic.

The *loadstone*, or natural magnet, is a heavy iron ore, and is found in large masses in every quarter of the globe.*

* The loadstone was originally called *lapis Heracleus*, from Heraclea, a city of Magnesia, a part of the ancient Lydia; where it is said to have been first found, and from which it is usually supposed to have

Three very large loadstones have lately been brought from Moscow to this country, and an account of them read before the Wernerian Society, by Mr. Deuchar. The largest of these natural magnets weighs more than 125lbs., and measures in length 10$\frac{3}{4}$ inches, in breadth 8$\frac{1}{2}$, and in height 9$\frac{1}{2}$ inches. When first examined, it supported 163lbs.; but, by gradually increasing the weight, it was afterwards brought to support 165lbs., exclusive of a connecting iron and supports of 40lbs. The weight of the second loadstone had not been taken previous to fitting on the armature, but it was supposed to be nearly half that of the large one, and it supported above 80lbs. These natural magnets were brought to this country in the same vessel, and it appeared probable that the corresponding poles had been placed together, as those of the weakest had been reversed.

A mode of protecting and increasing the power of natural magnets is sometimes resorted to—they are then said to be *armed*.



A A represents a magnet thus contrived, and A F the armature or pieces of iron, the projections for which are at F F, and to which the central piece of iron D, is made to

taken its name; though others derive the word from a shepherd named Magnes, who discovered it by the iron of his crook on Mount Ida.

adhere. The dotted line represents a brass box, having a ring O, at its upper part, by which the armed magnet may be suspended. Thus the two poles of the magnet which are at F and F, are made to act on every part alike, and the straight piece of iron D, may be conveniently applied for supporting a weight.

There are some important circumstances which require attention, in order to enable us to ascertain the best method of constructing artificial magnets.

The nature of the body must be adapted to the power which is to render it magnetic; remembering, that soft ferruginous bodies both acquire and lose magnetism more easily than those which are harder.

Several magnets are much preferable to a single one, for the purpose of communicating magnetism; in the application of which it must be remembered that the south pole of the magnet produces a north pole in the part of the ferruginous body to which it is first applied, while the north pole of the magnet produces a south pole.

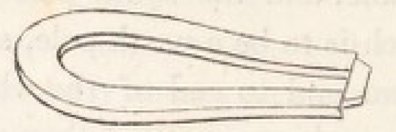
If it were required to construct a strong magnet, when the operator has either no magnet at all, or a very weak one, he must proceed gradually. It being impossible for a hard and large steel bar to receive any sensible degree of magnetism from the action of the earth, or of any other weak magnet; the operator must begin with giving magnetism to several small and soft steel bars, impregnating one at a time by means of the weak magnet, or, if he have no magnet, by means of one or more iron rods properly situated, which in that case are real, though weak magnets. Then, by joining in a proper manner the small steel bars already made magnetic, he may communicate a stronger power to larger and harder steel bars.

Mr. Michell's method of making magnets may be thus

described: prepare a dozen bars of steel, of about $1\frac{3}{4}$ ounce weight each, six inches long, and half an inch broad: let these be hardened by immersion into water at a red heat. The size and shape of the bars may be varied at pleasure, provided that the length be proportioned to the thickness. The best sort of steel is that which has no veins of iron in it, and Mr. Michell found the common blistered steel at least equal to any other. In order to preserve the bars, they must be placed in a box furnished with two pieces of iron, about an inch long each. These pieces of iron may be about a quarter of an inch square, and should be filed perfectly smooth on the sides. Against these are to be placed, with their edges towards them, the twelve magnetical bars, six on one side, with their south, or north poles one way, and six on the other side, with the same poles the contrary way. It is necessary to observe that these bars must neither be taken out, nor put in, all, or too many on a side at once; for if two only be left, with their poles of the same denomination the same way, without one or more on the other side, to counterbalance their effects, they will injure each other. In order to make the marked ends of these bars south poles, and the other ends north poles, place six of them in a line north and south, bringing the unmarked end of one, to touch the marked end of the next throughout; the marked ends lying towards the north, which will be some advantage to them. Then take an armed magnet, and placing it with both poles upon one of the bars, the north pole towards the marked end, which is to be a south pole, and the south pole towards the unmarked end, which is to be a north pole, slide it backwards and forwards from end to end of the whole line of bars three or four times, taking care that they all touch. Then taking it off, remove the two endmost bars into the middle,

and pass over them again three or four times. Having thus touched the bars, it will not be improper to turn them with the other side uppermost, and to magnetise again on that side as before, omitting the endmost bars, till they are removed into the middle, when they must undergo the same process.

Professor Steinhauser has ascertained, that if by the process of Canton, we unite, in the form of a square, two steel bars, and two contacts of iron, it is better to operate by the double touch in a circle, than by a motion backwards and forwards. Again, when we combine these bars in a square, the force of that which we wish to magnetise, ought to increase in proportion as the other magnet has become more energetic. In magnetising horse-shoe magnets, it is much more advantageous to place two of these bent bars, with their friendly poles so situated, as that the magnetic circle be completed; and that we should then touch circularly, with the magnet destined to communicate the power. When the two horse-shoe bars are separated, they lose usually a considerable part of their force, if we do not previously decompose the great circuit into two smaller ones, by applying each contact to its curved magnet before the separation. In this way, the two separated magnets lose little or nothing of their power; and two may be touched in the same time that one is on the usual plan. By conforming to these rules, Professor Steinhauser has succeeded in making magnets of extraordinary power, in the least possible time.



Among artificial magnets, those which are bent into a form

resembling the diagram on the preceding page, so that the two ends nearly meet, and therefore called horse-shoe magnets, are reckoned the most powerful. To render such a shaped piece magnetic, place a pair of magnetised bars against the ends of the horse-shoe, with the south end of the bar against that of the horse-shoe which is intended to be north, and the north end of the bar to that which is to be the south; the lifter, of soft iron, to be placed at the other end of the bars. Also rub the surfaces of the horse-shoe with the pair of bars disposed like the legs of compasses when a little open, or with another horse-shoe magnet, turning the poles properly to those of the proposed magnet; and being careful that these bars never touch the ends of the straight bars. To prevent a sudden separation of the bars from the horse-shoe, which would considerably diminish the force of the latter, slide on the lifter, or support, to the end of the horse-shoe magnet, but in such a manner that it may not touch the bars; they may then be taken away, and the support slid to its place.

The power of a magnet, and of iron or steel impregnated with the magnetic virtue, may be impaired by long lying in a wrong position, with regard to the earth or with respect to each other. Thus, if two magnets be placed so, that their contrary poles may be contiguous, they will preserve one another's power; but if the north pole of one be placed near the north pole of the other, and the south near the south, then they will entirely destroy, or diminish each other's magnetism; and if their original powers were very unequal, the polarity of the weaker magnet will be changed by the action of the stronger one.

In general, the same means which facilitate the communication of magnetism, when pieces of iron, &c. are properly situated with respect to the poles of the earth, or of other

magnets, will likewise facilitate the loss of magnetism, when the magnets are improperly situated; thus, a red heat destroys in a great measure, or entirely, the power of a magnet. A steel bar, strongly magnetic, will have its power much diminished by being repeatedly struck between two stones, especially if it be struck standing in a direction perpendicular to the magnetic meridian. A bar of hard iron, which has acquired some degree of permanent magnetism, by being made red-hot, and then cooled in the direction of the magnetical line, will have that power destroyed, or much diminished, by a few blows on its middle.*

The directive power of a magnet is extended to a greater distance than its attractive power; for instance, if a magnet be freely suspended, another magnet properly situated within a certain distance of the former, will turn it out of its ordinary direction; yet the degree of attraction exerted by these magnets against each other, is not sensible at that distance; which may be easily tried, by fixing one of the magnets to the scale of a balance. The reason of this property is, that the directive power depends both upon the attraction of the poles of different names, and on the repulsion of those of the same name; whereas the attraction takes place only between poles of different names. In order to render this view of the matter more intelligible, we may imagine a magnetic needle freely suspended, and placed within the influence, or sphere of action of a magnet. In this disposition, suppose that the north pole of a

* Some have imagined that iron or steel might be rendered heavier or lighter by magnetism. Whiston says that he found, by accurate experiments with large needles, that after the touch they weighed less than before. One of $4584\frac{1}{2}$ grains lost $2\frac{5}{8}$ grains by the touch; and another of 65,726 grains, lost no less than 14 grains. It appears, however, tolerably evident, that the vicinity of iron, or of some other ferruginous body, must have produced the change.

magnet attracts the south pole of a magnetic needle with a force equal to ten grains, and, as the attraction between poles of different names is nearly equal to the repulsion between poles of the same name, it follows, that the same north pole of the magnet repels the north pole of the magnetic needle with a force equal to ten grains: but these two forces both concur in altering the direction of the needle; therefore, the endeavour of the magnet to turn the needle's direction is equal to twenty grains; whereas the attraction, or the force by which the needle is drawn towards the magnet, is only equal to the difference between the two above-mentioned opposite forces, which difference arises from the pole of the magnet being nearer to one than to the other of the poles of the needle. The same reasoning may be applied to the action between the south pole of the magnet and the suspended needle.

Mr. Scoresby has invented a very useful piece of apparatus called a *magnetimeter*. This instrument consists of a small table of brass, about 4 inches square, and 3 inches high, having a plate of brass attached to it by hinges, and moveable by means of a wheel and pinion, through an arc of 250° of a vertical circle. This plate has a small straight groove running from end to end, for the purpose of receiving bars of metal, the polarity of which is to be determined. These bars are readily fixed to the plate, by being slipped through a circular aperture in the end of a spring, which, perforating the moveable plate, is marked by a graduated circle, screwed on the side of the table. On the brass table is placed a moveable flat plate of brass, divided into degrees, and furnished with a magnetic needle with an agate cap traversing on a brass or steel point. The needle can be changed according to the nature of the circumstances; a very light and strongly magnetised one being

used in delicate experiments. The compass, or plate carrying the needle, being moveable, its distance from the bar resting on the moveable plate, can be varied at pleasure. The centre of the hinge is one-tenth of an inch above the level of the table; and the bars in use, being one-fourth of an inch in diameter, are sunk in the groove of the moveable plate to such a depth, that their axis, or centre, precisely corresponds with the centre of the hinges; hence the middle of the extremity of each bar is at the same elevation, and at the same distance from the needle in every position of the moveable limb. To give firmness to the instrument in making experiments, the table is fixed by the feet to a mass of lead, of seven or eight pounds weight. By means of this plate of lead, which has a screw at each corner, the whole apparatus is readily put into a horizontal position. With this apparatus, Mr. Scoresby made a series of experiments, which are fully detailed in the Transactions of the Royal Society of Edinburgh, vol. 9th, and of which the following are the principal results.

1. Iron bars become magnetical by position, except when placed in the plane of the magnetic equator; the upper end, as regards the position of the magnetic equator, becoming a south pole, and the lower extremity a north pole.

2. No attraction or repulsion appears between a magnetised needle and iron bars; the latter being free from permanent magnetism, whenever the iron is in the plane of the magnetic equator; consequently, by measuring the angle of non-attraction, in a bar placed north and south, we discover the magnetic dip.

3. Before a magnet can attract iron, that is totally free from both permanent magnetism and that of opposition, it

infuses into the iron a magnetism of contrary polarity to that of the attracting pole.

4. A bar of soft iron, held in any position, except in the plane of the magnetic equator, may be rendered magnetical by a blow with a hammer, or other hard substance; in such cases, the magnetism of position seems to be fixed in it, so as to give it a permanent polarity.

5. An iron bar, with permanent polarity, when placed any where in the plane of the magnetic equator, may be deprived of its magnetism by a blow.

6. Iron is rendered magnetical if scoured or filed, bent or twisted, when in the position of the magnetic axis, or near this position; the upper end becoming a south pole, and the lower end a north pole; but the magnetism is destroyed by the same means, if the bar be held in the plane of the magnetic equator.

7. Iron heated to redness, and quenched in water, in a vertical position, becomes magnetic; the upper end gaining south polarity, and the lower end north.

8. Hot iron receives more magnetism of position than the same when cold.

9. A bar-magnet, if hammered when in a vertical position, or in the position of the magnetic axis, has its power increased, if the south pole be upward, and loses some of its magnetism if the north end be upward.

10. A bar of soft steel, without magnetic virtue, has its magnetism of position fixed in it, by hammering it when in a vertical position; and loses its magnetism by being struck when in the plane of the magnetic equator.

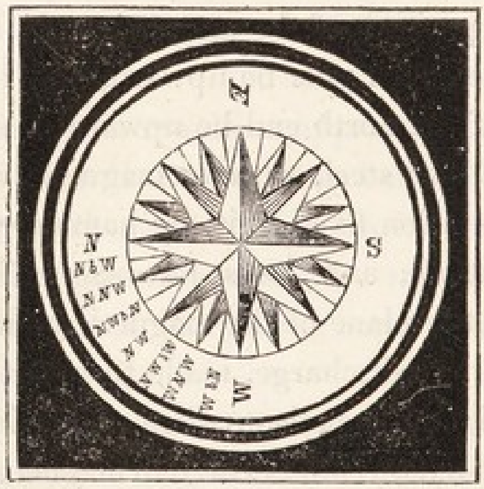
11. An electrical discharge, made to pass through a bar of iron, devoid of magnetism, when nearly in the position of the magnetic axis, renders the bar magnetic; the upper

end becoming a south pole, and the lower end a north pole; but the discharge does not produce any polarity if the iron be placed in the plane of the magnetic equator. The effects appear to be the same, whether the discharge be made on the lower or upper end of the bar, or whether it be passed longitudinally or transversely through the iron.

The action of light on ferruginous bodies is, under peculiar circumstances, capable of producing magnetism.

Morichini and Cosimo Ridolfi, two ingenious Italian philosophers, were the first to call public attention to the fact, for they found that small steel needles acquired magnetism, by being placed in the violet ray of a spectrum, produced by the decomposition of white light. Mrs. Somerville has, however, gone further than the Continental philosophers, for she proved that the magnetising power was not confined to the one coloured ray, but that nearly the whole series were capable of producing this singular effect.

The application of magnetism to *nautical* purposes must now be noticed. The history of the compass is involved



in much obscurity, as the Chinese appear to have possessed

this important instrument long prior to its use in Europe. The apparatus consists of a moveable magnet or needle, usually supported on a steel point, which occupies the axis of a cylindrical case, called the compass box, as is shown in the preceding page. For this purpose, there is formed in the needle itself, a cap or hollow conical centre of brass, or agate, on which it rests, and to this is attached the compass card. The tendency of the needle to be disturbed by agitation, will greatly depend upon the position of the vertex of the conical cavity. It is necessary that it should be above the centre of gravity; but this distance must be so small, as that the libration of the needle when one end is depressed, should be very slow, and yet speedy enough to recover the horizontal position. In fact, the whole of the steadiness of the compass and its box appears to depend on the principle of slow vibration. For, if a needle perform its vertical vibration in eight seconds, it will be very little disturbed by an alternate action that lasts but a second or two.

It is commonly imagined that the agitation of the compass is communicated by friction at the points or edges of suspension, and the compass-maker has accordingly exerted his ingenuity to diminish this friction, by contrivances similar to that of a conical cap balanced on a point, and itself affording another point to support the needle. But it may be readily proved by experiment, that the greatest disturbance of the needle is produced by the quantity of horizontal progressive motion, and not by the mere inclination or angular motion. A compass-needle supported on a simple point, will suffer very little agitation from any angular motion, or moderate deviation from perpendicularity in the pin; but it will instantly begin to vibrate if moved horizontally. Thus the common experiment of tilting the

compass-box in all positions, while its centre remains immoveable, is fallacious.

It appears, therefore, that the steadiness of a needle which vibrates slowly, is the consequence not only of the length of time it allows for alternate actions to operate, and destroy each other; but also of the difficulty with which it yields to such impressions. If the centres of suspension and of gravity in the needle were coincident, no angular motion would be produced by any action of the pin, excepting by the effects of friction; and the angular motion produced in other cases will be less, the shorter the distance between these two centres, or the lever by which it is propagated.

The simple suspension of the needle on a point, has been applied to the compass-box, for which it is little suited, not only because of the wear upon so small a surface, but also because it admits the box to traverse horizontally; an effect which is inconvenient, and cannot be remedied by any means not calculated in some respect to increase the effects of agitation. The method most generally employed, and in fact, the one best adapted to the purpose, consists in employing gimbals.

This well-known contrivance consists of a hoop supported upon two pins diametrically opposite each other, and issuing from the external surface of the ring in such a direction that both lie in the same diameter line. When the hoop is suspended on these pins, it is at liberty to turn freely round the diameter of which they constitute the prolongation. The notches or holes of support are disposed horizontally. The compass-box itself is placed in a similar ring, with two projecting pivots; and these pivots are inserted in holes made in the former ring at an equal distance from each of its pivots. If, therefore, we suppose

the whole to be left at liberty, the compass-box may vibrate upon the diametral line of the outer ring, and also upon a line formed by its own pivots, at right angles to that diametral line. The consequence of this arrangement is, that the centre of gravity of the compass-box will dispose itself immediately beneath the intersection of both lines on which it is at liberty to move:—that is to say, if the weight of the box or its parts be properly disposed, the compass will assume a position in which its upper surface shall be horizontal.

The same principles which were applied to the single centre of the magnetic needle will also apply to the axis of the gimbals. If the centre of gravity of the compass-box be so placed with respect to either axis as that its vibrations shall be quick, every horizontal action will greatly disturb it, and it will not speedily settle. The most favourable position of the pivots or edges of support in the gimbals will be when they all lie in the same plane; and the centre of gravity of the compass-box is very little below that plane.*

* The following valuable results relative to the best mode of constructing the compass-needle, form part of an admirable paper, by Captain Kater, inserted in the Transactions of the Royal Society. 1. That the best material for compass-needles is clock-spring; but care must be taken, in forming the needle, to expose it as seldom as possible to heat, otherwise its capability of receiving magnetism will be much diminished. 2. That the best form for a compass-needle is the pierced rhombus, in the proportion of about five inches in length to two inches in width, this form being susceptible of the greatest directive force. 3. That the best mode of tempering is, first to harden the needle at a red heat, and then to soften it from the middle to about an inch from each extremity, by exposing it to heat sufficient to cause the blue colour which arises, again to disappear. 4. That in the same plate of steel of the size of a few square inches only, portions are found varying considerably in their capability of receiving magnetism, though not apparently differing in any other respect.

The *azimuth compass* nearly resembles the instrument already described. The principal difference consists in the adaptation to it of two sights, through which the sun, or a star may be seen, to find its azimuth, and thence to ascertain the declination of the needle at the place of observation. These sights are upright pieces of brass, placed opposite each other; in one of them is an oblong aperture, with a thread or slender wire stretched down the middle of it: the other sight contains only a narrow slit, of the same length, consequently, the thread in the one sight is just opposite the space in the other, and the observer knows when he looks through them centrally. The ring of the gimbals rests with its pivots on a semicircle, the foot of which turns in a socket, so that, without moving its external box, the compass may be turned round, in order to place the sights in the direction of the sun, star, or other

5. That polishing the needle has no effect on its magnetism. 6. That the best mode of communicating magnetism to a needle, appears to be by placing it in the magnetic meridian, joining the opposite poles of a pair of bar magnets, (the magnets being in the same line,) and laying the magnets so joined, flat upon the needle, with their poles upon its centre; then having elevated the distant extremities of the magnets, so that they may form an angle of about two or three degrees with the needle, they are to be drawn from the centre of the needle to the extremities, carefully preserving the same inclination, and having joined the poles of the magnets at a distance from the needle, the operation is to be repeated ten or twelve times on each surface. 7. That in needles from five to eight inches in length, their weights being equal, the directive forces are nearly as the lengths. 8. That the directive force does not depend upon extent of surface, but, in needles of nearly the same length and form, is as the mass. 9. That the deviation of a compass-needle, occasioned by the attraction of soft iron, depends, as Mr. Barlow has advanced, on extent of surface, and is wholly independent of the mass, except a certain thickness of the iron, amounting to about two-tenths of an inch, which is requisite for the complete developement of its attractive energy.

object to be viewed. This instrument is used to take the bearings of headlands, ships, and other distant objects.

Lieutenant Littlewort has contrived a method, by which the ordinary hanging compass may be converted into an azimuth compass, so that merchant vessels may have the benefit of this important instrument, with which they are seldom supplied. The handle by which the compass is suspended to the roof of the cabin is capable of being inverted, and of supporting the compass, by sliding in a groove made in a box, which box is capable of motion on a central pin fixed in the board on which the box stands; moveable sights and a stop are also annexed, to enable it to act when required as an azimuth compass.*

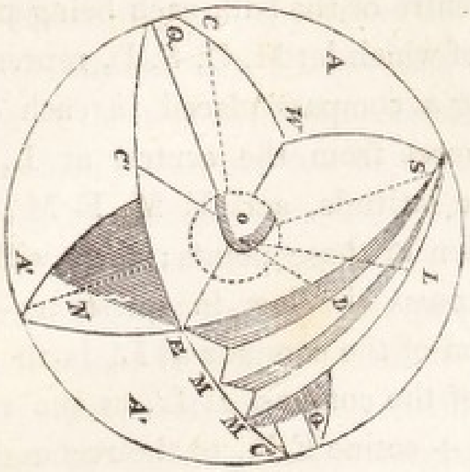
Mr. Wales, who accompanied Captain Cook in his second voyage, appears to have been the first person who observed the effects of the iron employed in ship building, upon the action of the magnetic needle. This subject was further investigated by Captain Flinders, who, in his survey of the coast of New Holland, succeeded in applying a correction for the use of his own vessel.

From an account of the survey, published some time after this navigator's return, it appeared that in Captain Flinder's vessel, and, indeed, in every ship, a compass would differ very materially from itself, in being removed from the head to the stern. This was found to arise from the iron which surrounds the compass becoming magnetic, and its entire attractive force is thus concentrated into one powerful focus. Of this, the principal south pole is situated near the middle of the upper deck. This focus of attraction so influences the compass-needle, that it is sub-

* A figure and description of this compass, will be found in the Transactions of the Society of Arts, vol. xi. p. 70.

ject to a considerable variation from the true meridian, different from what is observed by a compass on shore; the north point of the compass being constantly drawn towards the focus in our hemisphere, and the south point in the opposite hemisphere.

With these facts in view, Professor Barlow commenced a series of experiments to remedy the defective apparatus. Having procured a solid iron ball, thirteen inches in diameter, he found, on placing the compass above it, that the north end of the needle was attracted by the upper part of the ball; that when placed below the ball, the south end was attracted; and that when the needle was raised or depressed in any vertical around the ball, it always passed through a point in which both attractions became neutralized. The next step in his investigation was to ascertain whether these points of no attraction were all in the same plane; and if so, to determine correctly its inclination to the horizon,—since it had become obvious from the care with which the trials had been made, that it was not parallel to it. This question was soon decided: by a series of experiments it was demonstrated that the points were all in the same plane, and that the inclination of the plane itself to the horizon was about 20°, declining directly from the magnetic north point to the south, approaching very nearly to the compliment of the dip of the needle. This circle, Mr. Barlow now traced on his iron ball, assuming as its principal axis the direction of the dipping needle; and, imagining circles of latitude and longitude to be described around the whole ball, he had thus an ideal magnetic sphere, which would readily indicate the relative position of the iron and the compass in his subsequent experiments. The annexed diagram on the following page, will enable the reader to form a correct idea of the nature and pro-



perties of this magnetic sphere. Here O is supposed to represent an iron ball, and A, A, A, a sphere circumscribing it, and within which its influence is active; S, N, being in the magnetic meridian. The line N S, in the plane S, E., N, W, denotes the natural direction of the dipping needle, in those latitudes where its inclination to the horizon is about 70½°. Now, conceiving Q, E, Q′, W, to represent a plane, passing through the centre of the ball, and being perpendicular to the axis N S, it will be the *plane of no attraction*, which has this remarkable property, that if lines be drawn in it, (as for example, the lines O C, O, C′, O C″, &c.) and a compass be placed any where in those lines, or indeed in any point of the plane Q, E, Q′, W, it will be uninfluenced by the iron ball, and will preserve its natural magnetic direction.

As soon, however, as the compass is removed out of this plane, the needle is found to deviate from its original bearing—its south end being attracted towards the ball when the needle is below the plane, and its north end when it is above; and in every case the deviation follows a determinate law, so that the amount being given in any one case, it may be ascertained for all others.

Suppose, for example, any two other planes, passing

through the centre of the ball, each being perpendicular to Q, E, Q′, W, of which let M, O, S, L, represent quadrants; then supposing a compass placed in each of these planes, at equal distances from the centre, at L, we shall have M L, for the latitude, and E M, E M′, for the longitude of position of those points; then will the following proportion express the law in question:—The tangent of the deviation of the compass at L, is to the tangent of the deviation of the compass at L′, as the rectangle of the sine of 2 L M + cosine E M, to the rectangle of the sine of 2 L′ M′ + cosine of E M′, E, being the east point of the horizon.

Pursuing this inquiry, Mr. Barlow next ascertained by a series of experiments, the law of attraction at different distances of the compass from the iron ball; and which he thus states:—That while the position as to latitude and longitude is the same, *the tangents of the angles of deviation are reciprocally proportional to the cubes of the distances.*

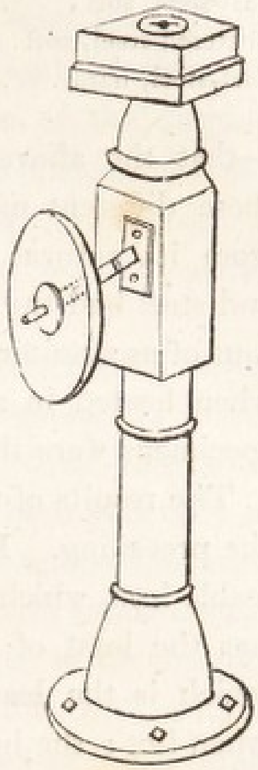
Still, however, there remained an important question to be solved, viz.—When the position and distance are the same, what is the law of deviation as it respects the mass of the attracting body? And here a most unexpected result was obtained. From the first experiments, which were made with a solid iron ball of ten inches in diameter, it appeared, as Mr. Barlow seems to have anticipated, *that the tangents of the deviations are proportioned to the cubes of the diameters*, all other things being the same; but happening at this time to make trial of an iron wheel of the same diameter as the ball, but only three-fourths of its weight, he was not a little surprised to find the results in both cases the same. "In fact," he remarks, "it appeared *that the power of attraction resided wholly on the surface, and was independent of the mass.*"

Before it was discovered that the power of an attracting body resides in its surface, Mr. Barlow had anticipated a great impediment in the way of final success, arising from the mass of iron which he considered as necessary to produce the desired effect. It now, however, readily occurred to him that, as surface is the principal thing to be attended to, a light, globular shell of iron, or a simple circular plate of the same metal, would be amply sufficient for the purpose. A plate of this description was accordingly tried; it was fifteen inches in diameter, and weighed only 4lbs. 13oz. With this plate Mr. Barlow repeated the series of experiments that had been made with the ball, and had the satisfaction of finding that its power was far greater than would be requisite for doubling the effect of the guns of any vessel in the navy, although applied to the exterior of the binnacle, and fifteen inches distant from the pivot of the needle. The precise situation for this correcting plate is, of course, a matter of essential importance, and cannot be fixed on until the local attraction of the vessel has been ascertained. This is effected in the following manner:— The ship being so moored as to admit of her head being directed to each point of the compass successively, and there steadied whilst the bearing of as remote an object as can be found is taken, it will then be found that the bearings thus taken vary from each other, according to the attractive power of the vessel, sometimes as much as 28°, which difference is caused by the iron of the ship drawing the needle from its proper direction to the eastward with the ship's head east, and to the westward with the head to the west. It will also be found that two of the bearings, taken at opposite points of the compass, nearly agree with each other, and the mean of these is to be taken as the true magnetic bearing of the object. By these points, also,

will be indicated *the line of no attraction* in the vessel, which in general is found to be nearly fore and aft, and in this line the plate is ultimately to be placed. This being accomplished, a pedestal or compass-stand is then taken ashore, and by trying different situations for it, and turning it about till the same deviations are produced by the plate at each point, as had been observed in the vessel. But this process, which is very troublesome, is now rendered unnecessary, the end being much more readily accomplished by means of a printed table, which is given with the correcting plate; and which comprises a series of attractions obtained by the plate, including all possible limits for every class of vessels. Corresponding to each degree of local attraction are given two numbers, the one indicating the distance of the centre of the plate below the pivot of the needle, and the other its distance from the centre line of the pedestal, and at this depth and distance the plate must be fixed, either fore or aft the compass; if the former, the effect of the vessel will be exactly doubled—and if the latter, it will be neutralized. When the plate is applied in front, which is reckoned preferable in southern voyages, it is not a fixture, but is applied at pleasure; but when placed behind, as recommended in northern voyages, where the disturbance from local attraction is very considerable, it is fixed in its place during the voyage, and the needle is thus left free to obey the influence of the magnetic power of the earth only.

It now remains to give some account of the plate itself. The plate employed by Mr. Barlow in his experiments, as well as those which he sent out by Captains Parry and Sabine, consisted of two circular pieces of sheet iron, weighing about 3lbs. per square foot, screwed together in such a

manner as to combine any strong irregular power of one plate, with a corresponding weak part on the other, by which means a more uniform attraction is produced; he is, however, of opinion that a single plate of iron, weighing about 6lbs. per square foot, would answer the purpose equally well. In diameter the plate may vary from twelve to sixteen inches, according to the power of the vessel. When the plate is made double, there is a circular board of the same size inserted between the iron discs, for the purpose of increasing the thickness, without adding much to the weight. The two plates thus separated are found to be more powerful than either a single plate, or two plates in immediate contact. The plates are perforated in the centre, and through this opening is passed a brass socket with a broad head, and having an exterior screw and nut, by which the two iron plates, and the interposed plate of wood, are compressed together. The accompanying figure represents the brass pin, socket, plate, pedestal, and compass, combined, as in action on ship-board.



Mr. Barlow, in the prosecution of his magnetical experiments, discovered a curious property in ferruginous bodies, which deserves to be recorded. Mr. Barlow's first object appears to have been to determine the relative magnetic power of different kinds of iron and steel on the needle, and his results, as connected with this determination, are as follow:—viz.

Malleable iron	100	Shear-steel, soft	66
Cast-steel, soft	74	Ditto, hard	53
Blistered-steel, soft	67	Blistered-steel, hard	53
Cast-steel, hard	49	Cast-iron	84

—that the above numbers express the relative powers of these different metals in deflecting a magnetised needle from its natural direction. Seeing that the hardest iron and steel had the least power, Mr. Barlow was next desirous of ascertaining what this comparative power might be when heated in a furnace, and while each of the different specimens were thus rendered soft.

The results of these experiments are not so uniform as in the preceding. It is remarkable, however, that the malleable iron, which has by far the greatest power when cold, has the least of any when heated; and that the cast-iron, which is the least powerful when cold, is the strongest when hot; the increase of strength in the latter case being nearly as 3 to 1.

It was also observed, that between the white heat of the iron, (when every species of magnetic action disappears), and the blood-red heat, (when the power manifests itself strongly), there was an intermediate action, which attracted the needle the contrary way when cold, or at the blood-red heat; that is, if the iron and compass are so posited that the north end of the needle is attracted towards the iron when cold, the south end will be attracted when the iron is red-hot, and vice versa; but as the red changes to the darkest shades of blood-red, the usual power of the iron commences, and the needle is deflected the contrary way. Moreover, this negative attraction is least in those positions where the natural cold attraction is the greatest, and greatest where the latter is the least, and greatest of all in that position where the cold attraction is zero; that is,

in the plane of no attraction, provided (of course) the needle is sufficiently near to the bar. The bars used in the experiments were twenty-five inches in length, one inch and a quarter square, inclined in the position of the dipping-needle; the distance varying from five to nine inches; but the nearer to the bar, the more obvious are the effects. In some of the experiments, the quantity of negative attraction exceeded 50°.

It appears from a curious paper, by Mr. Fisher, on the errors in longitude as determined by *chronometers* at sea, that a sudden alteration takes place in their rate when taken on ship-board, an effect which has been generally ascribed to the motion of the vessel. He ascribes the accelleration which takes place, to the "magnetic action exerted by the iron in the ship, on the inner rim of the balance, which is made of steel;" and in proof of this, he found that analogous effects took place in chronometers when under the influence of magnets placed in different positions with respect to their balances. "Upon the whole," says Mr. Fisher, "it appears that chronometers will be generally accelerated (particularly if their balances have received polarity by the too near approach of any thing magnetical) on ship-board. It appears probable, likewise, that the force of the balance-springs is affected in the same way, since it is well known that chronometers having gold balance springs, although more difficult to adjust, yet keep better rates at sea than others.*

If the magnetic poles always agreed with the astronomical poles of the globe, the compass-needle must of necessity point due north and south in every part of the earth. This however, is not the fact, as the needle is found to vary con-

* Philosophical Transactions, 1820.

siderably, not only after the lapse of ages, but also at stated periods, within a few hours of its maximum in either direction. In other words, the magnetic meridian, and the real meridian, seldom coincide. The angle which they make is called the *angle of declination*, and this is said to be *east* or *west* according as the north pole of the needle is eastward or westward of the true meridian of the place.

From the minuteness of the daily variation, and the extreme difficulty of measuring it, excepting with the nicest instruments, its laws, and consequently its cause, are still undiscovered. It occurred to Mr. Barlow, that this deviation might be increased, both in the horizontal and the dipping needle, to between three and four degrees, by reducing the directive power of the needle, by means of one or two magnets, so disposed, as to balance, at least in part, the terrestrial influence. Mr. Barlow used a delicate needle, eight inches and a half long; and, by means of two magnets, he kept the needle balanced in different directions of the compass; and in these different directions he observed the daily changes in its position. The following were the results for the horizontal needle.

When the N. end of the needle was directed to any point from the S. to N N W. its motion, during the forenoon, is towards the left hand, advancing, therefore, to some point between the N N W. and N. When the N. end is directed towards any point between the N. and S S E., it passes to the right hand, advancing to some point between the N. and N N W. Hence, there ought to be some direction between these limits: viz. between the N. and N N W., and the S. and S S E., in which the daily motion is zero, or at least a minimum. Mr. Barlow likewise concluded, that the daily change was not produced by a general deflection of the directive power of the earth, but

by an increase and decrease of attraction of some point between the N. and N N W., or between the S. and S S E.

Having reduced the power of a dipping-needle nearly eight times, by two magnets placed in the line of the dip, Mr. Barlow observed, that it passed suddenly one half-quarter degree to another, more or less, so as to give a difference in the dip of one and a half in one day.

A memoir was presented to the French National Institute, by Humboldt and Biot, "On the Variations of the Terrestrial Magnetism in different Latitudes." These philosophers, having first determined the position of the magnetic equator by direct observations, proved that the magnetic force must increase in proceeding from that equator to the poles; and the same distinguished foreigners have given a mathematical hypothesis, which, when reduced to a formula, accords with all the inclinations of the needle hitherto observed.

As to the position of the magnetic equator, supposing it to be a great circle of the terrestrial sphere, an hypothesis which is conformable to observations: the inclination of this plane to the astronomical equator, is equal to 12·2025° of the decimal division, (10°58′56″ of the common division,) and its occidental node on that equator is at 133·3719° (120°2′5″) longitude west from Paris, that is, a little beyond the continent of America, near the Gallipagos, in the South Sea; the other node is at 66·6281° (59°57′55″) eastward of Paris, that is to say, in the Indian Seas. The points where the axis of the magnetic equator pierces the earth's surface, are, the northern point at 87.7975° (79°1′4″) of north latitude, and at 33°3719° (30°2′5″) of longitude west from Paris; the southern point is situated in the same latitude south, and 166·6281° (149°67′55″) of longitude east from Paris. It is remarkable that this deter-

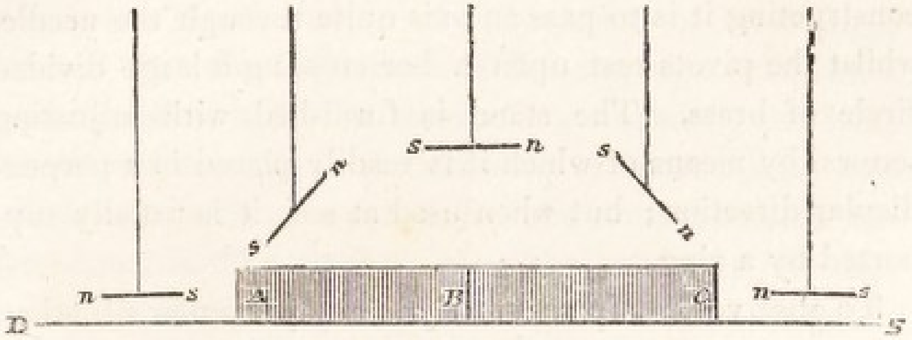
mination of the magnetic equator agrees almost perfectly with that given half a century back, by Wilke and Lemonnier.

With respect to the intensity of the magnetic force in different parts of the earth, these philosophers have ascertained that it varies in different latitudes; its increase proceeding from the equator towards the poles. The needles of Humboldt's compass, which, at his departure, gave at Paris 245 oscillations in ten minutes, gave no more in Peru than 211, and it constantly varied in the same direction; that is to say, the number of the oscillations always decreased by approaching the magnetic equator, and always increased by advancing towards the north. The differences can neither be ascribed to a diminution of magnetic force in the compass, nor to the effects of heat or of time; for after three years residence in the warmest countries of the earth, the same compass gave again in Mexico, oscillations as rapid as at Paris.

There are some anomalies, however, occasioned by local causes. Thus Biot having, in the summer of 1804, carried to the Alps the magnetic needle employed in one of his previous aerial excursions, he found that its tendency to return to the magnetic meridian was constantly stronger in these mountains than it was at Paris before his departure, and than it had been since his return. This needle, which made at Paris 83·9 oscillations in ten minutes of time, gave oscillations as below, at the places mentioned, in the same interval of ten minutes: viz. Paris, before departure, 83·9; Turin, 87·2; on Mount Genevre, 88·2; Grenoble, 87·4; Lyons, 87·3; Geneva, 86·5; Dijon, 84·5; Paris, after his return, 83·9. It appears to result from these observations, that the action of the Alps has a perceptible influence on the intensity of the magnetic force. Humboldt observed analogous effects at the bottom of the Pyrenees,

for instance, at Perpignan. It is not improbable that they arose from the mass of these mountains, or the ferruginous matters contained in them ; but whatever may be the cause, it is hence manifest that the general action of terrestrial magnetism is sensibly modified by local circumstances, the differences of which may be perceived in places very little distant from each other.

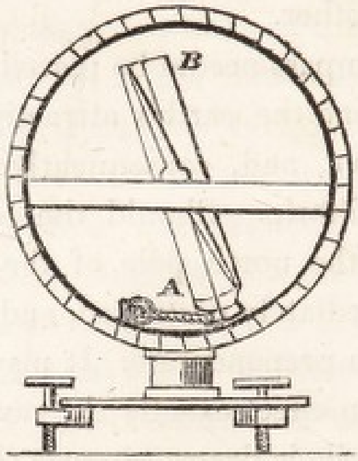
If a common compass-needle be placed at the equator, it will be evident that the earth's attractive power must be equal at either pole, and, consequently, that the needle will remain in equilibrio. Should the compass needle be removed towards the north pole of the earth, the equilibrium will be immediately destroyed, and the south pole of the needle will then preponderate. It may hardly be necessary to add, that an effect exactly the reverse of this takes place when the needle is drawn towards the opposite pole.



The bar magnet A B C, will best explain the nature of this phenomenon, which is called the *dip* of the needle. The magnetized needle suspended over the equator B, is exactly parallel to the bar, and would be so to the plane of the earth's horizon ; but if we suppose the needle thus balanced to be placed over the north pole A, the south pole of the needle will dip towards it. Should we remove the needle still further, and place it exactly over the pole, it

will arrange itself perpendicular to the plane of the horizon.

A reference to this simple experiment will serve to illustrate the construction and use of the *dipping needle* represented beneath. This instrument, though of late much



improved, is still far from perfect. The general mode of constructing it is to pass an axis quite through the needle, whilst the pivots rest upon a bar crossing a large divided circle of brass. The stand is furnished with adjusting screws, by means of which it is readily placed in a perpendicular direction; but when used at sea, it is usually supported by a ring.

To observe the dip accurately in any particular situation, it is necessary, after having noted the angle formed on one side of the circle, to reverse the magnetism of the needle by the application of magnetic bars, so that the end of the needle which before was elevated above the horizon, may then be below it; on again observing the dip, a mean of the two observations will produce the most accurate result.

The dip of the needle was first observed by Norman in 1576, at which period, the north-pole of the dipping-

needle, when placed in the neighbourhood of London, stood at 71°50′ below the horizon; and in 1775, it was at 71°.3′, the change in its angle during that period, being somewhat less than a quarter of a degree.

The phenomenon of the magnetic dip, or inclination of the needle, having been discovered by Norman, numerous theories were formed to account for such a wonderful phenomenon, and the latitude, on any meridian, was attempted to be discovered by its results; experience, however, very soon proved that its demonstrations were extremely erroneous; and it has since been adverted to more as a matter of scientific importance, than of real utility to navigation. Captain Flinders, in his last voyage of discovery, and M. Humbolt, in his valuable philosophical researches in the New World, have materially improved our acquaintance with the dipping needle, and have, in some measure, rendered its results valuable to the navigator. The former, at an early period of his voyage, observed that the indications of the dipping-needle had a close connexion with the change, occasioned by the local attraction of the ship, in the variation of the compass; and that, as the north or south end of the compass-needle was affected, so, in like manner, were the results of the dipping-needle increased or diminished: this affinity he considered as occasioned by the magnetism of the earth, and the attraction of the ship, acting upon the needle and forming a compound force; for when the north end of the needle had dipped, it was the north end of the compass-needle which was attracted by the iron-work in the ship; and that the errors produced by this combined attraction, were proportionate to the sines of the angles between the ship's head and the magnetic meridian. On the magnetic

equator, where the dipping needle stands horizontally, or there is no dip, there seemed to be no local attraction; but after passing some distance into the southern hemisphere, when the south end of the needle had dipped, observations again showed errors in the compass-needle, but they were of a contrary nature to those experienced in the northern, which evidently proved that the south end of the compass-needle was now attracted. The importance of this discovery, deduced from many observations during the voyage, and verified after his return, by a series of observations made on board other ships, induced him to conclude that the error produced at any direction of the ship's head, would be to the error at east or west, at the same dip, as the sine of the angle between the ship's head and the magnetic meridian, was to the sine of eight points or radii.

From what we have already stated of the nature of the magnetic dip, it will be evident that the angle formed by the needle, must vary as the observer approaches to, or recedes from the poles, and that at the equator, it would assume a line parallel with the plane of the horizon. In the following table, Professor Hausteen has furnished us with a series of valuable observations upon this subject; they were made in 1819.

	Dip.		Dip.
Peru	0° 0′	Arendahl	72°45′
Mexico	42 10	Brassa	74 21
Paris	68 38	Hare Island	82 49
London	70 33	Davis's Straits	83 8
Christiana	72 30	Baffin's Bay	84 25

From a series of numerous and accurate experiments made by Captain Sabine, he obtained the following measures of the dip of the magnetic needle at London:—

By ten experiments with Tobias Mayer's needle	70.2.9
By the times of oscillation in the magnetic meridian, and in the plane perpendicular to it. Mean by three needles .	70.4.0
By the times of vertical and horizontal oscillation . .	73.2.6
Mean . .	70.3.2

Hence Captain Sabine concludes, that 70°.3′ was the mean dip of the needle at London, in August and September 1821, within a few hours of noon.

As the observations of Nairne and Cavendish give 70°25′ for the dip in 1774, we obtain 3.′02″ as the mean annual rate of diminution between 1774 and 1821.

Taking Mr. Whiston's determination of the dip in 1720, at 75°10′, which Mr. Cavendish considered as accurate, the annual diminution is 3′05″.

Having thus illustrated the nature of the magnetic dip, it may now be advisable to notice Biot's hypothesis, in which he attempts to determine the law which regulates the inclination of the needle in different parts of the globe. M. Biot supposes two centres of attraction, or northern and southern poles, situated at equal distances from the centre of the earth, and in the axis of the magnetic equator. He then calculated the effects which ought to result from the action of these centres upon any point of the earth's surface, assuming the attractive force in the reciprocal ratio of the squares of the distances; and the result was, that the nearer these assumed poles were brought to each other, the more perfectly did the calculation agree with experiment.

ELECTRO-MAGNETISM.

Magnetic Phenomena exhibited by the agency of Charged Electrical Surfaces.—Franklin's Experiments.—Effects produced by Van Marum and Von Buch.—Oersted's Discoveries.—Revolving Apparatus.—Thermo-electricity.

The intimate connexion that subsists between many of the phenomena described in the preceding section, with those observed in electricity, has given birth to a new science, which may be said to date its origin from the commencement of the present century. Amongst those who have done most towards the developement of *electro-magnetism*, we may especially enumerate M. Oersted, Sir Humphry Davy, and Professor Barlow, and the latter of these gentlemen has published a very valuable work illustrative of the subject. It may, however, be right to add, that the facts yet developed are too scanty to admit of any very accurate mode of theorizing in this branch of science. We may advert in the first instance to the effects which are found to arise from the action of coated surfaces on ferruginous bodies, as these were observed at a much earlier period.

Dr. Franklin appears to have been the first electrician who paid any serious attention to this subject. He sent the charge of some large jars through fine sewing-needles: the ends of the needles were rendered blue, and on being carefully laid on water they traversed, evincing evident proofs of polarity. The most remarkable circumstance attending these experiments was, that if the needle lay east and west when the charge was passed through it, the end which was entered by the fluid pointed to the north; but

if it lay south and north, the end which lay pointing to the north would continue to do so, whether the charge entered by that end or the other; although the Doctor imagined that a still stronger charge would have reversed the poles, even in that situation, since this effect had been actually produced by lightning. The polarity he also found to be strongest when the needle received the charge while lying north and south, and weakest when it lay so as to point east and west.

But the experiments most to be relied on were made by Van Marum with the large machine and battery in the Tylerian Museum at Haarlem. He succeeded in giving polarity to needles made of watch-springs, of from three to six inches in length; and also to steel bars nine inches long, from a quarter of an inch to half an inch broad, and about a line in thickness. The result was, that when the bar was placed horizontally in the magnetic meridian, whichever way the shock entered, the end of it that stood towards the north acquired the north polarity, and the opposite end acquired the south. If the bar, before it received the shock, had polarity, and was placed with its poles contrary to the usual direction, its natural polarity was uniformly diminished, and often reversed; so that the extremity of it, which in receiving the shock pointed to the north, became the north pole.

When the bar was struck standing perpendicularly, its lowest end became the north pole in any case, even when the bar previously possessed magnetism, and was placed with the south pole downwards. Things remaining the same, the bars seemed to acquire an equal degree of magnetic power, whether they were struck whilst standing horizontally in the magnetic meridian, or perpendicular to the horizon. When the needle was placed in the mag-

netic equator, whichever way the charge entered, it never produced any magnetism; but if it was passed through its width, then the needle acquired a considerable degree of magnetism, and the end which lay towards the west became the north pole, and the other end the south pole. If a needle or bar, already magnetic, or a real magnet, was struck in any direction, its power was always diminished. For this experiment they used bars of considerable size and weight, one of which was 7·08 inches long, 0·26 broad, and 0·05 thick. When the shock was so strong in proportion to the size of the needle, as to render it hot, then the needle generally acquired no magnetism at all, or very little. These experiments were made with a battery composed of 135 jars, containing about 130 square feet of coated surface.

M. Von Buch, also, appears to have ascertained the action of common electricity in producing magnetism, without a previous knowledge of what had been done by others in that way, and he succeeded in producing the effect by a smaller power than had before been used for that purpose. He found that a strong discharge was not necessary, nor even a Leyden phial; but, fixing a helix between the prime conductor of a machine and another insulated conductor, placing a steel needle in it, and then drawing sparks from the latter conductor, the needle became magnetic. One single turn of a machine, with two discs, eighteen inches in diameter, was sufficient to make the needle evidently magnetic.

As the discharge of a considerable quantity of electricity through a wire seemed necessary to produce magnetism, it appeared probable that a wire electrified by the common machine would not occasion a sensible effect; and this was found to be the case, on placing very small needles across

a fine wire connected with a prime conductor of a powerful machine, and the earth. But, as a momentary exposure in a powerful electrical circuit was sufficient to give permanent polarity to steel, it appeared equally obvious, that needles placed transversely to a wire at the time that the electricity of a common Leyden battery was discharged through it, ought to become magnetic, and this was actually the case, and according to precisely the same laws as in the voltaic circuit; the needle under the wire, the positive conductor being on the right hand, offering its north pole to the face of the operator, and the needle above exhibiting the opposite polarity.

So powerful was the magnetism produced by the discharge of an electrical battery of seventeen square feet, highly charged, through a silver wire of one-twentieth of an inch, that it rendered bars of steel two inches long, and from one-twentieth to one-tenth in thickness, so magnetic, as to enable them to attract small pieces of steel wire or needles; and the effect was communicated to a distance of five inches above or below or laterally from the wire, through water, or thick plates of glass, or metal electrically insulated.

The major part of the discoveries made in this science, have, however, been effected by galvanic electricity; and to this powerful agent, M. Oersted directed his attention about the commencement of 1807, when he proposed to try "whether electricity, the most latent, had any action on the magnet."

If a magnetic needle be left to take its natural direction, and then a straight portion of the connecting wire of a galvanic battery be brought above it, and parallel to it, that end of the needle next the negative pole of the battery moves towards the west; and that too whether the wire be

on the one or the other side of the needle, so that it be above and parallel to it. If the connecting wire be sunk on either side the needle, so as to come into the horizontal plane in which the needle is allowed to move, there is no motion of the needle in that plane; but the needle, attempts to move in a vertical circle; and but for the imperfect suspension, and the influence of the earth's magnetism, would do so. When the wire is on the east of the needle, the pole of the needle next the negative end of the battery is elevated; and when on the west of the needle it is depressed. If the connecting wire be now sunk below the level of the needle, similar attractions and repulsions take place, but in opposite directions to those followed when it is above. The pole of the needle opposite the negative end of the battery then moves eastward, whatever the position of the wire, so that it be restricted as above.

That these positions of the magnetic needle may be retained with more facility in the memory, Professor Oersted proposed the following formula: "The pole above which the negative electricity enters is turned to the west; under which, to the east."

M. Oersted subsequently pointed out, what it is easy to see from the above experiments, that the movement of the needle took place in a circle round the connecting wire; and though, in the description of his first experiments, the quantity of declination given to the needle from the wire is expressed by an angle of so many degrees, yet it is afterwards stated to vary with the power of the battery. Whenever the needle is moved in a horizontal or any other circle from the position it naturally assumes, the power of the earth over it tends to restore that position, and is consequently an active force, in the present instance opposed to the power of the connecting wire; it therefore lessens the

declination the needle would otherwise have. Also when the wire is brought into the same horizontal circle with the needle, its effect over it is shown by the elevation and depression of its opposite ends; and it is the mode of suspension combined with the earth's magnetic power that prevents it from traversing in a vertical circle. But if those interfering circumstances be removed, viz. if the suspension be such as to allow of free motion to the needle in every direction, and the earth's magnetism be rendered null, or counteracted either by the position of the needle, or by the vicinity of another magnet, then a much simpler idea of the relative movements of the wire and needle may be obtained.

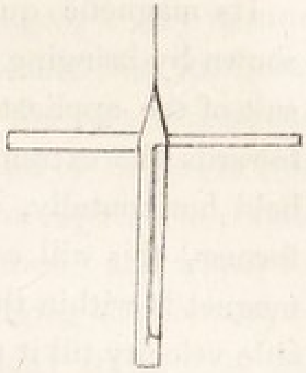
It is not, perhaps, easy to obtain this perfect state of apparatus, but it is not difficult so to arrange it as to examine the movements first in one direction, and then in another. It will then be found, if the connecting wires of a sufficiently powerful apparatus be placed near a magnetic needle so as to pass near its centre, that the needle will arrange itself directly across the wire, whatever the previous position of the two; that if the wire be carried round the centre of the needle, or the centre of the needle round the wire, the same relative position of the two will continue; and that the direction of the needle across the wire is not indifferent, but has its poles always in a constant position to the poles of the battery. If the positive pole of a battery be on the right hand, and the negative pole on the left, and a wire be stretched between, connecting them, then a needle above the wire will point the north pole from, and the south towards us: or if below, the south pole from, and the north towards the experimenter.

If the connecting wire and the needle be represented by two small rods named accordingly, and fastened perma-

nently together, then they will represent the wire and the needle in all positions; for, however one be placed, the other will correspond with it: or if, on the under side of a small square piece of glass, a line be drawn from top to bottom, the upper end being called negative and the lower positive; and on the upper surface a line be drawn from left to right, the left termination being named south, the right north; then the lower line will always represent the connecting wire, and the upper the needle.

The needle and wire being in this position, if the wire be moved along the needle towards either extremity, strong attractions will take place between it and the pole, notwithstanding the same part of the wire be employed; and the poles in the two positions are contrary to each other. In this case it appears that the same point in the wire has the power of attracting both the north and the south pole of the needle. If while the wire is thus situated near the end of the needle, the latter be turned round, so that the pole before there be replaced by the opposite pole, strong repulsions will take place; and that, to whichever pole the wire has in the first instance been carried, so that the same point which before attracted both poles will now repel them both. If, when the wire is near the extremity of the needle where the attraction is strongest, it be moved round the end so as to go from one side to the other, keeping the same point constantly towards the needle, its attractive power over the needle will be found to increase as it approaches the end, but remains on one side of it; will diminish as it turns the end; will become null when exactly opposed to the pole; and, as it passes on the other side, will resume repulsive powers, which will be strongest at the extremity of the pole on the opposite side to where the wire was situated at first.

In one of the earliest experiments to show the motion impressed on a galvanic arrangement by the close proximity of a magnetized bar, Professor Oersted suspended a copper trough, furnished with a plate of zinc, exposing a surface of about two square feet. The apparatus was supported by a silk thread, and then charged with a strong acid solution. The wire which is seen to connect the two plates was then found to obey the magnet. It may be attracted or repelled, and is capable of producing similar effects on light steel needles, placed in the neighbourhood of the apparatus.

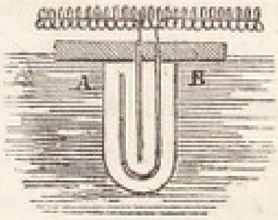


M. de la Rive's apparatus consists of a small galvanic combination attached to a cork; the plate of zinc is nearly half an inch wide, and extends about one and a half or two inches below its cork, its upper end passing through the same; the slip of copper is of equal width to the zinc, but passes round it, being thus opposed to both its surfaces, as in Dr. Wollaston's construction: its upper end also appears through the cork. A piece of copper wire, covered with silk thread, is coiled five or six times, and tied together so as to form a ring about an inch in diameter, and the ends of the wire are connected, by solder, one with the zinc, and the other with the copper slip above the cork.

When this small apparatus is placed in water slightly acidulated with sulphuric or nitric acid, the ring becomes highly magnetic, and will arrange itself in a plane perpendicular to the magnetic meridian, or it will at least indicate a tendency to take up that position; but the escape of the

bubbles, arising from the decomposition of the water, prevents it from preserving a fixed direction.

Its magnetic qualities, however, are more obviously shown by bringing to it a strong magnet. When the result of the application is attraction, the cork will advance towards the extremity of the magnet; and if the latter be held horizontally, and in a line with the centre of the former, this will continue to advance till the pole of the magnet is within the ring, and then proceed with considerable velocity till it reaches the middle of the magnet, where it remains perfectly stationary. If now the magnet be withdrawn, and changed end for end, and re-introduced into the ring, the latter will go off from the magnet, turn itself round when quite free from it, again advance, and settle itself as before in the centre.

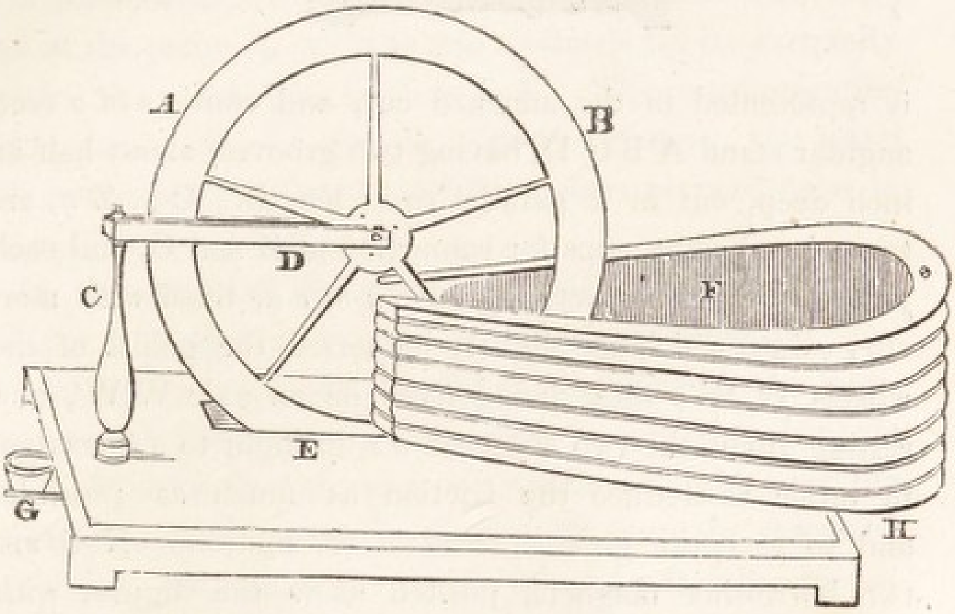


A perfect polar arrangement may be formed by the simple electro-magnetic apparatus, represented in the figure A B, which will be found to be attracted and repelled precisely in the same way as common magnets.

One of the most delicate pieces of apparatus for exhibiting electro-magnetic rotation, was suggested by Mr. Faraday. It is shown in the accompanying figure, and consists of a piece of glass tube, the bottom part of which is closed by a cork, and through it is passed a small piece of soft iron wire, so as to project above and below the cork. A little mercury is then poured in, to form a channel between the iron wire and the glass tube. The upper orifice is also closed by a cork, through which a piece of platinum wire passes, being terminated within by a loop; another piece of wire hangs from this by a loop, and its lower end, which

dips a very little way into the mercury, being amalgamated, it is preserved from adhering either to the iron or the glass. Things being thus arranged, a very minute galvanic power being applied by a contact with the lower and upper end of the apparatus, and the pole of a strong magnet being applied to the external end of the lower iron wire, the moveable wire within begins rapidly to rotate round the temporary magnet thus formed; and which rotation may be inverted either by changing the contact, or by inverting the magnet. Mr. Faraday states that this instrument is so sensible, that a rotation has been produced in it by two plates, each only one inch square.

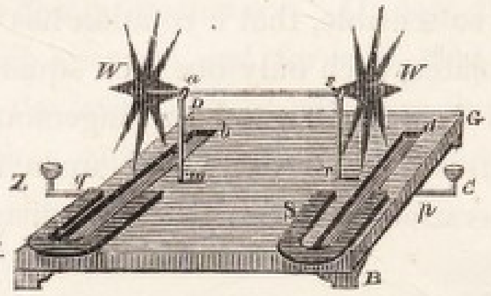
Mr. Marsh has constructed an ingenious machine, in which he causes a wheel to revolve upon its axis, by the combined operation of electricity and magnetism. The



apparatus by which this motion is produced, is shown above. The rectangular base G H, is furnished with a brass pillar and arm C D, on which is allowed to rest the wheel A B. A cup, containing mercury, is placed at G, and by a metallic wire beneath, serves to connect the re-

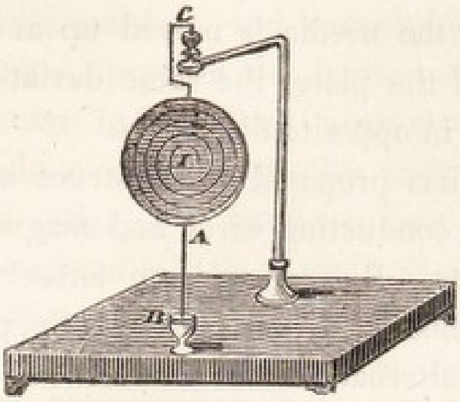
volving wheel with one pole of the battery, while a similar cup, which is hid from view by the horse-shoe magnet, connects the opposite pole with the mercurial trough E. On placing the magnet in its proper situation, the wheel is found to revolve rapidly on its axis; and if the poles be changed, motion occurs in the opposite direction.

A very curious revolving apparatus may be constructed, by employing two horse-shoe magnets in connexion with the opposite poles of a powerful voltaic arrangement. It



is represented in the annexed cut, and consists of a rectangular stand A B G D, having two grooves, about half an inch deep, cut in it parallel to its length. C *p*, Z *q*, are two wires having cups for connexion at Z and C, and each passing into its respective groove *a b*, *c d*, filled with mercury; into which are slightly immersed the points of the wheels W W′; these being fixed on an axle W W′, and resting upon the two supports *a s*, brought to a fine edge, in order to reduce the friction as much as possible, and to give the greater freedom of motion. N S are two horse-shoe magnets, posited as in the figure, with the like poles interior and exterior of the wheels. The apparatus being thus prepared, and the contact made at Z and C, the wheels will begin to rotate with great velocity.

A differently formed wire, and a more simple mode of



suspension, is shown in the accompanying diagram. Here a brass or copper wire C, rests at its bent end C, in a cup containing a little mercury, and is very moveable in azimuth round this point. The other end passes through the centre of a circular piece of pasteboard, and then forms a series of spiral turnings in the plane of this circular piece. The wire is attached by thread or silk to the pasteboard disc, and at the point A, it turns and descends till its extremity reaches the quicksilver in the cup B. The communication being now made at C and B, with the battery, the spiral will immediately arrange itself, in a plane perpendicular to the magnetic meridian.

M. Berzelius has described a curious experiment, which consists in placing a thin leaf of tin, eight inches long and two inches wide, parallel to, and in the plane of, the meridian, and in that position connecting it with the elements of a voltaic circle. A magnetic needle brought near the lower edge of this plate is thrown 20° from the magnetic meridian. On moving it slowly upwards, it takes its natural position, when level with the middle of the plate, except that it is raised at one end, and depressed at the other; and when near the upper edge, it moves from the magnetic meridian in the opposite direction to what it did

below. When the needle is moved up and down on the opposite side of the plate, the same deviation and effects take place, but in opposite directions.

M. Ampere has proposed to construct a *telegraph*, by using as many conducting wires and magnetic needles as there are letters. By placing each letter on a different needle, he establishes, by means of the pile, placed far from the needles, an alternate communication betwixt its two extremities and those of each conductor, and thus forms a sort of telegraph, fitted for writing all the details which it may be wished to transmit through any obstacle, to a person who is charged with observing the letters placed on the needles. By placing on the pile a row of stops, which carry the same letters, and establish the communication by their descent, this method of correspondence, observes M. Ampere, might be made both easy and rapid.

Sir H. Davy found, that when two wires were placed in a basin of mercury, perpendicular to the surface, and in the voltaic circuit of a battery with large plates, and the pole of a powerful magnet held either above or below the wires, the mercury immediately began to revolve round the wire as an axis, and with a highly increased velocity when the opposite poles of two magnets were used, one being above and the other below. Masses of mercury, several inches in diameter, were thus put in motion, and made to revolve in this manner, whenever the pole of the magnet was held near the perpendicular of the wire; but when the pole was held above the mercury between the two wires, the circular motion ceased; and currents took place in the mercury in opposite directions, one to the right, and the other to the left of the magnet. Sir Humphrey next inverted the form of the experiment. He took two copper wires of about one-sixth of an inch in diameter, the ends of which were

flat, and carefully polished, and passed them through two holes three inches apart, in the bottom of a glass basin, and perpendicular to it. They were cemented into the basin, and made non-conductors by sealing wax, except at the polished ends. The basin was then filled with mercury to the height of 1-11th of an inch above the wires. The moment the contacts were made, the mercury was seen in violent agitation; its surface became elevated to a small cone above each of the wires; waves flowed in all directions from these cones, and the only point of rest was apparently in the centre of the mercury between the two wires. On holding a powerful magnet some inches above one of the cones, its apex was diminished, and its base extended; by lowering the pole farther, these effects were increased, and the undulations became feebler; and at a smaller distance, the surface of the mercury became plain, and rotation slowly commenced round the wire. The elevations and depressions in some experiments were one-fifth or one-sixth of an inch.*

When a magnet is made to act on steel filings, these filings arrange themselves in curves round the poles, but diverge in right lines; and in their adherence to each other form right lines, appearing as spicula. In the attraction of the filings round the wire in the voltaic circuit, on the contrary, they form one coherent mass, which would probably be perfectly cylindrical, were it not for the influence of gravity. In first considering the subject, it appeared to Sir Humphry, that there must be as many double poles as there could be imagined points of contact round the wire; but when he found the north and south poles of a needle uniformly attracted by the same quarters

* Vide Philosophical Transactions, 1823, p. 156.

of the wire, it appeared to him that there must be four principal poles corresponding to these four quarters. Dr. Wollaston has, however, pointed out that there is nothing definite in the poles: that the phenomena may be explained, by supposing a kind of revolution of magnetism round the wire, depending for its direction upon the position of the negative and positive sides of the electrical apparatus.

To throw some light upon this matter, and to ascertain correctly the relations of the north and south poles of steel, magnetised by electricity to the positive and negative state, Sir Humphrey Davy placed short steel needles round a circle made on pasteboard, of about two inches and a half in diameter, bringing them near each other, though not in contact; and fastening them to the pasteboard by thread, so that they formed the sides of a hexagon inscribed within the circle. A wire was fixed in the centre of this circle, so that the circle was parallel to the horizon, and an electric shock was passed through the wire, its upper part being connected with the positive side of a battery, and its lower part with the negative. After the shock all the wires were found magnetic, and each had two poles; the south pole being opposite to the north pole of the wire next to it, and *vice versa*; and when the north pole of a needle was touched with a wire, and that wire moved round the circle to the south pole of the same needle, its motion was opposite to that of the apparent motion of the sun.

A similar experiment was tried with six needles arranged in the same manner, with only this difference, that the wire positively electrified was below. In this case the results were precisely the same, except that the poles were reversed: and any body, moved in the circle from the north to the south pole of the same needle, had its direction from east to west.

A number of needles were arranged as polygons in different circles round the same piece of pasteboard, and made magnetic by electricity; and it was found that in all of them, whatever was the direction of the pasteboard, whether horizontal or perpendicular, or inclined to the horizon, and whatever was the direction of the wire with respect to the magnetic meridian, the same law prevailed; for instance, when the positive wire was east, and a body was moved round the circle from the north to the south poles of the same wire, its motion (beginning with the lower part of the circle) was from north to south, or with the upper part from south to north; and when the needles were arranged round a cylinder of pasteboard so as to cross the wire, and a pencil-mark drawn in the direction of the poles, it formed a spiral.

It was perfectly evident from these experiments, that as many polar arrangements may be formed as chords can be drawn in circles surrounding the wire.

Supposing powerful electricity to be passed through two, three, four, or more wires, forming part of the same circuit parallel to each other in the same plane, or in different planes, it could hardly be doubted that each wire, and the space around it, would become magnetic in the same manner as a single wire, though in a less degree; and this was found to be actually the case. When four wires of fine platinum were made to complete a powerful voltaic circuit, each wire exhibited its magnetism in the same manner, and steel filings on the opposite sides of the wires attracted each other.

As the filings on the opposite sides of the wire attracted each other in consequence of their being in opposite magnetic states, it was evident, that if the similar sides could be brought in contact, steel filings upon them would repel

each other. This was very easily tried with two voltaic batteries, arranged parallel to each other, so that the positive end of one was opposite to the positive end of the other: steel filings upon two wires of platinum joining the extremities strongly repelled each other. When the batteries were arranged in the opposite order, viz. positive opposite to negative, they attracted each other; and wires of platinum (without filings) and fine steel wire (still more strongly) exhibited similar phenomena of attraction and repulsion under the same circumstances.

As bodies magnetised by electricity put a needle in motion, it was natural to infer that a magnet would put bodies magnetised by electricity in motion; and this was found to be the case. Some pieces of wire formed of platinum, silver, and copper, were placed separately upon two knife edges of platinum, connected with the ends of a powerful voltaic battery, and a magnet presented to them; they were all made to roll along the knife edges, being attracted when the north pole of the magnet was presented, the positive side of the battery being on the right hand, and repelled when it was on the left hand, and *vice versa*, changing the pole of the magnet. Some folds of gold leaf were placed across the same apparatus, and the north pole of a powerful magnet held opposite to them; the folds approached the magnet, but did not adhere to it. On the south pole being presented, they receded from it.

Imperfect conducting fluids do not give polarity to steel when electricity is passed through them; but electricity passed through air produces this effect. Reasoning on this phenomenon, and on the extreme mobility of the particles of air, Sir Humphry Davy concluded that the voltaic current in air would be affected by the magnet.

To put this important fact to the test of experiment,

Mr. Pepys made arrangements for charging the great battery of the London Institution, consisting of 2000 double plates of zinc and copper, with a mixture of 1168 parts of water, 108 parts of nitrous acid, and twenty-five parts of sulphuric acid; the poles were connected by charcoal, so as to form an arc, or column of electrical light, varying in length from one to four inches, according to the state of rarefaction of the atmosphere in which it was produced; and a powerful magnet being presented to this arc, or column, having its pole at a very acute angle to it, the arc, or column was attracted or repelled with a rotatory motion, or made to revolve by placing the poles in different positions, being repelled, when the negative pole was on the right hand, by the north pole of the magnet, and attracted by the south pole, and *vice versa.*

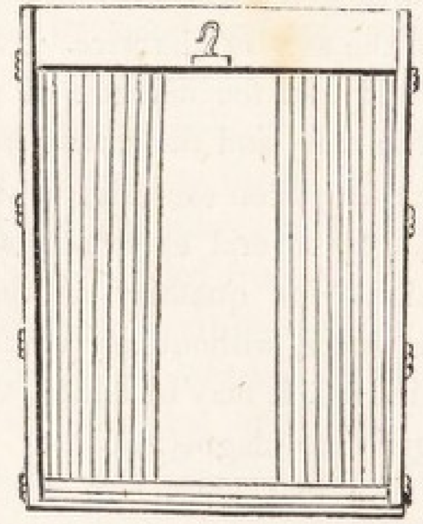
The same ingenious philosopher placed some silver wire of one-twentieth of an inch, and some of one-fiftieth, in different parts of the voltaic circuit when it was completed, and shook some steel filings on a glass plate above them: the steel filings arranged themselves in right lines, always at right angles to the axis of the wire. The effect was observed, though feebly, at the distance of a quarter of an inch above the thin wire, and the arrangement in lines was nearly to the same length on each side of the wire.

He ascertained, by several experiments, that the effect was proportional to the quantity of electricity passing through a given space, without any relation to the metal transmitting it; indeed, it may be added, that the finer the wires, the stronger their magnetism.

A zinc plate of a foot long, and six inches wide, arranged with a copper plate on each side, was connected by a very fine wire of platinum; and the plates were plunged an inch deep in diluted nitric acid. The wire did not

sensibly attract fine steel filings. When they were plunged two inches, the effect was sensible; and it increased with the quantity of immersion. Two arrangements of this kind acted more powerfully than one; but when the two were combined, so as to make the zinc and copper plates but parts of one combination, the effect was very much greater. This was shown still more distinctly in the following experiment:—Sixty zinc plates with double copper plates were arranged in alternate order, and the quantity of iron filings which a wire of a determined thickness took up, observed: the wire remaining the same, they were arranged so as to make a series of thirty. The magnetic effect appeared more than twice as great; that is, the wire raised more than double the quantity of iron filings.

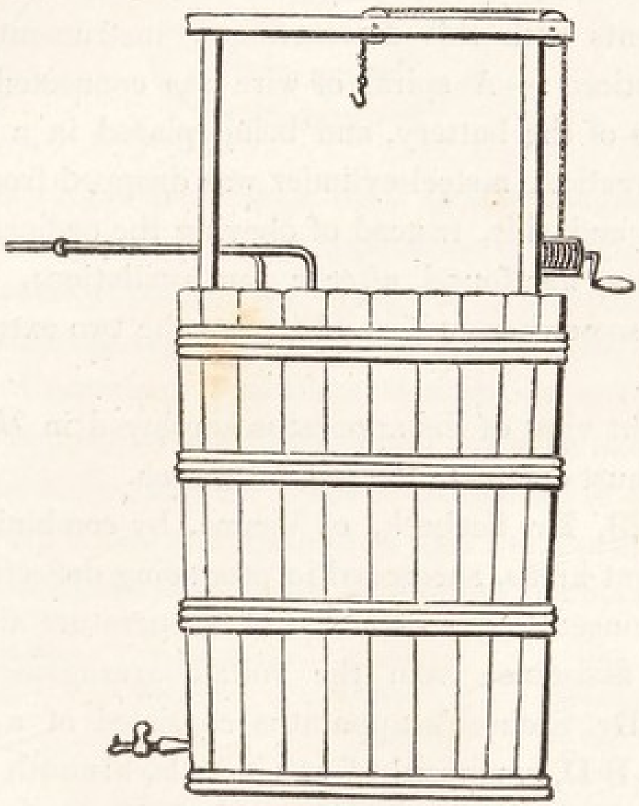
The most powerful galvanic arrangement for electro-magnetic purposes generally, that has yet been described, was constructed under the direction of Mr. Pepys. A section of the apparatus is shown in the accompanying engraving.



It forms a coil, and consists of two plates, each fifty

feet in length, and two feet in width; the one copper, and the other zinc, making a superficial surface of 4000 feet. They are rolled round a cylinder of wood, with three strands or ropes of horse-hair between each plate, to prevent contact of the metals; and, to maintain these in their situation, notched sticks are occasionally introduced in the rolling. Two conductors of copper, near three-fourths of an inch in thickness, are firmly attached to the end of each plate, from which the power is dispensed upon immersion in the acid.

The entire apparatus may be best illustrated by another figure.



Rather more than fifty gallons of dilute acid are requi-

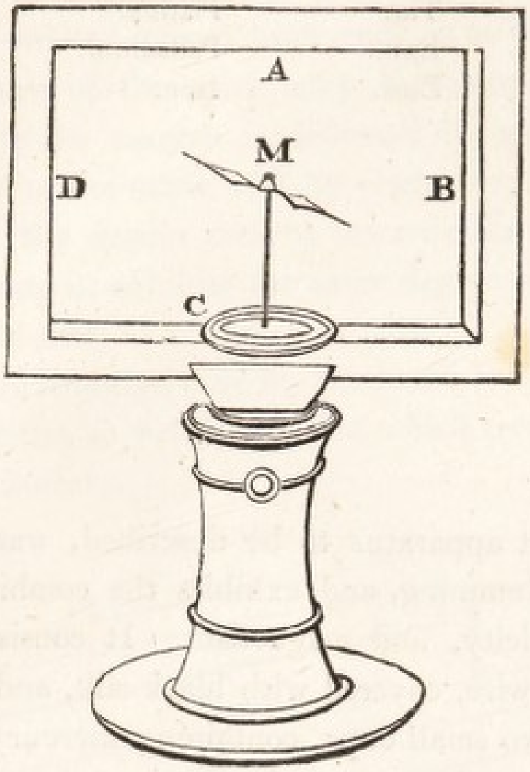
site to charge the receptacle intended for the metallic spiral; and to put the apparatus in operation, the coil is gradually lowered into the tub beneath. The immersion of the spiral, however, displaces a certain portion of water; so that, when a balance is resorted to, it is necessary to restore the equilibrium by withdrawing one of the counter-weights.

As a mere electrical battery, the effect to be derived from this pair of plates is comparatively small; but its powers as an agent for illustrating the connexion between magnetism and electricity are truly astonishing.

Magnetic needles, placed at a distance of several feet from the apparatus, were readily put into motion, and deflected from their previous position. The most singular phenomenon, however, which resulted from the series of experiments with this extraordinary instrument, remains to be noticed:—A spiral of wire was connected with the two poles of the battery, and being placed in a perpendicular direction, a steel cylinder was dropped from the upper end, and this, instead of obeying the ordinary laws of gravitation, was found, after a few oscillations, to take a position somewhere midway between the two extremities of the tube.

A slight view of the apparatus employed in *thermo-electricity*, must complete the present sketch.

In 1823, Dr. Seebeck, of Vienna, by combining metals of different kinds, succeeded in producing deflections of the magnetic needle by an increase of temperature alone, without any assistance from the voltaic arrangement before used. Dr. Seebeck's apparatus consisted of a parallelogram, A B D, composed of two metals, bismuth and antimony; one long and one short side being formed of each metal. On placing the needle, M, on a stand and centre



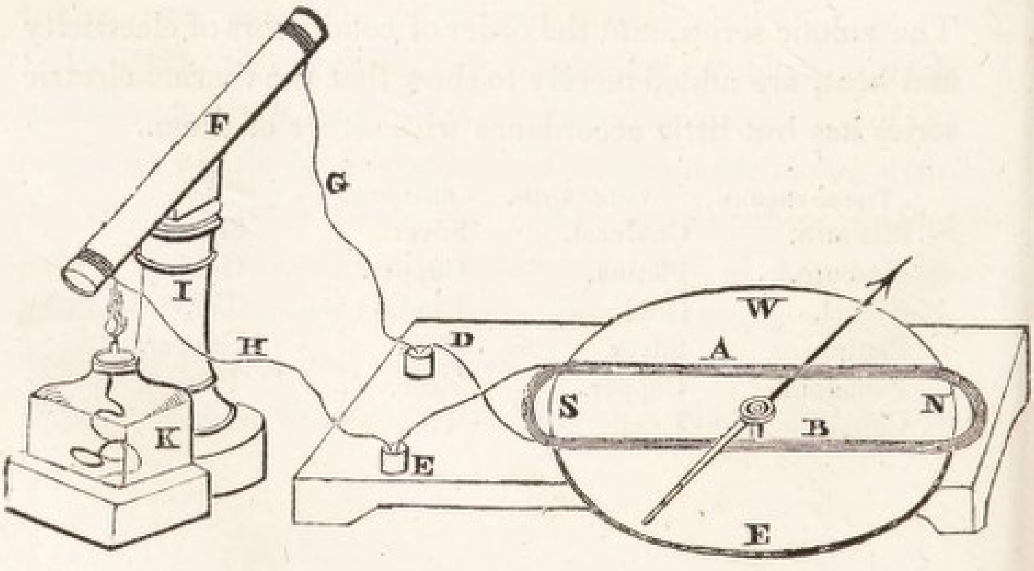
C, and allowing it to arrange itself in the magnetic meridian, it was found that the application of a spirit-lamp to either extremity, produced a change in its situation.

The following table of thermo-electrics is furnished by Professor Cumming: and when brought in contact, each substance is positive to all below, and negative to all above. The voltaic series, and the order of conductors of electricity and heat, are added merely to show that the thermo-electric series has but little accordance with either of them.

Thermo-electrics.	Voltaic Series.	Electricity.	Heat.
Bismuth.	Charcoal.	Silver.	Silver.
Mercury.	Platina.	Copper.	Gold.
Nickel.	Gold.	Lead.	Tin.
Platina.	Silver.	Gold.	Copper.
Palladium.	Copper.	Zinc.	Platina.
Cobalt.	Lead.	Tin.	Iron.

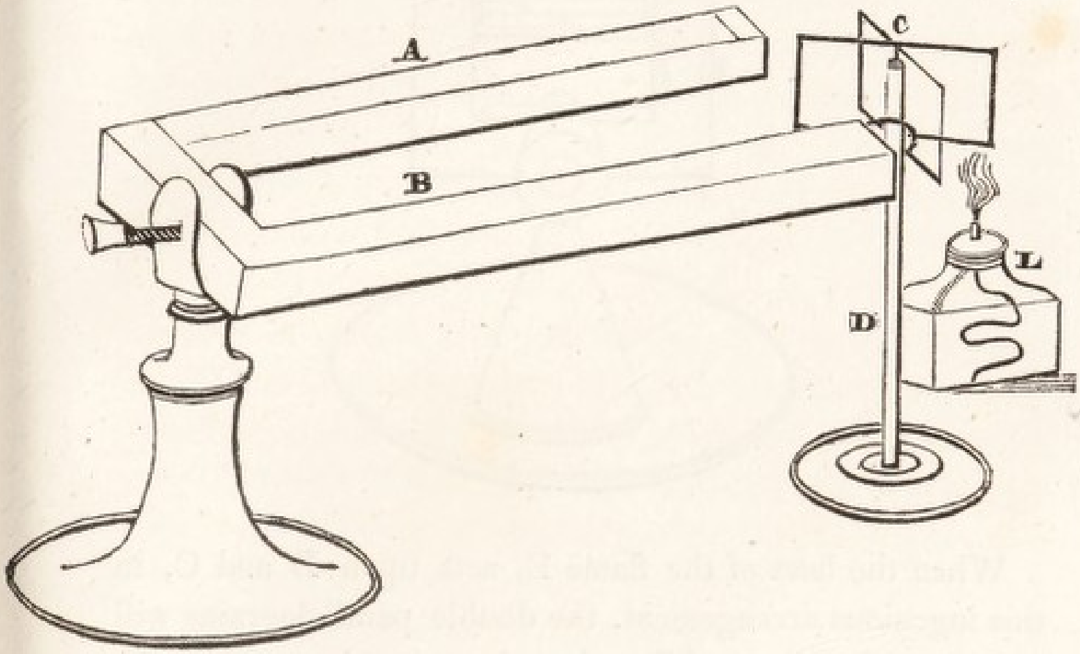
Thermo-electrics.	Voltaic Series.	Electricity.	Heat.
Silver.	Tin.	Platina.	Lead.
Tin.	Iron.	Palladium.	
Lead.	Zinc.	Iron.	
Rodium.			
Brass.			
Copper.			
Gold.			
Zinc.			
Charcoal.			
Plumbago.			
Iron.			
Arsenic.			
Antimony.			

The next apparatus to be described, was contrived by Professor Cumming, and exhibits the combined effects of heat, electricity, and magnetism. It consists of a small convoluted wire, covered with black silk, and its ends terminate in two small cups, containing mercury. When required to act, two pieces of wire, one silver and the other platina, twisted together at one end, and the others introduced into the cups, are heated by a spirit-lamp, and a needle placed in the coil may readily be deflected. A better arrangement may be illustrated by the accompanying wood-cut.



It consists of a cylinder of bismuth or zinc, F, with copper wires twisted round each end, as at G, H. The instant the flame of the spirit-lamp K, is applied to one end of the bar, the magnet is deflected in one direction, but upon heating the other end by changing the position of the lamp, the needle returns towards the convoluted wire, and passing it, exhibits the same degree of deflection on the opposite side.

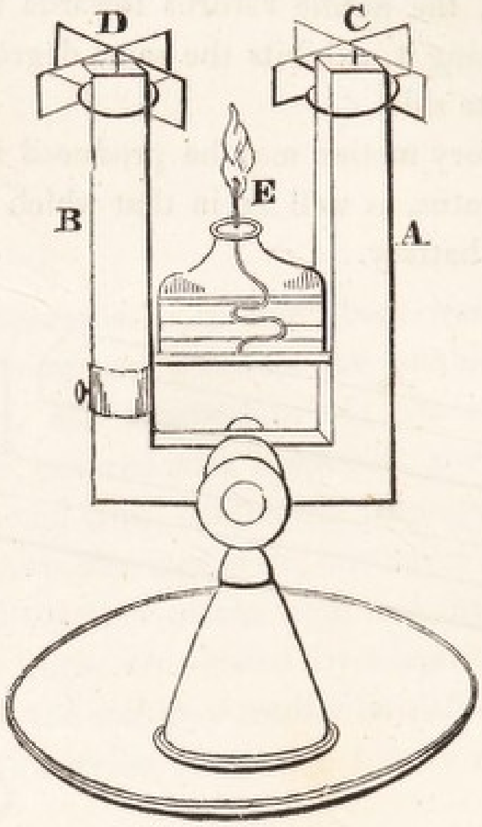
But a rotatory motion may be produced in the thermo-electric apparatus, as well as in that which owes its power to the voltaic battery.



The parallelograms which cross each other in this apparatus, are each composed of two pieces of metal, the lower side being platinum, and the other three sides silver. A horse-shoe magnet A B, being placed near the apparatus as represented in the figure, and the flame of a spirit-lamp L, applied to one of the angles of the transverse parallelo-

gram C, it instantly begins to revolve with considerable rapidity.

A double motion may be produced by a modification of the preceding apparatus.



When the heat of the flame E, acts upon D and C, in this ingenious arrangement, the double parallelograms will revolve with great rapidity, but they turn in opposite directions, in consequence of the opposite polarity of the horse-shoe support.

M. Ampere ascribes the diurnal variation of the needle to the corresponding motion of the globe, which produces a continued variation in its temperature. And to this he says, " We must also add, among the electro-motive ac-

tions of the different parts of the earth, that of the magnetic minerals which it contains, and which should be considered as so many voltaic piles. The elevation of temperature which takes place in the conductors of electric currents, ought also to take place in those of the terrestrial globe.

METEOROLOGY.

Construction of Meteorological Instruments.—Pressure of the Air as indicated by the Mercurial Column.—Barometer.—Thermometric Instruments.—Pyrometer.—Hygrometer.—Apparatus by Daniell and Leslie.—Rain-gauge.—Anemometer.

The materiality of the gaseous elements which constitute the atmosphere, has already been proved by a reference to their weight, and consequent pressure on the earth's surface. The pneumatic equilibrium is, however, continually destroyed, and we seldom find the mercurial column at the same altitude for any considerable length of time. But the variable character of the atmosphere is not confined to a change in its density: it is surcharged with moisture at one period, while at another it is found in an arid and burning state. To acquire a practical knowledge of the science, therefore, it will be necessary to notice the apparatus by which the meteorologist is enabled to furnish the data on which it is founded. The principal instruments in use in meteorology, are the barometer, by which the atmospheric pressure over any place is known; the thermometer, which ascertains the temperature of the air; the hygrometer, to indicate the moisture or dryness of the air; the pluviameter, or rain-gauge, to measure the depth of rain that falls; the wind-dial, to point out the direction of the wind; and the anemometer, to measure its force.

We may commence with the barometer, which owes its

power of foretelling changes in the weather to the mechanical operation of the air.

The great value of this instrument in meteorology will be a sufficient apology for describing its construction, especially as its principle will then be fully understood.

The tubes of which barometers are made, ought to be about one-third of an inch in diameter, and the one end hermetically sealed or closed, prior to its being removed from the glass-house. The mercury also must be perfectly pure, and should be freed from air by boiling in a glass vessel. To fill the tube with mercury, it should be first warmed, and the fluid metal may then be introduced by means of a small paper funnel. When the tube is nearly filled, small bubbles of air will be observed adhering to the glass; and to dissipate these, it will be necessary to close the open end of the tube with the finger, and then invert it. On again bringing the tube to its original situation, the air-bubbles will unite, and by their buoyancy ascend through the quicksilver, taking with them the smaller bubbles in their passage; should any air remain, this operation may be repeated, and the tube then filled to the top. The open end of the tube must now be immersed in a basin of mercury, and on withdrawing the finger, the fluid metal will subside in the tube, remaining suspended at the height of about twenty-nine or thirty inches.* To complete the

* It has long been known that an atmosphere of mercury exists in the upper part of the barometer, having a very small degree of tension; and Mr. Faraday has shown, by the following simple experiment, that a mercurial atmosphere may exist without removing the air. A small portion of mercury was put through a funnel into a clean dry bottle, capable of holding about six ounces, and formed a stratum at the bottom, not one-eighth of an inch in thickness: particular care was taken that none of the mercury should adhere to the upper part of the inside of the bottle. A small piece of leaf-gold was

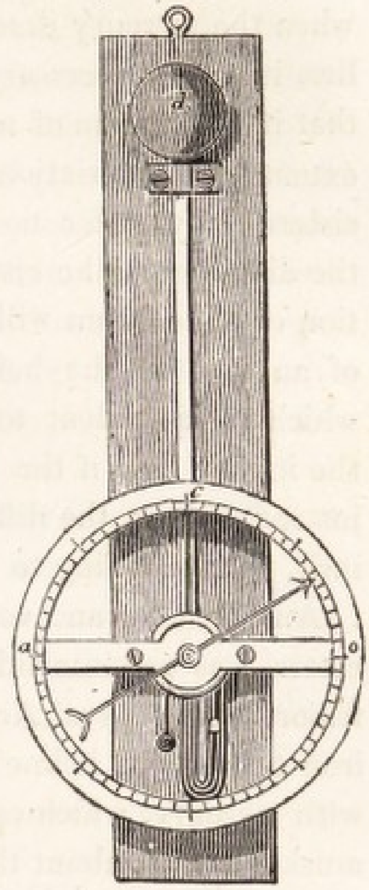
barometer, it will only be necessary to attach the basin and tube to a board placed in a perpendicular direction, having a scale of inches at the upper end, accurately measured from the surface of the mercury in the cistern ; and by the oscillations in the mercurial column, we ascertain the amount of pressure on the vessel beneath.

M. Pugh, in his Observations sur la Pesanteur de l'Atmosphere, directs, that to remedy the inconveniencies attendant upon the upright barometers, a graduated ruler should be applied parallel to the tube, having its lower end floating on the surface of the mercury in the cistern, according to the motion of which the scale will ascend or descend. Two or three supports, through which the ruler may pass so as to move freely, will be sufficient to keep it parallel to the column of mercury, whose length will be always visible; but for greater exactness, a moveable index, with a vernier, may be adapted to the scale, in such a manner that one end shall be on a level with the surface of the mercury in the tube, while the vernier indicates the exact measure of the column.

A very simple mode of enlarging the divisions of the barometer, is commonly ascribed to Sir Samuel Moreland. It consisted in bending the upper part of the tube into a very oblique position. By this plan, however, the scale, which depends on the perpendicular altitude, cannot be augmented beyond three or four times, without incurring evident risk of inaccuracy. This instrument is called the inclined, or diagonal barometer.

then attached to the under part of the stopper of the bottle, so that when the stopper was put into its place, the leaf-gold was inclosed in the bottle. After the lapse of six or eight weeks, it was examined, and the leaf-gold was found whitened by a quantity of mercury, which had evidently ascended from beneath.

The wheel-barometer is very generally employed, though its indications are not so accurate as the simple tube already described. It is represented in the accompanying diagram.



The tube is furnished with a large round head or ball, turned up at bottom; and upon the surface of the mercury in the recurved leg, there is placed a short glass tube loaded with mercury, with a string going over a pulley, and this is balanced by another weight, hanging freely in the air. As the surface at *d*, is large, and that at the lower extremity very small, the motion of the quicksilver, and, consequently, of the ball at bottom, will be very considerable; but as the weight moves up and down, it turns the pulley, and that gives motion to a hand or index; thus, by the divisions of a large graduated circle, the minutest variations of the air are shown, at least, if the instrument be accurately made, and the friction of the various parts inconsiderable.

But wheel-barometers may be constructed so as to avoid most of the defects hitherto thought unavoidable in such instruments. Let a solid piece of glass, in the form of a pear, float upon the surface of the mercury in the tube: to the bottom of this ball let a piece of thread be attached, which may descend quite through the column of mercury, and pass round a pulley placed under the orifice of the tube, from thence, it must proceed to a second pulley, placed parallel to the former in the cistern, and afterwards

over the pulley in the centre, which gives motion to the index: at the extremity of this thread must be fixed another small solid ball of glass, to give motion to the index when the mercury descends. On account of the two pullies, it will be necessary to make the cistern of such a size, that if the column of mercury should experience the whole extent of the variation, the height of the mercury in the cistern may suffer no visible change: thus, suppose that the diameter of the cistern is four inches, the total variation of the column will occasion a difference of 1-24th part of an inch in the height of the mercury in the cistern, which is equivalent to an angle of five degrees formed by the index; but if the diameter of the cistern be six inches instead of four, the difference will not exceed 1-48th of an inch, corresponding to an angle of two degrees and a half.

An ingenious and very substantial kind of marine-barometer, was recommended by Blondeau, one of the Professors of the Naval Academy at Brest. It consisted of an iron tube, bent below into a syphon, and filled carefully with mercury, which carried a float. For this purpose, a musket-barrel, about three feet long, was chosen, having a very smooth and even bore, and an iron breech closely welded to it, instead of being soldered with brass, which might become corroded by the action of the mercury. The lower end of the tube had a collar of leather, to which was screwed a piece of iron, perforated through its whole length, and bent into an arch, having a vertical cylinder of iron, four inches high, and of the same bore exactly as the tube, screwed at the other extremity. The contracted aperture at the end of the tube, not being exactly in the middle, was not always opposite that of the arch; and, therefore, by turning it occasionally aside, the communication could be contracted at pleasure, or even cut off

entirely. The cylindrical piece was tapered at the top to a narrow orifice, through which an iron wire, attached to a small ivory float, had been introduced. To prepare this instrument for action, the mercury was first boiled in the tube; then the arch, filled with hot mercury, was screwed to the end, the cock opened, and the surplus mercury allowed to flow over; next, the vertical piece, with its float, was screwed on, and a little mercury added. The origin of the scale was to be determined from the comparison with another good barometer of the ordinary construction; but, owing to the equality of the bores of the opposite tubes, the divisions were only half the usual size, or the inches were exhibited by half inches.

This species of barometer is certainly free from all sort of risk, while the facility which, by means of turning the arch, it affords in checking the ascent and descent of the mercury, prevents, in a great measure, the oscillations of that fluid. If the instrument were properly suspended, therefore, its indications would be tolerably steady and regular. The chief objection to it, however, consists in the diminutive range of its scale.

The following rules are the result of a series of comparative observations made with the barometer.

The barometer rising, may be considered as a general indication that the weather is becoming finer.

The atmosphere apparently becoming clearer, and the barometer above rain, and rising, show a disposition in the air for settled fair weather.

If, during a continued series of cloudy and rainy weather, the barometer rise gradually, though it remain below rain, especially if the wind changes from the south or west towards the north or east points, clear and dry weather may be expected.

The weather for a short period, viz. from morning until evening, may commonly be foretold with a considerable degree of certainty. If the barometer has risen during the night, and is still rising, the clouds are high, and apparently dispersing, and the wind calm, especially if it be in or about the north or east points, a dry day may be confidently expected. The same rule applies for predicting the weather from evening till morning.

During the increase of the moon there seems to be a greater disposition in the air for clear dry weather than in the wane; but this disposition does not usually commence till about three or four days after the new moon, and ceases about three or four days after the full moon.

The barometer should be observed at least three times in the day, or oftener, when the weather is changeable, in order to ascertain whether the mercury be stationary, rising, or sinking; for, from this circumstance, together with the direction of the wind, and the apparent state of the air at the time, is information to be collected; and a continuance of the same, or a sudden change of the weather to be foreseen.

Lastly. The higher the mercury stands in the scale in each instance, and the more regularly progressive its motion, the more conclusive will be the indication; and the more the wind inclines towards the north or east points, the greater will be the disposition in the air for fair weather. The indications of rainy weather will obviously be the direct reverse of those rules which predict fair weather. Frost is indicated in winter by the same rules that indicate fair weather; the wind being in or about the north or east points, and the thermometer sinking towards 32. A fall of snow seldom comes without a previous frost of some duration, and is indicated by the sinking of the barometer,

especially if the mercury be below changeable, and the thermometer at or near the freezing point. When the temperature of the air is about 35, snow and rain sometimes fall together; at a warmer temperature than 35, it seldom snows, or rains at a colder temperature. Thunder is presaged by the same rules which indicate rain, accompanied by sultry heat; the thermometer being up to 75. Storms, hurricanes, and high winds, are indicated by the barometer falling suddenly, or sinking considerably below much rain. The barometer is known to be rising or sinking, by the mercury having either a convex or concave surface: at any time, however, the weather may differ widely from the indications of the barometer, as it is sometimes known to happen, that a particular spot is affected by local circumstances. After a long-continued series of wet weather, we may, when the weather becomes fine, expect an uninterrupted continuance of dry weather. If, after a long series of wet weather, the barometer rise above changeable, and the wind veer steadily towards the north or east points, a continued duration of fair weather may be expected. Slow and progressive variations in the barometer, with a fixed and steady state of the wind, indicate permanency with the change.

The influence of heat will account for the semi-diurnal variations of the barometer, which are observed especially within the torrid regions. From ten o'clock in the morning till four in the afternoon, the mercury generally falls; but, after that hour, it rises again, till ten o'clock at night, when it sinks till four in the morning, and then ascends till ten in the morning. These regular changes, which amount to about the five-hundredth part of the whole atmospheric pressure, depend on the prevalence of the alternating land and sea-breezes, occasioned by the diversified

action of the sun's rays upon the earth and water. The accumulation of air is greatest at four o'clock in the morning and evening, and the mercury then attains its highest point; but it sinks lowest at ten o'clock in the morning and evening, when the incumbent mass has been the most reduced.

The regular decrease in the pressure of the atmosphere, which invariably arises from an increase of altitude, has suggested the employment of the barometer as a test for ascertaining the heights of mountains. Its fitness for this purpose may readily be explained by reference to the mechanical arrangement of the atmosphere, for we have seen that air possesses a gravitating force similar to that of all other fluids; the lowermost layer, or that which is nearest to the surface of the earth, being pressed with the whole weight of that which is piled above. Now it will be evident, that as we ascend a mountain, and as such, arrive at a higher stratum in the atmosphere, the column of air will decrease in altitude, and, consequently, its pressure will be diminished in a proportionate degree. So that, if we observe the amount of fall which takes place in the barometer at a given height, a similar fall will indicate a similar altitude at any other period.

We are indebted to Pascal for this application of Torricelli's tube. He made his first experiment in 1648, upon the Puy de Dome, a mountain 3565 feet in height, near Clermont, in France; and in the course of his ascent, he found the column continue to descend, till, on attaining the summit, it had sunk three inches and a half, which may be considered as the difference of atmospheric pressure between the summit and base.

At the surface of the earth, the mean density, or pres-

sure, is considered equal to the support of a column of mercury thirty inches high.

At 1000 feet above the surface, the column falls to		28.91
2000	ditto	27.86
3000	ditto	26.85
4000	ditto	25.87
5000	ditto	24.93
1 mile	ditto	24.67
2	ditto	20.29
3	ditto	16.68
4	ditto	13.72
5	ditto	11.28
10	ditto	4 24
15	ditto	1.60
20	ditto	0.95

It may be proper to add, that the barometer descends in a geometrical ratio for equal ascents in the atmosphere, subject to a correction for the decreasing temperature of the elevation.

It has been argued by some philosophers, that, however excellent this instrument is as an indicator of the weather, much surer indications may be drawn from the animal world. Their various motions, the uneasiness under which they labour, and the precautions they take previously to any atmospheric variation, not only strikingly discover the acuteness of their feelings, and their extreme susceptibility of the impressions of natural causes, but also convey accurate prognostications of a change in the weather. That this was a circumstance not unknown to the ancients, is evident from several of their writings, and particularly from the Georgics of Virgil, in

which it is observed that cows and various other animals are uncommonly affected before rain. Several others have also been remarked for this discriminating faculty; but the animal which appears, from a long series of regular and diligent observations, best entitled to notice, is the horse-leech; and it may be right to record a few remarks on its peculiarities. In fair and frosty weather it lies motionless, and rolled up in a spiral form at the bottom of the glass; but prior to rain or snow, it creeps up to the top, where, if the rain is likely to be heavy, or of some continuance, it remains a considerable time; if trifling, it quickly descends. Should the rain or snow be likely to be accompanied with wind, it darts about with amazing celerity, and seldom ceases until it begins to blow hard. If a storm of thunder and lightning be approaching, it is exceedingly agitated, and expresses its feelings in violent convulsive starts, at the top or bottom of the glass or vessel in which it is placed.

No person who has paid any attention to meteorology, can be ignorant of the great importance of ascertaining the precise quantity of moisture that exists in the atmosphere. There are a variety of instruments employed for this purpose, under the names of *hygrometers* or *hygroscopes*.

The most simple hygrometer is formed of the beard of the wild oat. If this be attached to a graduated dial, and a piece of straw connected with the opposite end to serve as an index, the straw will be found to pass over the dial, and by its change of situation, mark the hygrometric character of the atmosphere.

The substance which is found to possess by far the most delicate sensibility, and extensive range as an hygrometer, is the internal membrane of the Arundo Phragmites. A small bag, made of this membrane, is attached to the

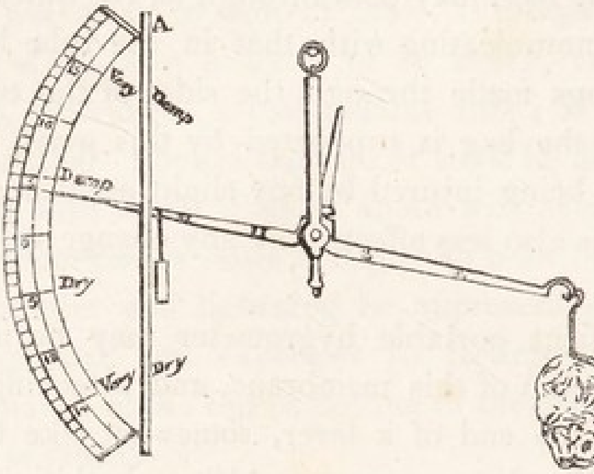
lower end of a thermometer tube, so as to form, as it were, its bulb. It is then filled with quicksilver, which rises, or falls, in consequence of the contraction or dilation of the membrane, by any change of moisture; and these changes are indicated upon a scale attached to the tube, the zero of this scale marking absolute humidity, and the other extremity of the scale absolute dryness. The lower end of the glass tube, instead of being merely inserted in the top of the bag, may pass through it, the quicksilver in the bag communicating with that in the tube by one or more openings made through the sides of the tube. By this means, the bag is supported by this glass, and prevented from being injured by any slight accident; and the instrument is also less affected by any change of temperature.

A convenient portable hygrometer may be made, by employing a slip of this membrane, and attaching its extremities to the end of a lever, somewhat like the small pocket metallic thermometers. Although this membrane is not entirely free from the change to which all animal and vegetable substances are liable, yet hygrometers made of it possess a considerable degree of uniformity.

Saussure contends for the superiority of human hair, for the purposes of hygrometers. Hair, he states, after it has been boiled in a weak alkaline lixivium, will expand by moisture nearly 1-40th of its length, and contract again by dryness; and that it is less liable to lose this effect by time than most other substances, and is moreover, from its tenuity, very quickly brought to the same state as the atmosphere. On these accounts, he gave it the preference to other substances, and constructed his hygrometers with it accordingly. The principle of the construction is to fasten one end of the hair to a fixed point, and the other

to the arbour of a small wheel, which carries a fine needle at one extremity; this needle points out, upon a graduated circular arch, the hygrometric degrees. The hair is stretched by a counterpoise of three or four grains, suspended from the same arbour by a silk thread.

The *sponge-hygrometer* is represented in the accompanying diagram. It consists of a sponge, suspended by a fine



thread of silk upon the beam of a balance, and exactly counterpoised on the other side, by a weight, so adjusted, as to cause an index or hand to point to the middle of a graduated arch, when the air is in a middle state, or rather, between the greatest moisture, and extreme dryness. Now, if the air become moist, the sponge growing heavier, will preponderate: if dry, it will, on the contrary, be raised, and show the increase or decrease of humidity in the air.

To prepare the sponge, it may be advisable to wash it first in water, and afterwards in a saline solution, as the deliquescent salts will take moisture from the atmosphere more readily than the sponge without such a provision.

Professor Leslie's apparatus may be thus described.

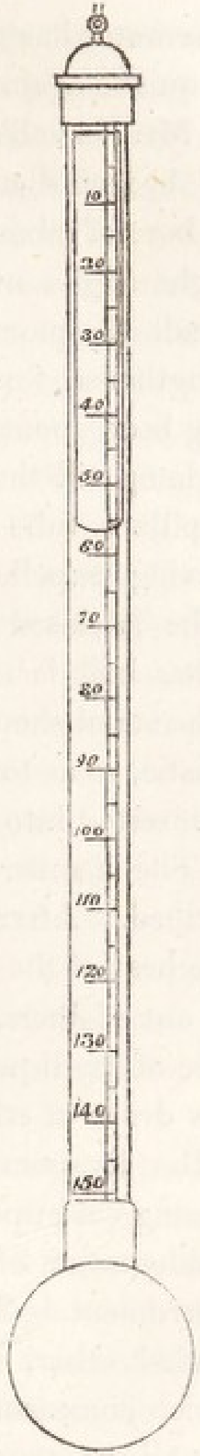
A piece of fine-grained ivory, about an inch and a quarter in length, was turned into an elongated spheroid, as thin as possible, weighing eight or ten grains, but capable of containing, at its greatest expansion, about three hundred grains of mercury; and the upper end, which was adapted to the body by means of a delicate screw, had a slender tube inserted, six or eight inches long, and with a bore of nearly the fifteenth part of an inch in diameter. The instrument being now fitted together, its elliptical shell was dipped into distilled water, or wrapped round with a wet bit of linen, and after a considerable interval of time, filled with mercury to some convenient point near the bottom of the tube, which forms the beginning of the scale. The divisions themselves were ascertained by dividing the tube into spaces, which correspond, each of them, to the thousandth part of the entire cavity, and equal to the measure of about three-tenths of a grain of mercury. The ordinary range of the scale included about seventy of those divisions. To the upper end of the tube was adapted a small ivory cap, which allowed the penetration of air, but prevented the escape of mercury, and thereby rendered the instrument tolerably portable.

This hygroscope was readily, though rather slowly, affected by any change in the humidity of the atmosphere. As the air became drier, it attracted a portion of moisture from the shell or bulb of ivory, which suffering, in consequence, a contraction, squeezed its contained mercury so much higher in the tube. But if, on the contrary, the air inclined more to dampness, the thin bulb imbibed moisture, and swelled proportionably, allowing the quicksilver to subside towards its enlarged cavity. These variations, however, were very far from corresponding with the real measures of atmospheric dryness or humidity. Near the

point of extreme dampness, the alterations of the hygroscope were much augmented; but they diminished rapidly, as the mercury approached the upper part of the scale. The contraction of the ivory answering to an equal rise in the dryness of the air, was found to be six times greater at the beginning of the scale than at the seventieth hygroscopic division; and seemed, in general, to be inversely as the number of hygrometric degrees, reckoning from 20, below. Mr. Leslie placed, therefore, another scale along the opposite side of the tube, the space between the zero and the seventieth division of the hygroscope being distinguished into 100 degrees, and corresponding to the unequal portions from the number 20 to 120 on a logarithmic line. The scale might probably be extended farther by continuing the logarithmic divisions. Thus, 320 degrees by the hygrometer, would answer to 108 of the hygroscope, or to a contraction of 108 parts in a thousand in the capacity of the bulk.

We are also indebted to Professor Leslie for a very ingenious, but fragile instrument, called an *atmometer*.

It is intended to measure the quantity of moisture exhaled from any humid surface in a given time; and consists of a thin ball of porous earthenware, represented in the accompanying figure. It is usually from one to three inches in diameter, having a small neck firmly cemented to a long tube of glass, to which is adapted a brass cap, with a narrow collar of leather to fit close. Being filled with pure or distilled water, the descent of this column serves to indicate the quantity of evaporation from the external surface of the ball. The tube is marked downwards, through its whole length, by the point of a diamond, with divisions across it, each of which corresponds to a ring of fluid that, spread over the whole exhaling sur-



face, would form a film only one-thousandth part of an inch in thickness. This graduation is performed by previously sealing one of the ends of the tube with wax, and introducing successive portions of quicksilver, to mark every twenty, fifty, or one hundred of those divisions; being calculated of equal bulk to discs of water, that have the surface of the ball (exclusive of the neck) for their base, and so many thousand parts of an inch for their altitude.

The instrument being thus constructed, has its cavity filled with pure water, and its cap screwed tight, and is then suspended freely, out of doors, sheltered indeed from rain, but exposed to the action of the wind. The water transudes through the porous substance of the ball, just as fast as it evaporates from the external surface; and this waste is measured by the corresponding descent of the liquid in the stem. At the same time, the column is suspended in consequence of the tightness of the cap, and prevented from oozing so freely as to drop from the ball. As the process of evaporation goes on, minute globules of air, separated by the removal of atmospheric pressure from the body of the water, or partly introduced by external absorption, continue to rise in fine streamlets to the top, where they partially occupy the space left by the subsidence of the fluid column. We need scarcely observe, that, after

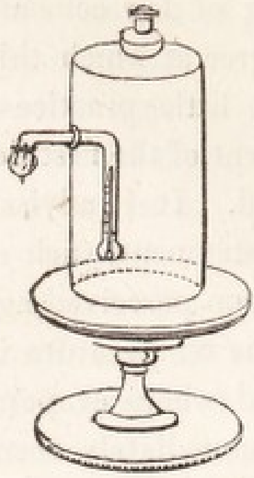
the water has sunk to the bottom of the stem, it will be requisite again to fill the cavity.

Mr. Daniell's hygrometer consists of two thin glass balls of $1\frac{1}{4}$ inch diameter, connected together by a tube, having a bore of about 1-8th of an inch. The tube is bent at right angles over the two balls, and the arm contains a small thermometer, whose bulb, which should be of a lengthened form, descends into the ball. This ball, having been about two-thirds filled with ether, is heated over a lamp till the fluid boils, and the vapour issues at the capillary tube which terminates the ball. The vapour having expelled the air from both balls, the capillary tube is closed hermetically by the flame of a lamp. The other ball is now to be covered with a piece of muslin. The stand should be of brass, and the transverse socket elastic, so as to hold the glass tube. A small thermometer is inserted into the pillar of the stand.

The manner of using the instrument may be thus described. After having driven all the ether into the ball by the heat of the hand, it is to be placed in an open window, or out of doors, with the balls so situated, as that the surface of the liquid may be upon a level with the eye. A few drops of ether are then to be poured upon the covered ball. Evaporation immediately takes place, which producing cold upon the ball, causes a rapid and continuous condensation of the ethereal vapour in the interior of the instrument. The consequent evaporation from the included ether, produces cold in the ball, the degree of which is measured by the thermometer. This action is almost instantaneous, and the thermometer begins to fall in two seconds after the ether has dropped. The artificial cold thus produced, causes a condensation of the atmospheric vapour upon the ball, which first makes its appear-

ance in a thin ring of dew coincident with the surface of the ether. The degree at which this takes place is to be carefully noted. A little practice may be necessary to seize the exact moment of the first deposition, but certainty is very soon acquired. It is advisable to have some dark object behind the instrument, such as a house or a tree, as the cloud is not so soon perceived against an open horizon. The depression of the temperature is first produced at the surface of the liquid where evaporation takes place, and the currents which immediately ensue to restore the equilibrium, are very perceptible. The bulb of the thermometer is not quite immersed in the ether, that the line of greatest cold may pass through it. The greatest difference that Mr. Daniell observed in the course of four months' daily experiments, between the external thermometer and the internal one at the moment of precipitation in the natural state of the atmosphere, was 20 degrees. In very damp weather, the ether should be slowly dropped upon the ball; otherwise the descent of the thermometer is so rapid as to render it impossible to be certain of the degree. In dry weather, on the contrary, the ball requires to be well wetted more than once to produce the requisite degree of cold.

Mr. Daniell proposes to employ the same apparatus for artificial atmospheres. The arrangement of his instrument for this purpose may be adverted to. It will be seen that the bell-glass is perforated at the side, through which the tube, proceeding from the ball placed under it, containing the thermometer, is passed, and welded with the tube proceeding from the other ball on its exterior side, by means of a lamp: the stem is then secured in the side of the glass by means of cement, and the ether boiled, and the capillary opening secured as before directed. The exterior ball



is then to be covered with muslin. In this way, the evaporation from the latter produces a corresponding degree of cold upon the ball under the bell-glass, and will measure the quantity of vapour included, by the precipitation, which may readily be marked. The hygrometric properties of any substance may thus be easily measured, by placing it under the receiver, and marking the absorption of the vapour.

The following table may be considered as forming a fair average estimate of the hygrometric state of the atmosphere:

January	7.93
February	8.52
March	10.27
April	11.39
May	12.38
June	13.10
July	12.42
August	12.68
September	11.72
October	11.15
November	10.02
December	9.75

In connexion with the subject now under consideration, we may place Mr. Howard's classified view of the clouds. These vaporous exhalations appear to be generally sustained in the atmosphere by the united agencies of heat and electricity.

Gay Lussac ascribes the suspension of clouds to ascending currents, which push them upwards, until this force is balanced by the weight of the cloud. A soap-bubble, he remarks, will not rise in a room, but will descend directly when left to its own weight; but if the bubble is blown in the open air above a heated soil, it will rise to a considerable height.

The different forms of the clouds are thus described :—

1. *Cirrus.*—A cloud resembling a lock of hair, or a feather, with diverging fibres.

2. *Cumulus.*—A cloud which increases from above, in dense, convex, or conical heaps.

3. *Stratus.*—An extended, continuous, level, sheet of cloud, increasing from beneath.

These three, Mr. Howard denominates simple and distinct modifications, constituting the elements of every other variety; the two next are of what he calls an intermediate nature.

4. *Cirro-cumulus.*—A connected system of small roundish clouds, placed in close order, or contact.

5. *Cirro-stratus.*—A horizontal, slightly-inclined sheet, attenuated at its circumference, concave downwards, or undulated.

Lastly, says Mr. Howard, there are two modifications which exhibit a compound structure, viz. :—

6. *Cumulo-stratus.*—A cloud in which the structure of the cumulus is mixed with that of the cirro-stratus, or cirro-cumulus; the cumulus flattened at top, and overhanging its base.

7. *Nimbus.*—A dense cloud, spreading out into a crown of cirrus, and passing beneath into a shower. In addition to these general definitions, the following is an abridgement of Mr. Howard's illustrations :—

The cirrus is always the least dense, and generally the most elevated modification, sometimes covering the whole face of the sky with a thin transparent veil, and at other times forming itself into distinct groups of parallel lines, or fibres. Its height, according to Mr. Dalton, is from three to five miles above the earth's surface. It is generally found to precede wind. When formed into horizontal sheets, with streamers pointing upwards, it indicates approaching rain; with depending fringe-like fibres, it is found to precede fair weather.

The cumulus is generally of a dense structure, and appears, after a clear morning, increasing from above, where its surface is convex, and forming at its greatest magnitude a pile of irregular semicircular clouds. This takes place about the time of the greatest heat of the day, and gradually diminishes towards evening, when it sometimes perceptibly evaporates: in this case it is an indication of the finest weather.

The cirro-cumulus appears to be formed by the descent of the cirrus, the oblique denser tufts of the latter changing into the spheroidical form, when the cloud assumes the appearance of a ball of flax, with one end left flying out. The cirro-cumulus sometimes consists of distinct beds, floating at different altitudes, the clouds appearing smaller and smaller, till they are lost in the blue expanse. It is most frequent in summer, and, when permanent, affords one of the surest indications of an increasing temperature, and fine weather.

The cirro-stratus assumes various appearances, from its

being frequently connected with other modifications. By itself, it is always an attenuated sheet or patch, of an uniform hazy appearance when viewed overhead, and of great apparent density towards the horizon. In this state, it gives rise to the phenomena of halos, mock-suns, &c. and indicates a depression of temperature, wind, and rain. When it alternates with cirro-cumulus, the prognostic is doubtful. It is frequently seen resting on the summit of high hills, and, in this state, has been long regarded as foreboding rainy weather.

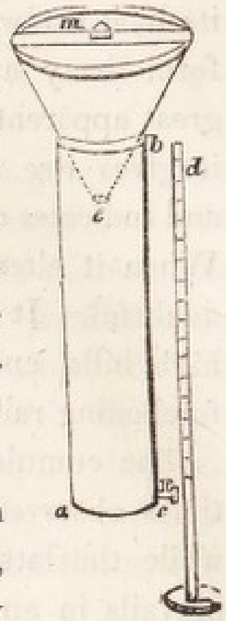
The cumulo-stratus is that fleecy cloud which is sometimes observed to settle on the summit of a cumulus, while the latter is increasing from beneath. It usually prevails in an overcast sky, and apparently without any regard to temperature, as it is found to precede either a fall of snow, or a thunder-storm. Before a storm, it is frequently to be seen in different points of the horizon, rapidly swelling to a great magnitude. Its indication is doubtful, and must be determined by the prevalence of the other modifications that accompany it.

The nimbus generally appears in the form of a dense, inverted cone of cloud, the upper part of which spreads in one continued sheet of cirrus to a great distance from where the shower is falling. When the total evaporation of the cloud takes place after the shower, it is reckoned a prognostic of fair weather. When the nimbus appears by itself, it generally moves with the wind; but when formed in the midst of cumuli, it sometimes moves in a contrary direction. This is often the case with thunder-showers.

From the hygrometer, we naturally pass to the *rain-gage*.

This useful instrument may be constructed in so simple a form, as to be accessible to every meteorological observer.

In the accompanying figure, it is seen to consist of a funnel *m*, attached to the top of a cylindrical vessel *b*. The bottom *a c*, is furnished with a stop-cock to draw off the water when full, and also to open a communication with the graduated glass tube *d*. The tube is divided into parts, so as to register the quantity of water that enters the vessel, and so proportioned, as to compensate for the difference between the sizes of the funnel and cylinder.



In fixing rain-gages, care should be taken that the rain may have free access to them, without being impeded or overshaded by any adjacent building. It may be proper also to add, that when the quantities of rain collected in them, in different places, are compared together, the instruments ought to be fixed at the same height above the ground at both places; because at different heights the quantities are always different, even in the same place. And hence, also, any register or account of rain in the gage, ought to be accompanied with a note of the height at which the instrument is placed above the ground. Dalton found the rain of a gage fifty yards high, in summer, two-thirds, and in winter, one-half as much as that of a gage below. The above ingenious experimentalist adds, that a strong funnel, made of sheet-iron, tinned and painted, with a perpendicular rim, two or three inches high, fixed horizontally in a convenient frame, with a bottle under it to receive the rain, is sufficient for this purpose.

The origin of *mists* must be sufficiently obvious to any person at all acquainted with meteorological phenomena,

and we only notice the subject, to direct attention to Sir Humphrey Davy's elegant and simple theory. According to this eminent chemist, land and water are cooled after sunset in a very different manner. The impression of cooling on the land is limited to the surface, and is very slowly transmitted into the interior. Whereas, in water, the upper stratum, when cooled, descends, and has its place supplied by warmer water from below. The surface of water will, therefore, in calm and clear weather, and in temperatures above 45° Fahrenheit, be warmer than that of the contiguous land; and, consequently, the air above the land will be cooler than that above the water. When the cold air, therefore, from the land, mixes with that above the water, both of them containing their due proportion of aqueous vapour, a mist, or fog, must be the result.*

There are mists which occasionally occur of a very peculiar character. They are sometimes attended by a smell, resembling that which is occasioned by an electric spark. There must, indeed, frequently be a multiplicity of substances of various kinds floating in the air: the wind has been found to carry the farina of plants as far as thirty or forty miles, and the ashes of a volcano more than two hundred. It is only necessary that the magnitude of the particles should be exceedingly small, in order to render them incapable of falling with any given velocity; and when this velocity is very trifling, it may easily be overpowered by any accidental motions of the air. The diameter of a sphere of water, falling at the rate of one inch only in a second, ought to be one six hundred thousandth of an inch, which is about the thickness of the upper part of a

* Philosophical Transactions, 1819, Part 1.

soap-bubble at the instant when it bursts; but the particles of mist are incomparably larger than this, since they would otherwise be perfectly invisible as separate drops: the least particle that could be discovered by the naked eye, being such as would fall with a velocity of about a foot in a second, if the air were perfectly at rest. But it is very probable that the resistance opposed to the motion of particles so small, may be considerably greater than would be expected from a calculation derived from experiments made on a much larger scale, and their descent consequently much slower.

When the particles of mist are united into drops capable of descending with a considerable velocity, they constitute rain; if they are frozen during their deposition, they exhibit the appearance of a perfect crystallization, and become snow: but if the drops already formed are frozen, either by means of external cold, or on account of the great evaporation produced by a rapid descent through very dry air, they acquire the character of hail,* which is often

* Mr. Dalton furnishes the following average statement of the number of days on which hail was observed in each succeeding month through the year.

Months.	No. of days on which hail was observed.
January	11
February	7
March	5
April	8
May	11
June	6
July	2
August	1
September	6
October	7
November	7
December	13

observed in weather much too hot for the formation of snow.

The phenomenon of *red snow* is so singular, that a few facts connected with the subject, from observations made by the Prior of the convent of Great St. Bernard, may with propriety be appended. He says that it is found at the heights of Buet, St. Bernard, Col de la Seigne, and Bonhomme; and also above and below, if masses exist large enough to remain through the summer. It is found sometimes on the glaciers. It is most abundant after strong winds from the west and south-west, and is most abundant as the summer advances, though no one has seen it fall. The Prior thinks it is earthy and ferruginous; that it is caused by particles brought by the winds, or sometimes by currents of water. It is not to be obtained before the middle of June.

Two portions of this coloured snow were furnished by the Prior to M. Peschier, who analysed them. One had an earthy appearance, and a ferruginous dirty-yellow colour: when heated, it lost a tenth of its weight, and deepened in colour. 100 parts gave

Silicious matter - - - -	65.5
Alumine - - - - - -	6.35
Peroxide of iron - - - - -	21.35
Organized matter - - - - -	6.8
	100

The other specimen appeared like a coarse vegetable earth, in which the eye could distinguish fragments of lichen, &c. It came from a spot of red snow, above which a red tint was observed, supposed by the Prior to be caused by the decomposition of a cryptogamous plant:

this kind of snow is rare, and occurs only in small spots. When strongly heated, it gave out vegetable fumes, and 100 parts lost 40. The residuum was of a brilliant violet colour. 100 parts, on analysis, gave

Insoluble matter - - - - -	20.
Alumine - - - - - -	4.25
Peroxide of iron - - - - -	31.25
Zinc - - - - - - -	.5
Insoluble organized matter - -	37.5
Soluble organized matter - -	6.5
	100.

The instruments that are employed to ascertain the comparative temperature of various bodies, must now be examined.

The *thermometer* will in the first instance occupy our attention.

A common thermometer consists of a tube terminated at one end by a bulb, and closed at the other. The bulb and part of the tube are filled with a proper liquid, generally mercury, and a scale is applied, graduated into equal parts. Whenever this instrument is applied to bodies of the same temperature, the mercury being similarly expanded, indicates the same degree of heat.

In dividing the scale of a thermometer, the two fixed points usually resorted to, are the freezing and boiling of water, which always takes place at the same temperature, when under the same atmospheric pressure. The intermediate part of the scale is divided into any convenient number of degrees; and it is obvious, that all thermometers thus constructed, will indicate the same degree of heat when exposed to the same temperature. In the cen-

tigrade thermometer, this space is divided into 100°; the freezing of water being marked 0°, the boiling point 100°. In this country we use Fahrenheit's scale, of which the 0° is placed at 32° below the freezing of water, which, therefore, is marked 32°, and the boiling point 212°, the intermediate space being divided into 180°. Another scale is Reaumur's, the freezing point is 0°, the boiling point 80°. These are the principal thermometers used in Europe.

It may be proper to state, that the spirit of wine thermometer is usually employed for very low temperatures, as mercury may be frozen in the atmosphere;* whilst mercury, on the contrary, is best calculated for high temperatures, as its point of ebullition is little short of a red heat.

* In the year 1780, Mr. Van Ellertein, of Vytegra, in Russia, froze quicksilver by natural cold. This occurred on the 4th of January, the thermometer being at 34° of Fahrenheit's scale. Expecting such a result, he placed three ounces of very pure quicksilver in a china teacup, covered with paper pierced full of holes. On examining it the next morning, he found the mercury solid, and looking like a piece of cast-lead, with a considerable depression in the middle. On attempting to loosen it in the cup, his knife raised shavings from it: and at length, the metal separated from the bottom of the cup in one mass. He then took it in his hand to try if it would bend: it was stiff like glue, and broke into two pieces; but his fingers immediately lost all feeling, and could scarcely be restored in an hour and a half by rubbing with snow. At eight o'clock, the thermometer stood at 57°; but by half after nine, it was risen to 40°; and then the two pieces of mercury which lay in the cup, had lost so much of their hardness, that they could no longer be broken, or cut into shavings, but resembled a thick amalgam, which, though it became fluid when pressed by the fingers, immediately afterwards resumed its original character. With the thermometer at 39, the quicksilver became fluid. The cold was never less on the 5th than 28, and by nine in the evening it had increased again to 33. This experiment, as well as those of Mr. Cavendish, seem to fix the freezing point of mercury at 39 or 40 of Fahrenheit's thermometer, which is 72° below the freezing point of water.

The principal thermometric scales in Europe are, as we have already stated, Fahrenheit's, which commences at the temperature produced by mixing snow and salt, and which is 32° below the freezing of water, so that the latter point is marked 32°, and the boiling point 212°, the intermediate space being divided into 172°; Reaumur's, in which the zero is the freezing point, and 80° the boiling point; and the centigrade, in which the space between the freezing and boiling of water is divided into 100°.

Each degree of Fahrenheit's scale is equal to 4-9ths of a degree on Reaumur's; if, therefore, the number of degrees on Fahrenheit's scale, above or below the freezing of water, be multiplied by 4, and divided by 9, the quotient will be the corresponding degree of Reaumur.

Fahrenheit. Reaumur.

$$68° - 32° = 36 \times 4 = 144 \div 9 = 16°.$$
$$212° - 32° = 180 \times 4 = 720 \div 9 = 80°.$$

To reduce the degrees of Reaumur to those of Fahrenheit, they are to be multiplied by 9, and divided by 4.

Reaumur. Fahrenheit.

$$16° \times 9 = 144 \div 4 = 36 + 32° = 68.$$
$$80° \times 9 = 720 \div 4 = 180 + 32° = 212.$$

Every degree of Fahrenheit is equal to 5-9ths of a degree on the centigrade scale; the reduction, therefore, is as follows:

Fahrenheit. Centigrade.

$$212° - 32 = 180 \times 5 = 900 \div 9 = 100°.$$

Centigrade. Fahrenheit.

$$100 \times 9 = 900 \div 5 = 180 + 32 = 212°.$$

In mercurial thermometers with a perfect vacuum above

the mercury, M. Flanguergues has observed, that the freezing point has gradually risen nine-tenths of a degree, and has gone on increasing for years. He attributes this to a permanent change of form, produced by the constant pressure of the atmosphere on the bulb. He therefore recommends, that the thermometers should be made with open terminations. The same fact had been long before observed by M. Angelo Bellani, who illustrates the matter by the following experiment. "Take a mercurial thermometer, which has not been exposed for some months to temperatures near that of boiling water, and whose degrees are at least a line long, so that tenths of a degree can be easily seen. Having carefully marked the freezing point, plunge it in boiling water, and upon replacing it in melting ice, it will be found, that the freezing point has sunk 1-10th of a degree, in consequence of the expanded glass not having resumed accurately its original form."

If a bulb of a thermometer be suddenly squeezed between the finger and the thumb, the mercury will rise in the stem several degrees, and will again sink as quickly after the pressure is removed. To prevent any derangement from communication of heat, the hand may be covered with a thick glove. This is a very important fact, and it may be shown in a less exceptionable way:—let a mercurial thermometer, with a large bulb and a long stem, be first held upright, and then immediately inverted; between these two positions the column of mercury will descend through a visible space: thus proving, that a variable pressure in the atmosphere, or mercury, will produce anomalies in the thermometer.

Mr. Breguet's thermometer consists of slips of two metals, unequally expanded by heat, twisted into a spiral: to the extremity of the spiral is fixed an index, which moves

round a graduated circle, pointing out the temperature. It is obvious, that when the spiral is heated, the index will move in one direction, and in another when the spiral is cooled, because it will twist or untwist itself according to the changes of temperature to which it is subjected. The two metals employed, are silver and platinum; and in order to render the extreme points more fixed, and to prevent sudden starts, a slip of gold, the expansibility of which is intermediate between that of silver and platinum, is soldered between these two metals. This thermometer is more delicate than any mercurial thermometer whatever. It is even more delicate than an air-thermometer. This spiral-thermometer, and a mercurial one, were placed together under the receiver of an air-pump. The temperature at the time of the experiment was 66.2°. The mercurial thermometer, when the air was pumped out, sunk 3.6°; but the spiral thermometer fell 41.4°, and descended to 24.8° Fahrenheit.

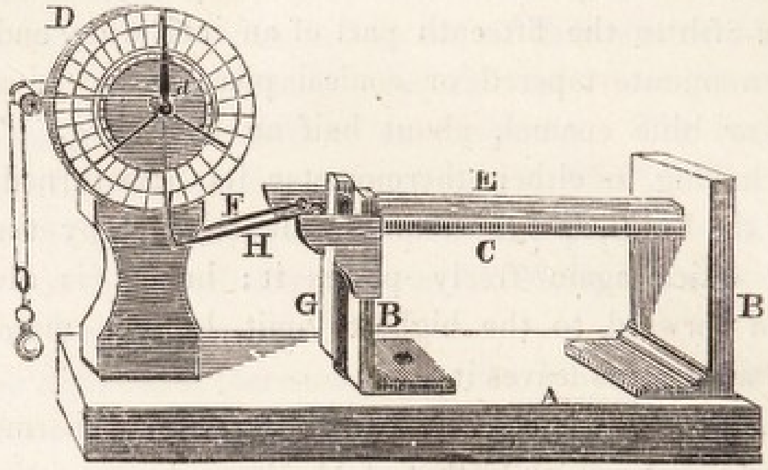
The *differential thermometer* invented by Professor Leslie, consists of two tubes, each terminating in a small bulb of similar dimensions; a small portion of dark-coloured fluid formed of sulphuric acid tinged with carmine, having previously been introduced into one of the balls. The instrument is then fixed on a stand, and furnished with a graduated scale. When the column is equally pressed in opposite directions, the fluid will point at zero, and whatever heat may be applied to the whole instrument, provided both bulbs receive it in an equal degree, the fluid must remain at rest. But if the one ball receives the slightest excess of temperature, the air which it contains will be proportionally expanded, and the column will be depressed with a force equal to the difference between the temperature of the two balls.

A *self-registering thermometer* is a most important instrument, and as such, must not be passed unnoticed. It is employed to indicate the extreme changes that occur in the temperature of the air. Dr. Rutherford employed two thermometers. The one which marks the minimum, is filled with alcohol; and the other, which indicates the maximum, is filled with quicksilver; and they are both attached to the same frame, or, what is still better, affixed to separate frames, placed nearly horizontal, or rather, elevated about five degrees, to prevent the separation of the thread of liquid. The tubes have bores from the twenty-fifth to the fifteenth part of an inch wide, and include a minute tapered or conical piece of ivory, or of white or blue enamel, about half an inch long. This mark having in either thermometer its base turned towards the bulbs, is drawn to the lowest point by the alcohol, which again freely passes it; but it is always pushed forward to the highest limit by the mercury, which afterwards leaves it.

Mr. Crichton has contrived a self-registering thermometer, somewhat similar to that of M. Breguet; consisting of two oblong slips of steel and zinc, firmly fixed together by their faces; so that the greater expansion or contraction of the zinc, over those of the steel, by the same variations of temperature, causes a flexure of the compound bar. As this is secured to a board at one end, the whole flexure is exercised at the other, on the short arm of a lever index, the free extremity of which moves along a graduated arc. The instrument is originally adjusted on a good mercurial thermometer; and the movements of the arm are registered by two fine wires, which are pushed before it, and left at the maximum deviation to the right or left of the last observed position, or temperature.

The *pyrometer* is employed to indicate higher degrees of temperature than the instruments hitherto described; and although it is not essentially a meteorological instrument, its construction is much too important to be passed unnoticed.

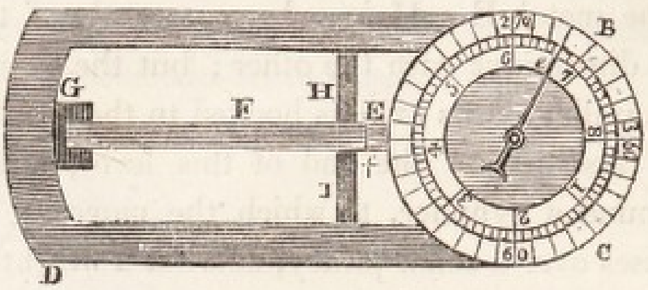
One of the earliest instruments invented for ascertaining the amount of expansion in solid bodies, was suggested by Muschenbroeck: it was, however, liable to some serious objections; and the accompanying figure represents Mr. Ellicott's improvements on the apparatus.



This instrument is formed of a flat piece of brass A, attached to a thick piece of mahogany. Upon this plate are screwed three pieces of brass, two of which, B B, serve to support the flat iron bar C, called the standard bar. The upper part of the third piece of brass is a circle, D, about three inches in diameter, divided into three hundred and sixty equal parts, or degrees: within this circle is a moveable plate *d*, divided likewise into three hundred and sixty parts, and a small steel index hand. The bar of metal, E, upon which the experiment is to be made, is laid on the standard-bar. F, is a lever two inches and a half long, fastened to an axis, which turns in two pieces of brass,

screwed to one of the supports B. To the end of this lever is fastened a chain, or silk line, which, after being wound round a small cylinder, to which the index in the brass circle, D, is fastened, passes over a pulley with a weight hung to the end of it. Upon the same axis as the lever, is placed a pulley a quarter of an inch in diameter, to which a piece of watch-chain is fastened, the other end of which is hooked to a strong spring at G, which bears against one end of the metal E. H is a lever, exactly of the same form and dimensions with the other; but the chain fastened to the pulley on its axis, is hooked to the standard bar. The line fastened to the end of this lever, after being wound round a cylinder, to which the moveable plate is fixed, passes over a small pulley, and has a weight hung to the end of it; or rather the same line, passing under a pulley, to which the weight is hung, has its other end fastened to the lever F, so that one weight serves for both levers. From this description, it will be obvious that whenever the bar E is lengthened, it gives liberty to the weight to draw the lever F upwards, by its action on the spring G; and the index will, at the same time, by means of the silk line, be carried forward in the circle; and as the bar shortens, it will return back again: the same motion will be communicated to the standard-bar. When the bar is lengthened the twentieth part of an inch, the index will be carried once round the brass circle, which is divided into three hundred and sixty degrees; and therefore, if the metal lengthens the 7200dth part of an inch, the index will move one degree. In order to make an experiment with this instrument, lay a bar of any kind of metal, as E, on the standard bar, then heat this bar to any degree of heat with a lamp, and mark the degree of its expansion, as indicated by the moveable plate; observe also the degree of

expansion of the metal E, by the heat communicated to it from the standard-bar, as marked on the brass circle by the index; let the instrument stand till the whole is thoroughly cold: then removing the bar E, lay any others successively in its place, and proceed exactly as before; and thus the degrees of expansion of different metals by the same degree of heat may be estimated.



Ferguson's pyrometer indicates the expansion of metals to the 45,000dth part of an inch. The upper surface of this machine is represented in the above figure. Its frame, B C D, is made of mahogany, on which is a circle, divided into three hundred and sixty equal parts: and within that circle is another, divided into eight equal parts. If the short bar E be pushed one inch forward, (or towards the centre of the circle,) the index *e* will be turned 125 times round the circle of 360 parts or degrees. As 125 times 360 is 45,000, it is evident, that if the bar E be moved only the 45,000dth part of an inch, the index will move one degree of the circle. But, as in this pyrometer the circle is nine inches in diameter, the motion of the index is visible to half a degree, which answers to the 90,000dth part of an inch in the motion of the short bar E.

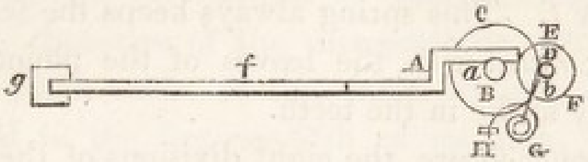
One end of a long bar of metal, F, is laid into a hollow place in a piece of iron, G, which is fixed to the frame of the machine; and the other end of this bar is laid against

the end of the short bar E, over the supporting cross-bar H I: and, as the end, *f*, of the long bar is placed close against the end of the short bar, it is plain, that if F expands, it will push E forward, and turn the index *e*.

The machine stands upon four short pillars, high enough from a table, to let a spirit lamp be put on the table under the bar F; and, when that is done, the heat of the flame of the lamp expands the bar, and turns the index.

There are bars of different metals, as silver, brass, and iron, all of the same length as the bar F, for trying experiments on their various expansive powers.

The inside of this pyrometer is constructed as follows:



In the above figure, A *a* is the short bar, which moves between rollers; and, on the side *a*, it has fifteen teeth in an inch, which revolve in the leaves of a pinion, B, (twelve in number,) on whose axis is the wheel C, of one hundred teeth, which move in the ten leaves of the pinion D, furnished with a wheel E, of one hundred teeth, connected with the pinion F, of ten leaves, and on the top of this axis is placed the index-hand.

Now, as the wheels C and E have one hundred teeth each, and the pinions D and F have ten leaves each, it is plain, that when the wheel C turns once round, the pinion F, and the index on its axis, will turn one hundred times round. But, as the first pinion B has only twelve leaves, and the bar A *a*, that turns it, has fifteen teeth in an inch, which is twelve and a fourth part more, one inch motion

of the bar will cause the last pinion F, to turn one hundred times round, and a fourth part of one hundred over and above, which is twenty-five. So that if A *a* be pushed one inch, F will be turned one hundred and twenty-five times round.

A silk thread is tied to the axis of the pinion D, and wound several times round it; and the other end of the thread is tied to a piece of slender watch-spring G, which is fixed in the stud H: so that as the bar *f* expands, and pushes the bar A *a* forward, the thread winds round the axle, and draws out the spring; and as the bar contracts, the spring pulls back the thread, and turns the work the contrary way, which pushes back the short bar A *a* against the long bar *f*. This spring always keeps the teeth of the wheels in contact with the leaves of the pinions, and so prevents any shake in the teeth.

In the former figure, the eight divisions of the inner circle are so many thousandth parts of an inch in the expansion or contraction of the bars; which is just one-thousandth part of an inch for each division moved over by the index.

The ingenious Mr. Wedgwood, so well known for his various improvements in the different sorts of pottery-ware, also contrived an instrument for measuring the higher degrees of heat. This was effected by reference to a distinguishing property of argillaceous bodies, namely, their diminution in bulk by fire. This diminution commences at a low red-heat, and proceeds regularly, as the heat increases, till the clay becomes vitrified. The total contraction of some clay being considerably more than one-fourth part of their entire dimensions. Some of the purest Cornish porcelain clays seem the best adapted, both for supporting the intensity, and measuring the degrees of heat. This ma-

terial is prepared for use by washing it over, and, whilst in a diluted state, passing it through a fine lawn sieve: it is then dried and put up in boxes. The dry clay is then softened for use, with about two-fifths its weight of water, and formed into small pieces, in moulds of metal, six-tenths of an inch broad, with the sides exactly parallel; about four-tenths of an inch deep, and an inch long.

For measuring the diminution which they have suffered from the action of fire, another gauge is made of two pieces of brass, twenty-four inches long, divided into inches and tenths, fixed five-tenths of an inch asunder at one end, and three-tenths at the other, upon a brass plate; so that one of the thermometric pieces will just fit in the wider end. If this piece be supposed to have diminished in the fire one-fifth of its bulk, it will then pass on to half the length of the gauge; if diminished two-fifths, it will go on to the narrowest end; and in any intermediate degree of contraction, if the piece be slid along till it rests against the converging sides, the degree at which it stops will be the measure of its contraction, and consequently of the degree of heat it has undergone.

The pyrometer invented by Mr. Daniell is very simple in its construction, is easily repaired when injured, and will extend the scale of the thermometer as far as the fusing point of cast-iron. It distinctly indicates a change of about seven degrees of Fahrenheit's scale.

The instrument consists of a bar of platinum, 10½ inches long, and 0.14 of an inch in diameter. It is placed in a tube of black-lead, and the difference between the expansion of the platinum bar, and the black-lead tube, is indicated upon a circular scale, by means of a fine platinum wire, one-hundredth of an inch in diameter, which

is fixed to the end of the platinum bar, and is coiled three or four times round the axis of a small wheel, fixed at the back of the circular scale. The other end of the small platinum wire is bent back, and attached to the extremity of a slight spring, which keeps the wire in a state of extension. The axis of the wheel is 0.062 of an inch in diameter, and the wheel itself is toothed, and plays in the teeth of another smaller wheel, whose diameter is one-third of the first, and which has one-third of the number of teeth. An index fastened to the axis of the small wheel, indicates the temperature on a circular scale, which is divided into 360°. Instead of passing the platinum wire round the axle of the first wheel, it has been found better in practice, to attach a short silken thread to its extremity, and pass that round, and fix it to the spring.

Of all the vital phenomena, there is none at first sight more remarkable than that which animals possess of resisting the *extremes of temperature*.

It may be observed, that the heat of the body continues at nearly the same degree, though the temperature of the atmosphere is continually varying, so that a man is able to live, and to preserve the temperature of his health, either on the burning sands of Africa, or the frozen plains of Siberia.

The alterations of temperature which the human body has been known to bear, without any fatal, or even bad effects, are not less than 400° or 500° of Fahrenheit. The natural heat of the human body, in a healthy state, is about 96° or 97°. In the West Indies, the heat of the atmosphere is often at 100°, and sometimes rises even to 130° above the temperature of the human body; notwithstanding which, a thermometer introduced beneath the tongue,

stands at 96° or 97°. The inhabitants of the hot regions of Surinam support, without inconvenience, the heat of their climate. We are assured, that in Senegal, about the latitude of 17°, the thermometer in the shade generally stands at 108°, without any fatal effects to men or animals. The Russians often live in places heated by stoves to 110°; and some philosophers in this country, by way of experiment, remained a considerable time in a room, heated above the boiling point of water.

On the other hand, an equal excess of cold seems to have no greater effect in altering the degree of heat proper to animal life. Delisle has observed the temperature in Siberia 70° below the zero of Fahrenheit's scale, notwithstanding which, animals lived. Gmelin has seen the inhabitants of Jeniseisk, under the 58th degree of northern latitude, sustaining a degree of cold, which in January became so severe, that the spirit in the thermometer was 116° below the freezing point. Professor Pallas, in Siberia, and our countrymen at Hudson's Bay, have experienced a nearly similar degree of cold.

Frosts often occasion a diminished supply of water in natural springs and wells. This is sometimes erroneously accounted for, by supposing that the water freezes in the bowels of the earth. But this is a mistaken view of the matter, as the most intense cold of a Siberian winter would not freeze the ground two feet in depth; but a very moderate frost will consolidate its entire surface, and make it impervious to the air. When this happens, the water which was filtering through the ground, is arrested and kept suspended in its capillary tubes by the pressure of the air.*

* The expansion of water during congelation, must of necessity occasion the bursting of those pipes in which it is imprisoned; and

Having seen that heat expands all bodies that are brought within the sphere of its operation, whilst the absorption of caloric produces an opposite effect; we may now proceed to examine the phenomena of aërial currents, and the instruments that are employed for ascertaining their velocity.

We may commence with air in motion, or *wind*, which is a stream or current of air; and artificial winds, on a small scale, may be observed every day, in the currents of air that occur in our houses. Smoke ascends in chimneys merely from its admixture with heated air, and if a current of air is made to pass up a chimney by means of a fire in a room, the deficiency will immediately be made good by fresh air passing through the open doors and crevices. Indeed, it is found that a double current of air prevails in

this peculiar effect of a reduced temperature has been sometimes advantageously employed in rending masses of stone, and other purposes connected with the arts. The experiments of Colonel Williams on this subject are curious and interesting. These experiments were made in America, the climate of which was admirably adapted for the purpose; and he found that, when a bomb-shell was filled with water, and a plug driven in with a sledge-hammer, a few hours' frost would so expand the water, as to project it to a distance of four or five hundred feet. When the plug was screwed in, so as to prevent a possibility of its being expelled, the shell was rent asunder, and a thin film of congealed water invariably driven out.

A great inconvenience arises from the freezing of water in the pipes employed for hydraulic purposes, particularly in the small tubes which connect the street mains with the cisterns in the metropolis. This, however, may be readily obviated by substituting a valve in the main pipe for the present ball-cock: so that the small pipe may be drained of its contents by placing it in an inclined direction: or the same effect may be produced by dispensing with the ball-cock altogether, and the pipe will empty itself when the main ceases to furnish a supply. It will, however, be evident, that a considerable waste of water will result.

all rooms which are heated beyond the temperature of atmosphere: the light air which occupies the upper part rushing outwards, while the cold air enters beneath.*

The different winds may be reduced to three classes, viz. general, periodical, and variable winds.

The *general winds* are usually called trade-winds. They always blow nearly in the same direction. In the open seas, that is, in the Atlantic and Pacific Oceans, under the equator, the wind is found to blow almost constantly from the eastward: this wind prevails on both sides of the equator, to the latitude of 28°. To the northward of the equator, the wind is between the north and east; and the more northerly, the nearer the northern limit. To the southward of the equator, the wind is between the south and east; and the more southerly, the nearer the southern limit.

Between the parallels of 28° and 40° south lat., in that tract which extends from 30° west to 100° east long. from the meridian of London, the wind is variable, but by far the greater part between the N. W. and S. W.; so that the outward-bound East-India ships generally run down their easting on the parallel of 36° south.

* The ventilation of rooms and buildings can only be perfectly effected, by suffering the heated and impure air to pass off through apertures in the ceiling, while fresh air, of any desired temperature, is admitted from below. Various contrivances have been resorted to, to prevent the passage of cold air from above downwards through the ventilator, which can only be completely effected by keeping the ventilating tubes at a higher temperature than the surrounding air; heating them, for instance, by steam, passing them through a fire, or placing a lamp beneath them, of sufficient dimensions to cause a strong current upwards; upon the latter principle, the gas chandelier in Covent-Garden Theatre being placed under a large funnel, which passes through the roof into the outer air, operates as a very powerful ventilator, all its own heat and smoke passing off with a large proportion of the air of the house.

Beyond the northern limit of the general wind, in the Atlantic Ocean, the westerly winds prevail, but not with any certainty of continuance.

In the Atlantic Ocean, the S. E. trade-wind extends as far as 3° north, and the N. E. trade-wind ceases at the fifth degree N. In the intermediate space are found calms, with rain, and irregular uncertain squalls, attended with thunder and lightning. But this space is shifted farther to the northward or southward, according as the sun's declination is more northerly or southerly.

Periodical winds are such as blow in a certain direction for a time; and at stated seasons change, and blow for an equal space of time from the opposite point of the compass. These may be divided into two classes: viz. *monsoons*, or winds that change annually; and land and sea breezes, or winds that change diurnally.

While the sun is to the northward of the equator, that is to say, in the months of April, May, June, July, August, and September, the wind blows from the southward, over the whole extent of the Indian Ocean: namely, between the parallels of 28° N. and 28° S. latitude, and between the eastern coast of Africa, and the meridian which passes through the western part of Japan. In the sea between Madagascar and New Holland, the S. E. wind prevails as far as the equator, when it is deflected, and blows into the Arabian Gulph, and Bay of Bengal, from the S. W. Between Madagascar and the main land of Africa, a S. S. W. wind obtains, and coincides with the S. W. wind in the Arabian Gulph. To the northward of New Holland, the S. W. wind is predominant, but varies very much among the islands; and between the peninsula of Malacca and the island of Japan, a S. S. W. prevails. All this is to be understood for the above-mentioned months.

But in the other months, October, November, December, January, February, and March, a remarkable alteration takes place. In the sea between Madagascar and New Holland, the S. E. wind extends no farther to the northward than about the tenth degree of south latitude, the other ten degrees being occupied by wind from the opposite point of the compass, or N. W.; at the same time that the winds in all the northern parts of the Indian Ocean shift round, and blow directly contrary to the course they held in the former six months.

These winds are called monsoons, or shifting trade-winds. These changes are not suddenly made. Some days before and after the change, there are calms, variable winds, and dreadful storms, attended with thunder, lightning, and rain.

On the greater part of the coasts situated between the tropics, the wind blows towards the shore in the day-time, and towards the sea in the night. These periodical winds are termed land and sea breezes, and are much affected, both in their direction and velocity, by the courses of rivers, tides, &c.

Variable winds are those which are subjected to no period, either in duration or return, and are too well known to need description.

If the earth did not revolve on its axis, it is plain that the sun, being stationary over one particular spot, would rarefy the air at that spot: it would consequently ascend, by the pressure of the circum-ambient and less rarefied air, till it arrived at a region in which the air was sufficiently rare to suffer it to expand on all sides; and thus there would be produced a converging wind near the surface of the earth, and a contrary, or divergent wind in the upper region of the air. But since the earth revolves on its

axis, and the sun therefore is not stationary, it must follow, that the place where the air is rarefied, will be found successively in every point of the parallel, over which the sun moves in the course of a day. And as this place continually moves to the westward, the lower air must as constantly follow it. Hence we have the origin of the general N. E. and S. E. trade-winds, which no doubt would extend over the whole of the space between the tropics, were it not for the different temperatures of the continents and islands over which the sun passes. For the surface of the earth is more readily heated than that of the sea, as the transparency of the water permits many of the rays of light to pass directly to its lower strata. The air, therefore, contiguous to the land, being more heated than that which rests upon the sea, will prevent the regularity of the effect. Thus, near the western coasts of Africa and America, the winds blow from the westward, to supply the constant rarefaction those heated lands produce.

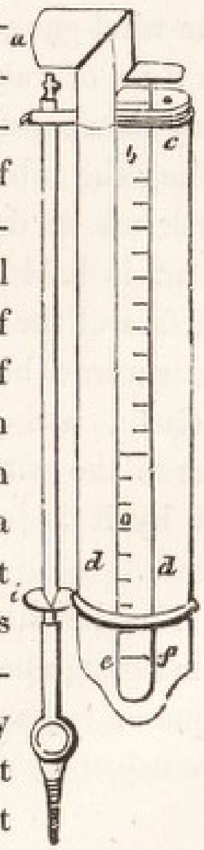
The general N. E. and S. E. trade-winds, producing in the upper regions of the air winds in the contrary directions, seem to be the cause of the westerly winds, which are observed to prevail between the latitudes of 28° and 40°.

In accounting for the monsoons, or periodical trade-winds, it is necessary to mark the peculiar circumstances which obtain in the Indian Ocean, and which are not to be found in the Atlantic and Pacific Oceans: they seem to be these: that the ocean is bounded to the northward by shores, whose altitude does not exceed the limits of the general trade-wind, and that the general trade-wind falls on the lee-shores to the westward.

Southerly winds are most frequently accompanied with rain; but northerly and easterly, with clear, dry, and

severe weather. Because southerly winds are not only warmer, proceeding from warmer climates, but also more highly electrified than the soil of the colder countries into which they flow; hence, the copious vapours they contain, are quickly deprived of part of their electricity, and thus converted into spherules of water: but the superior strata of the atmosphere under which the southern air is introduced, not being supported by air as dense as that which subsisted under them before their introduction, necessarily descend and mix with the inferior southern air; by this intermixture, they are warmed, and deprive the clouds already formed, and their vicinity, of part of their electricity. Hence proceeds their gradual attraction to each other, which terminates in the gentle showers that usually accompany this wind.

In meteorological observations, the strength and velocity of the wind are no less important than its direction; Dr. Lind's apparatus is well calculated for experimental purposes. This simple instrument consists of two glass tubes, of five or six inches in length. They are connected together like a syphon, by a small bent tube *c f*, the bore of which is 1-10th of an inch in diameter. On the upper end of the leg *d e*, there is a tube of thin brass, which is bent at a right angle, and has its mouth open towards *a*. On the other leg *c d*, is a cover, with a round hole in the upper part of it, 2-10ths of an inch in diameter. This cover and the kneed tube, are connected together by a slip of brass, which not only gives strength to the whole instrument, but also serves to hold the scale *b o*. The bent



tube and cover are fixed on with hard cement, or sealing-wax. To the same tube is soldered a piece of brass, with a round hole in it, to receive a steel axle, and at *i*, there is another piece of brass soldered to the brass hoop, which surrounds both legs of the instrument. There is a small shoulder on the spindle, upon which the instrument rests, and a nut screwed on to prevent it from being blown away. The instrument is easily turned round upon its axis by the wind, so as always to present the mouth of the bent tube towards it. The lower end of the spindle is furnished with a screw, by which it may be attached to the top of a post or stand. It is also provided with a hole at the bottom, to admit a small lever for screwing it into the wood with more facility. There is likewise a crooked tube, to be put occasionally on the mouth of the kneed tube, in order to prevent rain from being blown into the mouth of the wind-gauge when it is left out all night, or exposed in time of rain. The force, or momentum of the wind may be ascertained by the assistance of this instrument, by filling the tubes half full of water, and pushing the scale a little up or down, till the 0 of the scale, when the instrument is held up perpendicularly, be on a line with the surface of the water in both legs of the wind-gauge. The instrument being thus adjusted, hold it up perpendicularly, and turning the mouth of the kneed tube towards the wind, observe how much the water is depressed by it in one leg, and how much it is raised in the other.

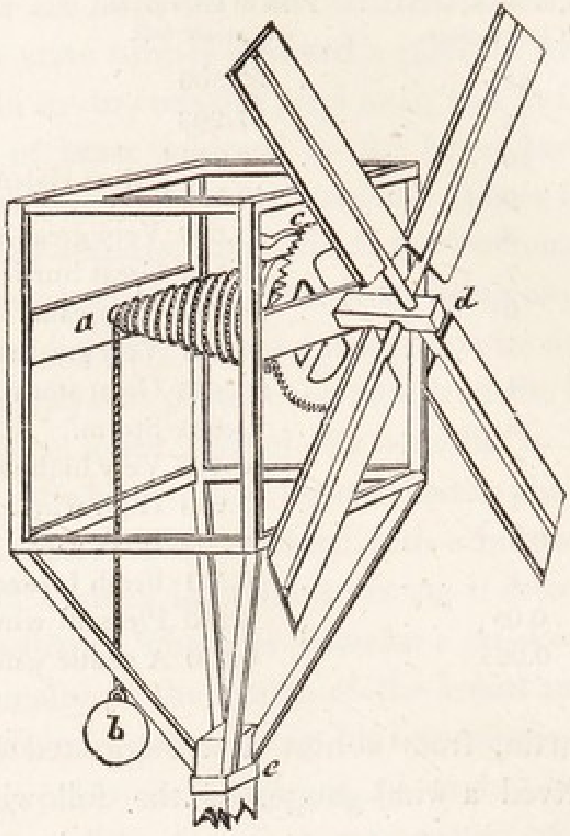
The height of the column of water sustained in the wind-gauge being given, the force of the wind, upon a foot square, is easily ascertained by the following table, and consequently on any known surface.

Height, in inches, of the water in the gauge.	Force of the wind on one square foot.	
12	62.500	
11	57.293	
10	52.083	Most violent hurricane.
9	46.875	
8	41.667	Very great hurricane.
7	36.548	Great hurricane.
6	31.750	Hurricane.
5	26.041	Very great storm.
4	20.833	Great storm.
3	15.625	Storm.
2	10.416	Very high wind.
1	5.208	High wind.
0.5	2.604	Brisk gale.
0.1	0.521	Fresh breeze.
0.05	0.260	Pleasant wind.
0.025	0.030	A gentle wind.

Mr. Martin, from a hint first suggested by Dr. Burton, contrived a wind-gauge, of the following construction.

It consists of an open frame of wood, firmly supported by the shaft or postern *e*. In the two cross pieces, is moved an horizontal axis *d a*, by means of the four sails, exposed to the wind in a proper manner. Upon this axis is fixed a cone of wood, upon which, as the sails move round, a weight *b* is raised by a string on its superficies, proceeding from the small to the largest end. Upon the great end, or base of the cone, is fastened a ratchet-wheel *c*, in the teeth of which falls the click, to prevent any retrograde motion from the depending weight.

From the structure of this machine, it is easy to understand that it may be accommodated to estimate the variable force of the wind, because the force of the weight will



continually increase as the string advances on the conical surface, by acting at a greater distance from the axis. And, therefore, if such a weight be put on the smallest part, as at *a*, which will just keep the machine in equilibrio with the weakest wind, then, as the wind becomes stronger, the weight will be raised in proportion, and the diameter of the base of the cone may be so large in comparison to that of the smaller end or axis at *a*, that the strongest wind shall but just raise the weight to the great end.

Thus, for example, let the diameter of the axis be to that of the base of the cone as 1 to 28; then if *b* be a weight of one pound at *a* on the axis, it will be equivalent to twenty-eight pounds, or a quarter of an hundred, when raised to the larger end. If, therefore, when the

wind is weakest, it supports one pound on the axis, it must be twenty-eight times as strong to raise the weight to the base of the cone. Thus, if a line or scale of twenty-eight equal parts be drawn on a bar at the side of the cone, the strength of the wind will be indicated by the number, or graduation at which the string is placed.

THE SOLAR SYSTEM.

Apparent System of the Material Universe.—Planetary Bodies.—The Moon.—Eclipses.—Comets.—Fixed Stars.

When we view the vast concave above us on a clear night, and observe with attention the gradual ascent and descent of the spangled firmament that surrounds the visible horizon, the uninformed observer is at once disposed to adopt the belief of Ptolemy, and conclude that the earth is a fixed body, and that the surrounding orbs are really in motion. This very obvious phenomenon may, however, be illustrated in a more familiar way.

If we suppose a person seated in a vehicle, and that vehicle in rapid motion, it will be evident that the traveller will fancy that the fixed objects in his immediate neighbourhood are also in motion, though, of course, going in a direction the reverse of his own. This simple fact must have come within the observation of all; and yet by applying the same principle to the motions of the heavenly bodies, we shall find, that as a traveller seated in a carriage imagines that the passing objects are in motion, so do we, who are travelling at a much greater rate upon our planet or earth, suppose that the other planetary bodies partake of a motion which exists but in our own imagination.

This, then, may be considered as a brief view of the apparent motions of the planetary orbs, which has been noticed only as introductory to a more particular examination of the real motions of the heavenly bodies.

In astronomy, as well as in other sciences, the Greeks

were the disciples of the Egyptians: they appear to have divided the stars into constellations, thirteen or fourteen hundred years before Christ. Newton attributes this arrangement to Chiron, and he supposes that he made the middle of the constellations correspond to the beginning of the respective signs. But until the time of the foundation of the school of Alexandria, the Greeks treated astronomy as a purely speculative science, and indulged themselves in the most frivolous conjectures respecting it. It is singular, that amidst the confusion of systems heaped upon each other, without affording the least information to the mind, it should never have occurred to men of such great talents, that the only way to become accurately acquainted with nature, was to institute experimental inquiries throughout her works.

The most ancient observations of which we are in possession, that are sufficiently accurate to be employed in astronomical calculations, are those made at Babylon, about seven hundred and nineteen years before the Christian era, of three eclipses of the moon. Ptolemy, who has transmitted them to us, employed them for determining the period of the moon's mean motion, and, therefore, had probably none more ancient on which he could depend. The Chaldeans, however, must have made a long series of observations, before they could discover their Saros, or lunar period of 6585$\frac{1}{3}$ days, or about eighteen years, at which time, as they had learnt, the place of the moon, her node, and apogee, return nearly to the same situation with respect to the earth and sun, and of course, a series of nearly similar eclipses recurs. The observations attributed to Hermes, indicate a date seven hundred years earlier than those of the Babylonians; but their authenticity appears to be extremely doubtful. The Egyptians were very

early acquainted with the length of the year, as consisting of nearly three hundred and sixty-five days and a quarter, and they derived from it their Sothic period of 1460 years, containing three hundred and sixty-five days each. The accurate correspondence of the faces of their pyramids with the points of the compass, is considered as a proof of the precision of their observations.

Without, in the present case, going into the history of ancient astronomy, it may be enough to state that the sun forms one vast centre, round which the planetary bodies revolve, with their attendant satellites, or moons.

Astronomers have divided the planets into two classes. The first class they call primary, or principal planets: they are eleven in number, and consist of Mercury, Venus, the Earth, Mars, Ceres, Pallas, Juno, Vesta, Jupiter, Saturn, and the Georgium Sidus. Those of the second class are called secondary planets, or satellites.

The primary planets are such as revolve round the sun only. These are also divided into superior and inferior; those being called superior planets, whose distance from the sun is greater than that of the earth; and those inferior planets, whose distance is less than that of the earth.

The superior planets are, Mars, Ceres, Pallas, Juno, Vesta, Jupiter, Saturn, and the Georgium Sidus; these are farther from the sun than the earth, and consequently, environ the latter in their revolution. It is for this reason we see them sometimes on one side of the sun, and sometimes on the other. The inferior planets are Mercury and Venus, which are nearer the sun than the earth, and which, consequently, never environ the latter in their revolution. On this account, we see them always on the same side as the sun, and never in opposition, because the earth is never between them and the sun.

Having thus briefly examined the general arrangement of the planetary bodies, it may now be advisable to notice more particularly their size, velocity, and distance from the sun. In illustrating these important particulars, it has been found necessary to adhere closely to the data furnished in the admirable unpublished work by Francis Baily, Esq. President of the Astronomical Society.

The planet nearest to the sun, and as such, the one whose orbit round that body is least in diameter, is Mercury. The near proximity of this planet to the sun, renders it but seldom visible, and consequently, our acquaintance with it is not of a very accurate nature. According, however, to Sir Isaac Newton, the heat and light of the sun on the surface of Mercury are almost seven times as intense as on the surface of the earth in the middle of summer, and this, it may very readily be shown, is quite equal to the boiling point of Fahrenheit's thermometer; and such a degree of heat as this must evidently render Mercury uninhabitable to beings at all like those who inhabit our planet.

Mercury performs his mean sidereal revolution in 87·9692580 mean solar days, or in $87^{d}.23^{h}.15^{m}.43^{s}.9$: and his mean synodical revolution in 115.877 mean solar days.

His mean longitude, at the commencement of the present century, was in $166°.0'.48''.6$.

His orbit is inclined to the plane of the ecliptic, in an angle which, at the commencement of the present century, was $7°.0'.9'',1$: and which angle is subject to a small increase of $0'',1818$ in a year.

The rotation on his axis is accomplished in $24^{h}\ 5^{m}.28^{s}.3$.

The inclination of its axis to that of the ecliptic is not known.

Mercury changes his phases like the moon, according to

his various positions with regard to the sun and earth: but this cannot be discovered without the aid of a powerful telescope.

His true diameter, compared with that of the earth, considered as unity, is 0.398, which makes it about 3140 miles.

The proportion of light and heat, which it receives from the sun, is about 6.68 times greater than that received on the earth.

Mercury is sometimes seen to pass over the sun's disc, which can happen only when he is in his nodes, and when the earth is in the same longitude. Consequently this phenomenon, for many centuries to come, can take place only in the months of May or November. The first observation of this kind was made by Gassendi, in November, 1631; since which period they have been frequent.*

* The following is a list of all those which have happened since the above date, inclusive, and of those that will happen till the end of the present century.

1631, Nov. 6.	1776, Nov. 2.
1644, Nov. 8.	1782, Nov. 12.
1651, Nov. 2.	1786, May 3.
1661, May 3.	1789, Nov. 5.
1664, Nov. 4.	1799, May 7.
1674, May 6.	1802, Nov. 8.
1677. Nov. 7.	1815, Nov. 11.
1690, Nov. 9.	1822, Nov. 4.
1697, Nov. 2.	*1832, May 5.
1707, May 5.	1835, Nov. 7.
1710, Nov. 6.	*1845, May 8.
1723, Nov. 9.	*1848, Nov. 9.
1736, Nov. 10.	*1861, Nov. 11.
1740, Nov. 2.	*1868, Nov. 4.
1743, Nov. 4.	*1878, May 6.
1753, May 5.	1881, Nov. 7.
1756, Nov. 6.	1891, May 9.
1769, Nov. 9.	1894, Nov. 10.

Those marked with an asterisk are such future ones as will be visible in this country.

Venus is very nearly as large as the earth. Her revolution occupies about seven months, her distance from the sun being about 7-10ths of that of the earth, and her orbit nearly circular, inclined in an angle of 3°.24′ to the ecliptic. Mr. Schroeter considers her mountains as much higher than those of the earth. Her density has been estimated from the perturbations occasioned by her attraction in the motions of the other planets, and it has been supposed to be a little less than that of the earth.

The mean distance of Venus from the sun is 0.7233316; that of the earth being considered as unity. This makes her mean distance nearly sixty-eight millions of miles.

She performs her mean sidereal revolution in precisely 224.7007869 mean solar days, or in $224^{d}.16^{h}.42^{m}.8^{s},0$: and her mean synodical revolution in 583.920 mean solar days.

The rotation on her axis is accomplished in $23^{h}.21^{m}.7^{s}.2$.

Venus changes her phases like the moon, according to her various positions with respect to the sun and the earth, which causes a very considerable difference in her brilliancy.

Her true diameter, compared with that of the earth, considered as unity, is 0,975, which makes it about 7,700 miles.

A body which weighs one pound at the equator of the earth, would, if removed to the equator of Venus, weigh only 0.98 pound.

The proportion of light and heat which she receives from the sun, is about one hundred and ninety-one times greater than that received on the earth.

She is surrounded by an atmosphere, the refractive powers of which differ very little from those of the terrestrial atmosphere.

As viewed from the earth, Venus is the most brilliant of

all the planets; and may sometimes be seen with the naked eye at noon-day. She is known and recognised as the morning and evening star; and never recedes far from the sun.*

Venus must have a climate far more temperate than Mercury, yet much too torrid for the existence of animals or vegetables, except in some circumpolar parts; her magnitude and diurnal rotation differ but little from those of the earth, and her year is only one-third shorter; so that her seasons, and her day and night, must greatly resemble ours. The earth, when in opposition to the sun, must be about four times as bright as Venus ever appears to us, and must, therefore, always cast a shadow; it must be frequently, and perhaps generally, visible in the day; and, together with the moon, must exhibit a very interesting object.

The *Earth* is the next planet beyond Venus in the solar system. Her distance from the sun is at a mean 95,000,000 of miles, and her annual revolution is performed in $365^d.5^h.48.^m49^s$: this is called her tropical year; but the time she takes to perform an annual revolution from any fixed star to the same again, as seen from the sun, is $365^d.6^h$.

* Venus is sometimes seen to pass over the sun's disc, which can happen only when she is in her nodes, and when the earth is in the same longitude. Consequently this phenomenon, for many centuries to come, can take place only in the months of June or December. It is a phenomenon indeed of very rare occurrence, as may be readily seen by the following list, which contains all those transits of Venus which have occurred since that which took place in December 1639, inclusive, (the first that was ever known to have been seen by any human being,) to the end of the 21st century.

1639, Dec. 4.	1882, Dec. 6.
1761, June 5.	2004, June 7.
1769, June 3.	2012, June 5.
1874, Dec. 8.	

$9^{m}.9^{s}$, which is called a sidereal year. Her rotation on her axis is performed in twenty-four hours, which is called the length of a natural day. The earth's mean diameter is 7916 miles. Her diurnal rotation being from west to east, the diurnal motion of all the heavenly bodies appears to be from east to west.

Next to the sun, the moon appears to us the most splendid of all the heavenly bodies, though she is but a satellite, or attendant, to our own planet. Her orbit is an ellipse, with the earth in one of its foci; her synodical revolution round the earth is performed in $29^{d}.12^{h}.44^{m}.3^{s}$., and with the earth she revolves round the sun in a year. Her mean diameter is about 2160 miles; it is therefore her comparative nearness to us that makes her appear so large and afford so much light. Her rotation on her axis is performed in the same time as her revolution round the earth; hence she always keeps the same side towards our planet. The phenomena of the moon's phases, and the nature of eclipses, will be fully discussed under *planetary motion.*

The next planet beyond the earth in the solar system, is *Mars*, whose mean distance from the sun is rather more than 142,000,000 of miles. The colour of this planet is a dusky red, an appearance attributed to the great density of his atmosphere, which permits only the red rays to be reflected to us. From the spots which have been observed on his disc, his rotation on his axis has been ascertained to be performed in $24^{h}.39^{m}.21^{s}$. His equatorial is to his polar diameter as 16 to 15; the true diameter being about 4100 miles.

Mars is not subject to the same limitation in his motion as Mercury or Venus, but appears sometimes very near the sun, and at other times a great distance from that luminary; sometimes rising when the sun sets, or setting when the sun rises. He sometimes appears gibbous, but never

horned like the moon; a proof that his orbit includes that of the earth, and that he shines by a borrowed light. When he is opposite to the sun, or when we see him on the meridian at midnight, he is much more brilliant than in another situation, being five times nearer to us than at a conjunction.

The sun affords to Mars only about a third of the light he affords to the earth, and it has therefore been thought singular that he has not yet been discovered to have a moon; but perhaps he is compensated for this apparent want, and the light he receives may be prolonged, by the height and density of his atmosphere, which is so remarkable, that when he approaches any of the fixed stars, they change their colour, grow dim, and often become nearly invisible, though at some little distance from the body of the planet.

Mars appears to move from west to east round the earth, but his apparent motion is very unequal. When we first perceive him in the morning, separating from the sun, his motion is the most rapid; but this rapidity diminishes gradually, and ceases altogether when the planet is about 137° from the sun; then his retrograde motion commences, and increases in rapidity till he comes into opposition with the sun. It then gradually diminishes again, till the planet is within 137° of the sun; it then becomes direct, till at last the planet is lost for a time in the evening rays of that luminary.

Besides the dark spots which serve to determine the diurnal revolution of Mars, several early astronomers observed that a segment of his globe about the south pole, exceeded the rest of his disc so much in brightness, as to appear as if it were the segment of a larger globe. Maraldi informs us, that this bright spot had been taken notice of

for sixty years, and was more permanent than the other spots on the planet. One part of it is brighter than the rest, and the least bright part is subject to great changes, and has sometimes disappeared. A similar brightness about the north pole was also sometimes observed, and these observations are now confirmed by Dr. Herschel, who has viewed the planet with much better instruments, and much higher magnifying powers, than any other astronomer. "The analogy, says the Doctor, "between Mars and the Earth, is by far the greatest in the whole solar system. Their diurnal motion is nearly the same; the obliquity of their respective ecliptics not very different. Of all the superior planets, the distance of Mars from the sun is by far the nearest alike to that of the earth; nor will the length of the year to Mars appear very different from what we enjoy, when compared to the surprising duration of the years of Jupiter, Saturn, and the Georgium Sidus. If then we find that the globe we inhabit has its polar region frozen and covered with mountains of ice and snow, that only partly melt when alternately exposed to the sun, I may well be permitted to surmise, that the same causes may probably have the same effect on the globe of Mars; that the bright polar spots are owing to the vivid reflection of light from frozen regions, and that the reduction of those spots is to be ascribed to their being exposed to the sun. In the year 1781, the south polar spot was extremely large, which we might well expect, as that pole had but lately been involved in a whole twelvemonth's darkness and absence from the sun; but in 1783 I found it considerably smaller than before, as it decreased considerably from the 20th of May till about the middle of September, when it seemed to be at a stand. During this last period, the south pole had already been above eight months

enjoying the benefit of summer, and still continued to receive the sun-beams, though, towards the latter end, in such an oblique direction as to be but little benefited by them. On the other hand, in the year 1781, the north polar spot, which had been its twelvemonth in the sunshine, and was but lately returning into darkness, appeared small, though undoubtedly increasing in size. Its not being visible in the year 1783, is no objection to these phenomena, being owing to the position of the axis, by which it was removed out of sight."

In the interval between Mars and Jupiter, and nearly at the distance where, from a dependance on the regularity of the progression already mentioned, a number of astronomers had for some years been seeking for a primary planet; the observations of Mr. Piazzi, Dr. Olbers, and Mr. Harding, have placed four very small bodies, differing but little in their mean distance and their periodical time.

They have named them Ceres, Pallas, Vesta, and Juno.

Vesta was discovered by Dr. Olbers, on March 29, 1807; its mean distance from the sun is 2·367870; that of the earth being considered as unity.

It performs its sidereal revolution in 1325·7431 mean solar days; and its mean synodical revolution in 503·41 days.

Its mean motion in its orbit, in a mean solar day, is 16′.17″.9516: its mean motion in 365 days is consequently 99°.9′.15″,33.*

Ceres was first discovered by M. Piazzi in 1801; its mean distance from the sun is 2·767245; that of the earth being considered as unity.

* Mr. Baily observes that the elements of this planet are not yet sufficiently determined to be depended on, and require correction from future observations. The same may be observed of the remainder of the asteroids.

It performs its mean sidereal revolution in 1681·3931 mean solar days: and its mean synodical revolution in 466·62 days.

Its orbit is inclined to the plane of the ecliptic at an angle of 10°.37′.26″,2: which, according to M. Gauss, has an annual decrease of 0″,44.

The eccentricity of its orbit is 0·078439; half the major axis being considered as unity: which, according to M. Gauss, is subject to an annual decrease of ·00000583.

The greatest equation of the centre is 8°.59′.42″.

Pallas was discovered by Dr. Olbers, in 1802: its mean distance from the sun is 2·772886; that of the earth being considered as unity.

It performs its sidereal revolution in 1686·5388 mean solar days: and its mean synodical revolution in 466·22 solar days.

Its mean motion in its orbit, in a mean solar day, is 12′.48″.3934: its mean motion in 365 days is consequently 77°,54′.25″,59.

The eccentricity of its orbit is 0·241648; half the major axis being considered as unity.

Juno was first discovered by M. Harding, on September 1, 1804: its mean distance from the sun is 2.669009; that of the sun being considered as unity.

It performs its sidereal revolution in 1592·6608 mean solar days: and its mean synodical revolution in 473·95 days.

Its mean motion in its orbit, in a mean solar day, is 13′.32″.9304: its mean motion in 365 days is consequently 82°.25′.19″,1.

Its orbit is inclined to the plane of the ecliptic, in an angle of 13°.4′.9″,7.

Jupiter is one of the most beautiful planets in our system. Its mean distance from the sun is above 485,000,000 of miles.

His orbit is inclined to the plane of the ecliptic, in an angle which, at the commencement of the present century, was 1°.18′.51″,3; and which angle is subject to a small decrease of about 0′,226 in a year.

The rotation on his axis is performed in $9^{h}.55^{m}.49^{s},7$.

The inclination of his axis to that of the ecliptic is 3°.5′.30″.

His apparent diameter, (measured equatorially,) at his mean distance from the earth, is 36″,74. At its conjunction it is sometimes only 30″,0; but it increases as the planet approaches its opposition, when it sometimes amounts to 45′,88.

His true diameter, compared with that of the earth considered as unity, is 10·860, which makes it near 90,000 miles. The axis of the poles is to his equatorial diameter, as 167 to 177.

A body which weighs one pound at the equator of the earth, would, if removed to the equator of Jupiter, weigh 2·716 pounds. But this must be diminished about a ninth part, on account of the centrifugal force due to each planet.

The proportion of light and heat which he receives from the sun is ·037; that received by the earth being considered as unity.

Almost every person is sufficiently acquainted with the telescopic appearance of Jupiter, to know that its surface is remarkable for being always covered with a number of belts, or stripes, of various shades. These appearances differ much at different times, and even at the same time in telescopes of different powers. Usually, these belts seem to be of an uniform tint; but, in very favourable weather,

they sometimes appear to consist of a number of curved lines, like the strokes of an engraving.

These belts were first observed at Naples, by Zuppi and Bartoli, two Jesuits; and about the year 1660 they were noticed by Campani, with refracting telescopes of his own construction, and not much inferior in distinctness to those of the present day; the great modern improvement in refracting telescopes consisting rather in the reduction of their size, than in the increase of their magnifying power.

Jupiter is accompanied by four satellites, which were discovered by Galileo, the 8th of January, 1610. He at first took them for telescopic fixed stars; but continued observation soon convinced him that they really accompanied the planet. The relative situation of these small bodies changes at every instant: they oscillate on each side the planet, and it is by the extent of these oscillations that the ranks of these satellites is determined; that being called the first satellite, whose oscillation is the least. They are sometimes seen to pass over the disc of the planet, and project a shadow in the form of a well-defined black spot, which then describes a chord of this disc.

The shadow which Jupiter himself projects behind him, relative to the sun, gives rise to another phenomenon of considerable importance. For the satellites frequently disappear, or are eclipsed in that shadow, although they appear, with respect to us, to be at a distance from the disc of the planet. These eclipses are similar in principle to lunar eclipses, which will presently be described; and vary in duration according to the relative position of the bodies with respect to the sun.

In the following table are given the mean sidereal revolution of the satellites in mean solar days; together with their mean distances from Jupiter, the semi-diameter of

that planet's equator being considered as unity; and likewise their masses, compared with that of Jupiter, considered also as unity.

Sat.	Sidereal Revolution.		Mean distance.	Mass.
1	1.18.28	1.769137788148	6.04853	·0000173281
2	3.13.14	3.551810117849	9.62347	·0000232355
3	7. 3.43	7.154552783970	15.35024	·0000884972
4	16.16.32	16.688769707084	26.99835	·0000426591

First satellite. The plane of the orbit of this satellite coincides nearly with the plane of the equator of Jupiter; the inclination of which, to the orbit of the planet, is 3°.5′.30″. Its eccentricity is insensible.

Second satellite. The eccentricity of the orbit of this satellite is also insensible. The inclination of its orbit to that of its primary is variable; as well as the position of its nodes. These variations are represented nearly, by supposing the orbit of the satellite inclined 27′,49″,2 to the equator of Jupiter; and by giving the nodes a retrograde motion on this plane, so as to make a revolution in thirty Julian years.

Third satellite. This satellite has a little eccentricity, which is subject to a very sensible variation. Towards the end of the century before the last, the equator of the centre was at its maximum, and was then as much as 13′.16″,4. It afterwards diminished, and was at its minimum about the year 1777, when it was only 5′.7″,5. The line of the apsides has a direct, but variable motion. The inclination of its orbit, to that of Jupiter, and the position of its nodes, are also variable. These variations may be represented nearly by supposing the orbit inclined 12′.20″ to the equator of Jupiter; and by giving the nodes a retro-

grade motion on this plane, so as to make a revolution in one hundred and forty-two Julian years.

Fourth satellite. The eccentricity of this satellite is greater than that of the other three. The line of the apsides has an annual and direct motion of 42′.58″,7. The place of the nodes has a direct annual motion on the orbit of the planet, of 4′.15″,3. The inclination of the orbit to that of Jupiter is about 2°.58′.48.″ It is in consequence of this great inclination that this satellite frequently passes behind the planet, with respect to the sun, without being eclipsed. Since the middle of the last century, the inclination of the orbit has increased, and the motion of the nodes has diminished very perceptibly.

Saturn is about 890,000,000 of miles from the sun.

His orbit is inclined to the plane of the ecliptic in an angle which, at the commencement of the present century, was 2°.29′.35″,7; and which angle is subject to a small decrease of 0″,155 in a year.

His ascending node was, at the commencement of the present century, in 111°.56′.37″,4; having a motion to the westward, every year, of 19″,4. But, when referred to the ecliptic, the place of the node will (on account of the precession of the equinoxes) fall more to the eastward, by 30″,7 in a year.

The rotation on his axis is performed in $10^{h}.29^{m}.16^{s},8$.

The inclination of his axis to that of the ecliptic is 30°.19′.

A body which weighs one pound at the equator of the earth, would, if removed to the equator of Saturn, weigh 1·01 pounds.

The proportion of light and heat which it receives from the sun is about ·0011; that received by the earth being considered as unity.

He is sometimes marked by zones or belts, which are probably obscurations in the atmosphere.

Saturn is accompanied by seven satellites, and also surrounded with a double ring.*

The ring of Saturn casts a deep shadow upon the planet. It is sharply defined both in its inner and outer edge, and appears to be more luminous than Saturn himself. Hence Dr. Herschel has concluded, that it is not any shining fluid, or aurora borealis, as some have concluded, but a solid body, equal in density to the planet. The Doctor is also of opinion, that the edge of the ring is not flat, but of a spherical, or rather of a spheriodal form.

In examining the plane of the ring with a powerful telescope, he perceived, near the extremity of its arms, several lucid or protuberant points, which seemed to adhere to the ring. At first, he imagined them to be satellites; but he afterwards found, upon careful examination, that none of the satellites could exhibit such an ap-

* Maupertius, in his "Discours sur la Figure des Astres," maintained, that this luminous girdle was the tail of a comet, which the attraction of Saturn had compelled to circulate round the planet. Mairan asserted that the diameter of the planet was originally equal to the diameter of its outer ring, and, that by some unknown cause, the exterior shell of Saturn was broken to pieces, which were attracted by his body; but the equatorial parts of the exterior shell remained entire, and thus formed a ring about the planet. Buffon imagined that the ring must be a part of the equator which had been detached by the excess of centrifugal force. Without, however, discussing these chimerical hypotheses, it may be sufficient to observe, that we may as well attempt to account for the formation of these satellites, as of the ring of Saturn; that none of them seem to have been the effect of any accidental cause, and that the most rational solution of the difficulty, is to suppose, that when Saturn was created and launched into the heavens, he was at the same instant encircled with a luminous ring, to answer some important purpose, which astronomers have not yet had the sagacity to discover.

pearance; and he therefore concluded, that these lucid points adhered to the ring, and that the variation in their position arose from a rotation of the ring round its axis, which he found to be performed in $10^h.32'.15''$,4. This result is very remarkable; for if we conceive a satellite moving round Saturn, and having for its orbit the mean circumference of the ring, and if we calculate, according to the second law of Kepler, its sidereal revolution, we shall find that the duration of its revolution is nearly equal to the revolution of the ring. According to Dr. Robison, the inner edge of Saturn's ring should revolve in $11^h.16^m$, and the outer edge in $17^h.10^m$. Schroeter seems to doubt of the rotation of the ring.

The double ring consists of two concentric rings, detached from each other, and from the body of the planet, the innermost of which is nearly thrice as broad as the outermost. The following are the dimensions of this luminous zone, as determined by Dr. Herschel. (See Philosophical Transactions, 1792, part 1.)

	Miles.
Inside diameter of the interior ring .	146,345
Outside diameter of the interior ring .	184,393
Inside diameter of the exterior ring .	190,248
Outside diameter of the exterior ring .	214,883
Breadth of the interior ring . .	20,000
Breadth of the exterior ring . .	7,200
Breadth of the dark space between the two rings	2,839
Diameter of the ring, the orbit of the earth being 1, ...	26,8914
Angle which it subtends, when seen at the mean distance of the planet .	7'.25''.332

The last of the planetary bodies that remain to be de-

scribed, was discovered to form a part of our system, by Sir William Herschel, in 1781, who gave it the name of the *Georgium Sidus*, in honour of his Royal Patron.* Its mean distance from the sun is 19·182390; that of the earth being considered as unity. This makes his mean distance upwards of 1,800,000,000 of miles.

The mean motion in its orbit, in a mean solar day, is 0°.0117695, or 42″,37. His mean motion in 365 days is 4°.295876, or 4°.17′.45″,16.

His orbit is inclined to the plane of the ecliptic in an angle of 46′.28″,44.

His apparent diameter, even at the time of his opposition, is scarcely 4″.0.

The proportion of light and heat which it receives from the sun, is about ·003; that received by the earth being considered as unity.

From the Georgium planet the sun must be seen but as a little star, not one hundred and fiftieth part as bright as he appears to us. The axis of this planet being probably near to the plane of its ecliptic, it must be directed twice in the year towards the sun, and the limit of illumination must approach to the equator, so that almost every place on his surface must sometimes remain for a great number of diurnal revolutions, in light and in darkness; the most moderate climates having one night, in their long year, equal in duration, at least, to several of our years: and it must be confessed that this planet would afford but a comfortless habitation to those accustomed to our summer sunshine, even if it were possible to colonise it.

* Mr. Baily states that this star, under the name of "Uranus," was observed as far back as 1690. It was seen three times by Flamsteed, once by Bradley, once by Mayer, and eleven times by Lemonnier, not one of whom suspected it to be a planet. That brilliant discovery was reserved for Herschel.

These ten planetary bodies are the only ones hitherto discovered, which have any title to be considered as primary planets, that is, as bodies revolving round the sun, in orbits so nearly circular as to remain always within the reach of our observation. It has been conjectured that the number of planets may in reality be much greater; that not only many small, and perhaps invisible bodies may be revolving in the intervals of the planets with which we are acquainted, but that larger bodies also may belong to our system, which never approach within such a distance as to be seen by us.

In order to retain in memory a general idea of the proportional distances of the primary planets from the sun, we may call that of the Earth 10, and that of Saturn 100; the distance of Mercury will then be 4, to which we must add 3 for Venus, making 7; twice 3, or 6, for the Earth, making 10; twice 6, or 12 for Mars, making 16; twice 12, or 24, making 28, for the three small planets, Juno, Pallas, and Ceres; twice 24, or 48, making 52 for Jupiter; twice 48, or 96, for Saturn, making 100; and twice 96, or 192, making 196 for the Georgium planet; and these sums will represent the distances without any material exception, in the nearest integer numbers.

The Sun, which forms so important a part of our system, must be briefly examined, preparatory to a notice of Dr. Herschel's peculiar views relative to solar light and heat.

This brilliant luminary revolves on its axis in about twenty-five days ten hours, from west to east; that is, supposing the order of the signs to be known, and a point in the sun to be opposite Aries, it moves towards Taurus. All the rotations of the different bodies, which compose the solar system, as far as they have been ascertained,

are in the same direction. The time and direction of the sun's rotation is ascertained by the change in the situation of the spots, which are usually visible on his disc. The spots are frequently observed to appear and disappear, and they are in the mean time liable to great variations; but are generally found about the same points of the sun's surface.

In 1788, Mr. King published a dissertation on the Sun, in which he states, that the real body of that luminary is less than its apparent diameter: that we never discern the real body of the sun itself, except when we behold the spots: that the sun itself is inhabited as well as the earth and planets, and is not necessarily subject to burning heat; and that there is no violent elementary heat existing in the rays of the sun, but that they produce heat only when they come in contact with the planetary bodies.

Doctor Herschel also considered the Sun to be a magnificent habitable globe, surrounded by a double set of clouds; those which are nearest its opaque body being less bright and more closely connected together than those of the upper stratum; which he concluded from the luminous apparent globe it exhibits. This luminous external matter, he observes, is neither a liquid nor an elastic fluid of an atmospheric nature; for in either of these two cases it would not admit of any chasms or openings. Therefore, it must be concluded that this shining matter exists in the manner of empyreal, luminous, or phosphoric clouds, residing in the higher regions of the solar atmosphere. The Doctor then is of opinion that the spots are only accidental openings between the luminous clouds, through which we behold the opaque body of the sun, or the inferior less luminous clouds; hence, the spots appear of different shades. The Doctor rejected the terms maculæ, faculæ, luculi, and

others previously in use, and substituted the following, as better adapted to express what he considered the true phenomena of the sun.

"*Openings*, are those places where, by the accidental removal of the luminous clouds of the sun, its own solid body may be seen; and this not being lucid, the openings through which we see it, may, by a common telescope, be mistaken for mere black spots, or their nuclei.

Shallows, are extensive and level depressions of the luminous solar clouds, generally surrounding the openings to a considerable distance. As they are less luminous than the rest of the sun, they seem to have some distant, though very imperfect resemblance to penumbræ, which might occasion their having been called so formerly.

Ridges, are bright elevations of luminous matter, extended in rows of an irregular arrangement.

Nodules, are also bright elevations of luminous matter, but confined to a small space. These nodules and ridges correspond to what have hitherto been called faculæ and luculi.

Corrugations, he applies to that very particular and remarkable unevenness, ruggedness, or asperity, which is peculiar to the luminous solar clouds, and extends all over the surface of the globe of the sun. As the depressed parts of the corrugations are less luminous than the elevated ones, the disc of the sun has an appearance which may be called mottled.

Indentations, are the depressed or low parts of the corrugations; they also extend over the whole surface of the luminous solar clouds.

Pores, are very small holes or openings, about the middle of the indentations."

As Dr. H. considered the solar clouds to consist rather

of a flame than a liquid substance, he attributed the spots to the emission of an aëriform fluid, not yet in combustion, which displaces the general luminous atmosphere, and which is afterwards to serve as fuel for supporting the process: hence he supposed the appearance of copious spots to be indicative of the approach of warm seasons on the surface of the earth; a theory which he has attempted to maintain by historical evidence. The shallows he considered as parts of an inferior stratum of opaque clouds, capable of protecting the immediate surface of the sun from the excessive heat produced by combustion in the superior stratum, and probably of rendering this stupendous world fit for animated existence. In general, more or less of the real body of the sun is supposed to be visible through its lucid atmosphere, where its substance is not very intense, or where it is removed by the varying circumstances of the combustion. As some of the spots appear below the surface of the shining fluid, it may be presumed that they show us the lower parts of the sun's surface; and as other spots appear above the shining fluid, it is equally reasonable to conclude that they are the solar mountains. The former kind of spots are very variable in situation, and it is clear, that if we have the true theory of the sun before us, they may never occur twice precisely at the same place. The spots attributed to the projection of the solar mountains, are fixed with respect to the sun's surface, and are those by which the sun's rotation on his axis has been determined. Dr. Herschel, taking into consideration the great attraction exerted by the sun upon bodies placed at its surface, and the slow revolution it has about its axis, thought that the solar mountains might be more than three hundred miles high, and yet stand very firmly.

Dr. Young, in opposition to the theory of Dr. Herschel,

argues, that if we inquire into the intensity of the heat which must necessarily exist wherever this combustion is performed, we shall soon be convinced that no clouds, however dense, could impede its rapid transmission to the parts below: besides, the diameter of the sun is one hundred and eleven times as great as that of the earth, and at its surface, a heavy body would fall through no less than four hundred and fifty feet in a single second; so that if every other circumstance permitted human beings to reside on it, their own weight would present an insuperable difficulty, since it would become thirty times as great as upon the surface of the earth, and a man of moderate size would weigh about two tons.

The *periods* and *velocities* of the planets, or the time in which they perform their courses, are found to preserve the most perfect harmony with their distances from the sun, and with one another. The nearer each planet is to the sun, the quicker is its motion, and its period the shorter. The great law they observe, may be thus briefly stated: the squares of their periodical times are as the cubes of their distances from the centres of their orbits.

We are indebted for a knowledge of this law to the sagacity of Kepler, who found it to obtain in all the primary planets; as astronomers have since found it also to do in the secondary ones.

Kepler deduced this law merely from observation, and comparison of the several distances of the planets with their periods: the credit of investigating it from physical principles is due to Sir Isaac Newton, who demonstrated, that such a law was inevitable.

When a body is retained in a circular orbit, by a force directed to its centre, its velocity is everywhere equal to that which it would acquire, in falling, by means of the

same force, if uniform, through half the radius, that is, through one-fourth of the diameter. We may in some measure demonstrate the truth of this proposition by means of the *whirling-table*: an apparatus which is arranged on purpose for exhibiting the properties of central forces, although it is more calculated for showing their comparative, than their absolute magnitude; for, accordingly as we place the string on the pulleys, the two horizontal arms may be made to revolve either with equal velocities, or one twice as fast as the other. The sliding stages, which may be placed at different distances from the centres, and which are made to move along the arms with as little friction as possible, are in a certain proportion to the weights, which are to be raised, by means of threads passing over the pulleys in the centres, as soon as the centrifugal forces of the stages with their weights are sufficiently great; and the experiment is to be so arranged, that when the velocity, having been gradually increased, produces a sufficient centrifugal force, both stages may raise their weights, and fly off at the same instant. But, for the experiment just described, one of the stages only is required, and the time of revolution may be measured by a half-second pendulum. We may make the force, or the weight to be raised, equal to the weight of the revolving body, and we shall find that this body will fly off when its velocity becomes equal to that which would be acquired by any heavy body in falling through a height equal to half the distance from the centre, and as much greater as is sufficient for overcoming the friction of the machine.

The whirling-table is a convenient auxiliary for experimentally elucidating a variety of curious phenomena, connected with the form and motions of the planetary bodies; and the author employs the following modification of the

apparatus, for illustrating the form of the earth. A large glass globe, partly filled with coloured water, is attached to the axis of the table, in the centre of which is placed a lighted taper. On making the globe revolve rapidly, the coloured water occupies the equator of the glass, and forms a fluid wall completely round the burning body.

It having thus been shown that the Earth must of necessity be protuberant in its equatorial direction, another proof of this fact may now be adduced, namely: that a pendulum, calculated to swing seconds at the poles, or in a high latitude, will not swing seconds at the equator, unless it be shortened;* therefore, as a pendulum swings by the power of gravity, that power is rather less at the equator than at the poles; partly on account of the greater distance of those parts from the equator, and partly from their greater centrifugal force, which tends to throw every thing in a tangent from its surface.† If

* The length of a pendulum to vibrate seconds at Unst, is 39·17146. But in the neighbourhood of London, only 39·13929. Vide Captain Kater in Transactions of the Royal Society, vol. cix. p. 416.

† The centre of gravity of any mass of matter, is that point about which its parts exactly balance each other. Hence, if a body is suspended by this point, it will rest in any position in which it may be put, and whatever supports the weight at that point, bears the weight of the whole body. If a line be drawn from the centre of gravity of a body, perpendicular to the horizon, it is called the line of direction, and if this fall within the base, the body will remain stable; when, however, it falls without the base, the body must fall.

In the equilibrium of animals, many circumstances occur illustrative of the nature of gravity. When a person stands on one foot, and leans forward in the attitude which is usually exhibited in the statues of Mercury, the other foot is elevated behind, in order to bring back the centre of gravity, so as to be vertically over some part of the foot on which he stands. But, in the event of any want of precision in performing this operation, or from the narrowness of the base, it is

the diurnal motion of the earth were to cease, its centrifugal force would of course be destroyed at the same time; in which case, the water it supports, would immediately retire, in order to restore the perfectly globular form of the earth, and would overwhelm the polar regions.

The mensuration of the Earth has been effected by various mathematicians. Mr. Richard Norwood, in the year 1635, took the sun's altitude when it was in the summer solstice, both at London and York, with a sextant of five feet radius; and by that means found the difference of latitude between these two cities to be two degrees and twenty-eight minutes. He then measured their distance in as exact a manner as possible; and having taken into the account all the windings of the road, with the ascents and descents, he reduced it to an arc of the meridian, and found it to contain 12,849 chains; and this distance being compared with the difference of latitude, gave him 5209 chains to a degree, or about 57,300 French fathoms or toises. This method requires no explanation, if the two places are considered as lying under the same meridian, which, indeed, is nearly the case. The same operation may also be easily performed by trigonometry, when the two places lie under different meridians; for if we measure the distance of any two objects, and take the angles which each of them makes with a third, the triangle formed by the three objects will become known; so that the two

often found necessary to use muscular exertion, in order to bring the point of support to that side towards which the operator is beginning to fall. When elevated on the point of the toe, the base is still more contracted, and the body never remains at rest, but by a succession of actions of this kind, sometimes too minute to be visible, it is kept in a state of perpetual vibration, without ever attaining such a position as would ensure positive stability; and by this means, aided by habit, the arts of rope-dancers, and balancers, are acquired.

sides may be as accurately determined by calculation, as if they had been actually measured in the same manner as the first. And by making either of these sides the base of a new triangle, the distances of other objects may be found by trigonometry as before; and thus, by a series of triangles connected together at their bases, we might measure the whole circumference of the Earth. But this would be an enterprise as useless as it is laborious; for, since we know the relation which any part of a circle bears to the entire circumference, the measure of a few degrees, or even of one single degree, will give the measure of the whole. But by applying the telescope to the quadrant, and furnishing it with a micrometer, we are enabled to correct a great many inaccuracies attending this kind of mensuration.

The Academy of Sciences at Paris, perceiving from these considerations the necessity of a new measure of the Earth, represented the execution of it as a measure of national honour and importance. M. Picard was the person employed to perform this business. He began by measuring the distance between Villejuif and Juvisy; and this base, which he found to be 5663 fathoms, was that to which he referred all his calculations. He next placed himself at Juvisy, and by directing the telescopic sights of his quadrant, the one to the windmill at Villejuif, and the other to the spire of the church at Brie, he measured the angle subtended by these two objects. Leaving that station, he removed to Villejuif, and, by measuring the angle between Juvisy and Brie, the distance between Villejuif and Brie was found by calculation to be 11,012 fathoms. This distance he made a new base, and by forming a second triangle between Brie, Villejuif, and Monthleri, he found the distance, in like manner, between Brie and Monthleri, to be 13,121 fathoms. He then

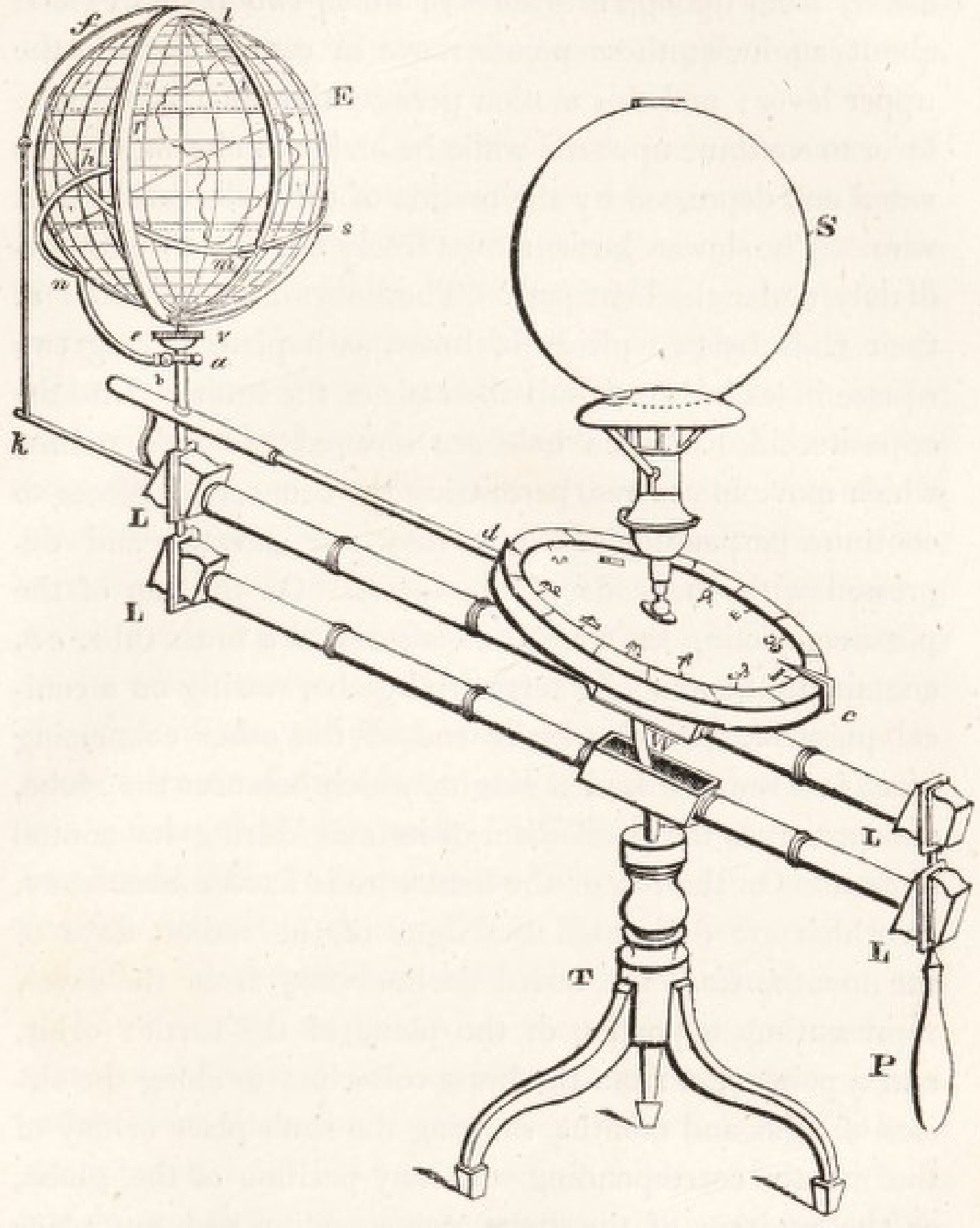
formed a third triangle between Monthleri, Brie, and Monjay; a fourth between Monthleri, Brie, and Malvoisine; and a fifth between Monthleri, Monjay, and Mareil; and from all these measures, the distance between Mareil and Malvoisine was found to be 31,897 French fathoms. In a similar manner, by means of thirteen triangles, he proceeded as far as Sourdon, near Amiens, and found the distance between Sourdon and Malvoisine to be 68,430 fathoms. But as calculations are less subject to errors than mechanical operations, Mons. Picard, in order to avoid every inaccuracy of this kind, took a new base near Sourdon, and found its length, both from a continuation of his trigonometrical operations, and from an actual mensuration; and as these exactly agreed, he could no longer doubt of the truth of his former calculations. This part of his project being finished, he had now to reduce the distance between Sourdon and Malvoisine to an arc of the meridian. Having obtained this terrestrial distance to a great degree of accuracy, he had only to find the celestial arc which corresponded with it. This he did by observing the meridian distances of the same star, both from the zenith of Sourdon and Malvoisine, and taking their difference; and as this difference, which he found to be one degree eleven minutes and fifty-seven seconds, answered to a distance of 68,430 fathoms upon the earth, he concluded, by the rule of proportion, that the length of a degree must be 57,064 fathoms. But having connected Amiens to his series of triangles, and finding from this new measure, that a degree would be 57,057 fathoms, he took a mean between the two, and fixed his degree at 57,060, or about sixty-nine and a half English miles.

The surveys were all taken upon a supposition, that the Earth was a perfect sphere; but the truth of this doctrine

was soon called in question as the science advanced. Newton and Huygens had shown, from the known laws of gravitation, that the true figure of the Earth must be that of an oblate spheroid, flattened at the poles, and protuberant at the equator. Cassini, on the other hand, depending more upon the accuracy of his measures, than upon deductions drawn from theoretical reasoning, asserted it to be that of a prolate spheroid, flattened at the equator, and protuberant at the poles. To decide this important question, which had now become a national dispute, it was ordered by the French king, that a degree should be measured, both at the equator and polar circle, so that from a comparison of these with that in France, the true figure of the Earth might be determined in as exact a manner as possible. For this purpose, Mess. Maupertuis, Clairaut, Carnus, Le Monnier, and Outhier, were sent to the North of Europe to measure the remotest degree they could reach; and Messrs. Godin, Bouger, and La Condamine, to Peru, in South America, to measure a degree near the equator. The first of these mathematicians commenced their operations at Tornea, near the Gulph of Bothnia, on the 8th of July, 1736, and finished them about the beginning of June, 1737. M. Maupertuis, soon after their return to France, published an exact account of the survey. The result of this measurement was found to be, that an arc of the meridian contained between the parallels of Tornea and Kittis, was equal to 55,023$\frac{1}{2}$ fathoms. And as the magnitude of this arc was found, by means of the zenith distances of certain fixed stars, to be $57'28\frac{2}{3}''$, it was determined, after proper corrections, that the true length of a degree of the meridian, which cuts the polar circle, is 57,422 fathoms. Those who were sent to Peru, in South America, had still greater difficulties to encounter

than their friends in Lapland, and were a longer time employed in their operations. They set out upon their expedition about a twelvemonth before the former, and did not finish their survey till the year 1741. The province of Quito was the place determined on as the most proper for their purpose. Here they measured an arc of the meridian, of three degrees seven minutes and one second, and found it to contain 176,950 fathoms; which being reduced to the level of the sea, and properly corrected, the first degree of the meridian from the equator was found to be equal to 56,753 fathoms. These measures afford a complete demonstration that the Earth is flattened at the poles, and protuberant at the equator. For had the figure of it been a complete globe, as was formerly imagined, a degree of the meridian, in every latitude, would have been found the same; and had the figure been that which was given to it by Cassini, a degree at the polar circle would have been less than a degree at the equator.

In explaining the phenomena of the Seasons, which result from the motion of our planet, the teacher usually has recourse to an orrery, or tellurian; but the large orreries that are generally employed for the illustration of planetary motion, though well calculated for scenic effect, are of but little use in solving the simplest problems in practical astronomy. But a very ingenious apparatus has been contrived by Mr. Christie, which materially assists in the elucidation of this science. It is represented in the accompanying engraving, and consists of a lamp covered by a hollow sphere of ground-glass, S, representing the sun, round which a terrestrial globe, E, moves in a circle, whose plane makes with the horizon an angle of $23\frac{1}{2}°$, two parallel levers, L L, L L, supporting the globe, and its counterpoise, P, an horizon, *h h*, and a meridian, *i m*,



turning with it on its axis, a terminator, *t r*, distinguishing the parts of the earth enlightened from those in darkness, and a claw-feet pillar or stand, T, supporting the whole.

The top of the stand is furnished with a piece of strong steel wire, W, bent $23\frac{1}{2}°$ from the perpendicular, corresponding with the inclination of the earth's axis to the plane of its orbit. On the bent part of the wire is fitted a brass

collar, from the opposite sides of which two points extend about an inch; these points move in centres fixed in the upper lever; and this motion permits the same side of the lever to continue upwards while its ends are alternately elevated and depressed by the motion of the collar on the bent wire. The lower lever moves freely on the wire immediately under the bent part. The levers are connected at their ends by two pieces of brass, each piece having two square holes in it to admit the ends of the levers. Into the opposite sides of each hole are screwed two steel points, which move in centres, permitting the connecting pieces to continue perpendicular while they are elevated and depressed with the ends of the levers. On the top of the piece connecting the long ends is screwed a brass tube, *a b*, containing the axis of a terrestrial globe, resting on a conical point, *b*. On the lower end of the other connecting piece is screwed a leaden weight, which balances the globe, and preserves the parallelism of its axis during its annual motion. On the top of the bent wire is fixed a board, *d c*, on which are delineated the signs of the zodiac, days of the month, &c.; the board declines $23\frac{1}{2}°$ from the level, representing a portion of the plane of the earth's orbit, and a pointer, *c*, from the brass collar moves along the circles of signs and months, showing the sun's place or day of the month, corresponding with any position of the globe, or the position of the globe corresponding with any place of the sun or day of the month. A silk line extends round the circumference of this board, and round a pulley on the axis of the globe, to produce the diurnal motion; the line is conveyed from the board to the axis through a brass tube, *b d*, and after passing the pulley on the axis, it is carried round another pulley, (at *b*) which is fixed to the end of the upper lever, and preserves an equal tension on the

line. Into the board immediately over the centre of motion of the levers, is screwed a stem supporting a lamp, with its ground glass cover.

The remaining parts, viz. the hour-circle, the meridian, the horizon, and the terminator, are more immediately connected with the globe. The hour-circle, *e o*, is fitted on the axis below the globe, sufficiently stiff to preserve its adjustment, when set to the meridian of any place. The meridian is a ring of brass attached to the poles, with its flat surface towards the globe; one semicircle of it is divided into degrees, and numbered from the equator towards the poles, for finding the latitudes of places, declination of the sun, &c. The horizon is a thin slip of brass, one end of which fits into a socket fixed on the other: it is attached to a wire which moves up or down with it in a groove near the edge of the meridian, representing at pleasure the rational horizon of any place; and it is divided into degrees and points of the compass, for finding the sun's azimuth, amplitude, &c.; it is necessary to separate the ends of the horizon when it is changed from N. to S. or from S. to N. latitude. Both meridian and horizon are turned with the globe on its axis, so that, when they are adjusted to the latitude and longitude of any place, they retain their adjustment till an alteration is required: in the pole of the horizon a point, *i*, is fixed on the wire, showing the zenith, to which a quadrant of altitude is occasionally attached. The terminator is sufficiently large to permit the globe with the other circles to turn within it; this circle is made a little concave, to reflect light on those parts which receive but little of the direct light, and to mark more distinctly the difference between the light and dark hemispheres: it is supported by two pivots, (one of which is seen at *r*,) fixed in its opposite sides even with the equator; these pivots are

fitted into the ends of a strong semicircular wire, *r n*, which is supported behind the globe by a very strong piece of bent wire, *n a*, extending from the brass tube containing the axis: and the lower part of the terminator is cut to permit its passing the axis. From it a circular wire, *o s*, extends 90° upwards, on the top of which a point, *s*, is fixed, representing a central ray from the sun: this point shows the sun's declination, azimuth, amplitude, altitude, and the place where he is vertical at a given time: from the top a similar wire, *f g*, extends 90° downwards behind the globe, where it is attached by a vertical piece, *g k*, to the upper lever produced; the lower end of the vertical wire is the same distance from the piece connecting the levers as its upper end is from the centre of the globe; thus forming a kind of parallelogram, which in some positions of the globe takes the form of a rectangle, and in others that of a rhomboid. This contrivance preserves the face of the terminator constantly towards the lamp, and alternately exposes to its light the north and south poles during its annual motion.

If we commence in the summer months, we shall find the north pole of the Earth inclined to the Sun, and it will be evident that a larger proportion of this end of the globe is illuminated than of the opposite end. In this season then, the days will be longer than the nights; but if we still preserve the Earth's poles in the same direction, and pass through one-fourth of its orbit, it will be seen that as much of the globe is illuminated above the equator as there is beneath; consequently, the day and night must be equal. Passing on towards the winter season, we find the south pole of the Earth presented towards the Sun, and as Great Britain is situated North of the equator, our nights

must then be longer than the day; this, then, is our winter season.

Thus we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is periodically no day or night for many turnings of the earth within the polar circles; why there is but one day and one night in the whole year at the poles; and why the days and nights are equally long all the year round at the equator, which is equally cut by the circle bounding light and darkness. The inclination of an axis, or of the plane of an orbit, is merely relative, arising out of the comparison we make with some other axis or orbit, which we do not consider as inclined at all.

Though we say that the inhabitants within the arctic and antarctic circles are at opposite times of the year deprived of the sight of the sun, yet they are not altogether deprived of his light; for the atmosphere reflecting and refracting the sun's light, forms a twilight at the distance of even eighteen degrees. Hence, the day breaks to us when the sun is still eighteen degrees below the eastern horizon; and we have his light in the evening till he sinks eighteen degrees below the western. But as the sun in summer rises considerably to the north of the east, and sets also to the north of the west with us, he rises and sets very obliquely to the horizon, and the twilight is of long duration. At Midsummer, Great Britain has no night, for the whole island is within eighteen degrees of the horizon, or boundary of the sun's light. In high southern latitudes, they enjoy in their turn the same advantage; but at the equator, the sun sinks abruptly from the horizon, because his path is at right angles to it, or very nearly so; and the quick transition from the glare of day to utter darkness, cuts off the enjoyment of the twilight hour.

Astronomers, however, usually commence the year in the spring, when the sun is in that node of the equator, or equinoctial point, at which the days begin to lengthen in the northern hemisphere. Now it is plain that if the equinoctial points had no motion, the earth would complete one revolution in its orbit in the same time that the sun employs in apparently passing from one of the equinoxes, and returning again to the same. But as there is a retrograde motion, the line of the nodes of the equator, or diameter of the earth which joins the equinoctial points, is brought to coincide again with the line which joins the centres of the sun and earth, before its periodical revolution is completed; and therefore the circle of the seasons is performed in less time than the earth's revolution in its orbit. The actions both of the sun and moon on the redundant matter in the equatorial regions, tend to produce this motion, which is so slow, that a complete revolution will not be finished in less than twenty-five thousand years. This is called the precession of the equinoxes, and is the reason that the fixed stars appear to advance in longitude about fifty seconds of time in a year: whence it has happened, that, since the time of Ptolemy, the zodiacal figures have advanced the greater part of a whole sign: the constellation Aries being situated in that part of the ecliptic which is denominated from Taurus; Taurus in the place of Gemini, &c. The difference between the natural year, or period of the seasons, and the periodical year, or time of the earth's revolution in its orbit, has already been fully examined when treating of the sun and earth.

The sidereal year, or time employed by the sun in returning to the same apparent position with respect to a fixed star, is $365^{d}.6^{h}.9'.9''$. The difference between the

periodical and sidereal year is occasioned by the motion of the apsis of the earth's orbit.

The motion of the *moon*, or satellite that attends on our planet, must next be examined, as its phases depend on a continual change of place.

Although the moon, in reality, revolves about the common centre of gravity between itself and the earth, and not about the earth itself, and consequently their motions and irregularities are similar, and not confined to the moon alone; yet it may be easily conceived, that the conclusions with reference to the latter body, are not affected in any degree that may be here regarded, when, for the sake of conciseness, we suppose one of the two bodies to be quiescent, and the other to revolve about it.

When the moon is visible in the day-time, its light is so nearly equal to that of the lighter thin clouds, that it is with difficulty distinguished amongst them. Its light continues the same during the night; but the absence of the sun, suffering the aperture or pupil of the eye to dilate itself, renders it more conspicuous. It therefore follows, that if every part of the sky were equally capable of reflecting light with the moon's disc, the light would be the same as if, in the day-time, it were covered with the thin clouds above-mentioned. We discern a variety of spots with the naked eye, which the imagination naturally supposes to be spacious seas, and continents; but on a more accurate inspection, with the assistance of a telescope, it is perceived that many of those appearances are occasioned by vast cavities, closely intersected by mountainous ridges. The heights of these mountains may easily be found; for by the horizontal parallax, we know that the earth's apparent diameter, seen from the moon at its mean

distance, is 1°54′ (132, ×) or 6840 seconds; while that of the moon, seen from the earth at the same distance, is 31′29″, or 1889 seconds. Their absolute diameters must therefore be in proportion to these numbers. Consequently, if we find the proportion the height of a lunar mountain bears to the moon's diameter, we may, without difficulty, find the quantity of that height in miles, or other terrestrial dimensions.

These mountains and cavities are known to be such, from their shadows. In the first and second quarters, when the sun shines obliquely on the face of the moon, the elevated parts cast a triangular shadow in the direction from the sun; and, on the contrary, the cavities are dark on the side next the sun, and illuminated on the opposite side. The shadows shorten as the sun becomes more directly opposed to the anterior face of the moon, and at length disappear at the time of the full. During the third and last quarters, the shadows appear again, but all fall towards the contrary side of the moon, though still with the same distinction: namely, that the mountains are dark and shady on the side farthest from the sun, and the pits are dark on the side next the sun.

The most remarkable appearance in the moon, is the continual change of figure to which it is subject. Sometimes it appears perfectly full, or circular, at other times less than half-illuminated, changing through a very great variety of figures. These changes being always the same at the same elongation from the sun, are a proof that it receives its light from that luminary; for the moon is enlightened only on the side that faces the sun; and a greater or less quantity of that enlightened part is visible to us, according to our position. This cannot be better illustrated than by an ivory ball, which being held in the

sun in various positions, will present a greater or less part of its illuminated side to the view of the observer. If it be held nearly in opposition, so that the eye of the observer may be almost immediately between it and the sun, the greatest part of the enlightened side will be seen. But if it be moved in a circular orbit towards the sun, the visible enlightened part will gradually decrease, and at last disappear when the ball is held directly towards the sun. Or, to apply the experiment more immediately to our present purpose, if the ball at any time, when the sun and moon are both visible, be held directly between the eye of the observer and the moon, that part of the ball on which the sun shines, will appear exactly of the same figure as the moon itself.

Since the earth, when beheld from the moon, must always appear in the part of the heavens immediately opposite the moon's apparent place, as seen from the earth, the enlightened side of the earth will have the same figure, when seen from the moon, as the dark side of the moon would exhibit if it could be seen at the same instant from the earth. Thus, when the moon is invisible, or near the conjunction, the earth is in opposition, and presents a full luminous face to the moon; and on the contrary, when the moon is at the full, or opposite the sun, it must be on the dark side of the earth, which consequently then becomes invisible.

When the earth, in turning on its axis from west to east, has revolved from one meridian to the same meridian again, the moon, which also revolves from west to east, has advanced over little more than a thirtieth part of her orbit, or 12° and some minutes: this is not, however, constantly the case, except at or near the equator; for on account of the different angles made by the horizon at di

ferent parts of the moon's orbit, this retardation differs considerably in places of high latitude. Twice in the year she rises for a week together, nearly at the same time; and these phenomena happening successively in autumn, the earlier is called the *harvest moon*, and the latter the *hunter's moon*. We shall chiefly be indebted to Ferguson for the explanation of these problems.

The plane of the equinoctial is perpendicular to the earth's axis; and, therefore, as the earth turns round on its axis, all parts of the equinoctial make equal angles with the horizon, both at rising and at setting; so that equal portions of it always rise or set in equal times. Consequently, if the moon's motion were equable, and in the equinoctial, at the rate of 12°11′ from the sun every day, as it is in her orbit, she would rise and set fifty minutes later every day than on the preceding day: for 12°11′ of the equinoctial rise or set in 50′ of time in all latitudes. But the moon's orbit is so nearly in the same plane as the ecliptic, that we may consider her at present as moving in the ecliptic. Now the different parts of the ecliptic, on account of its obliquity to the earth's axis, make very different angles with the horizon as they rise or set. Those parts or signs which rise with the smallest angles, set with the greatest, and *vice versa*.

In northern latitudes, the smallest angle made by the ecliptic and horizon, is when Aries rises, at which time Libra sets; the greatest when Libra rises, at which time Aries sets. From the rising of Aries to the rising of Libra, (which is twelve siderial hours,) the angle increases; and from the rising of Libra to the rising of Aries, it decreases in the same proportion; hence it appears that the ecliptic rises fastest about Aries, and slowest about Libra.

On the parallel of London, as much of the ecliptic

rises about Pisces and Aries in two hours, as the moon goes through in six days; therefore, whilst the moon is in these signs, she differs but two hours in rising for six days together, that is, about twenty minutes later every day or night than on the preceding, at a mean rate. But in fourteen days afterwards, the moon comes to Virgo and Libra, which are the opposite signs to Pisces and Aries: and then she differs almost four times as much in rising; namely, one hour and about 15′ later every day or night than the preceding, whilst she is in these signs. As the signs Taurus, Gemini, Cancer, Leo, Virgo, and Libra, rise successively, the angle of the ecliptic with the horizon increases gradually; and decreases in the same proportion as they set; and for that reason, the moon differs gradually more in the time of her rising, every day whilst she is in these signs, and less in her setting: after which, through the other six signs, viz. Scorpio, Sagittarius, Capricorn, Aquarius, Pisces, and Aries, the rising difference becomes less every day, until it arrive at the least of all; namely, in Pisces and Aries.

The moon goes round the ecliptic in about twenty-seven days and eight hours; but not from change to change in less than about twenty-nine days and a half, so that she is in Pisces and Aries at least once in every lunation, and all; in some lunations twice.

If the earth had no annual motion, the sun would never appear to shift its place in the ecliptic, and then every new moon would fall in the same sign and degree of the ecliptic, and every full moon in the opposite; for the moon would go precisely round the ecliptic from change to change. So that if the moon was once full in Pisces or Aries, she would always be full when she came round to the same sign and degree again. And as the full-moon

rises at sun-set, (because, when any point of the ecliptic sets, the opposite point rises,) she would constantly rise within two hours of sun-set, on the parallel of London, during the week in which she was full. But during the time that the moon goes round the ecliptic from any conjunction or opposition, the earth goes almost a sign forward, and, therefore, the sun will seem to go as far forward in that time, namely, $27\frac{1}{2}°$; so that the moon must go $27\frac{1}{2}°$ more than the round, and as much farther as the sun advances in that interval, which is $2\frac{1}{15}°$, before she can be in conjunction with, or opposite to the sun again. Hence it is evident, that there can be but one conjunction or opposition of the sun and moon in a year, in any particular part of the ecliptic. This may be familiarly exemplified by the hour and minute hands of a watch, which in twelve hours are never in conjunction or opposition in that part of the dial-plate where they were so last before.

As the moon can never be full but when she is opposite to the sun, and the sun is never in Virgo and Libra but in our autumnal months, it is plain that the moon is never full in the opposite signs, Pisces and Aries, but in these two months; and therefore we can only have two full moons in the year which rise nearly at the time of sun-set for a week together, as has been mentioned above.

When the moon is in Pisces and Aries, she must rise with nearly the same difference of time in every revolution through her orbit, which is exactly the phenomenon of the harvest-moon; but it passes unobserved, because in winter, those signs rise at noon, and being then only a quarter of a circle distant from the sun, and the moon in them is in her first quarter, and rises about noon, at which time her rising is not noticed. In spring, those signs rise with the sun, for the sun is in them; consequently, the moon being

in them too, is in conjunction with the sun, and therefore her rising is invisible. In summer, those signs rise about midnight, and the sun is three signs, or about 90° before them, therefore, the moon in them must be in her third quarter, when she gives little light, and rises late, on which accounts, the phenomenon of her rising for some nights with little difference of time, passes unnoticed. In autumn, however, the case is different, for the signs of Pisces and Aries then rise about sun-set, and therefore the moon being in them, is in opposition to the sun, consequently full, and rises in great splendour when the sun sets, and seems to prolong the day, for the advantage of the husbandman at the time of harvest.

In northern latitudes, the autumnal full-moons are in Pisces and Aries; and the vernal full-moons in Virgo and Libra. In southern latitudes, just the reverse, because the seasons are contrary. But Virgo and Libra rise at as small angles with the horizon in southern latitudes, as Pisces and Aries do in the northern; and therefore the harvest-moons are just as regular on one side of the equator as on the other.

As those signs which rise with the least angle, set with the greatest, the vernal full-moons differ as much in their times of rising every night, as the autumnal full-moons differ in their times of setting; and set with as little difference as the autumnal full-moons rise; the one being in all cases the reverse of the other.

Hitherto, to avoid the complication of the subject, the moon's orbit has been supposed to coincide with the ecliptic; but since her orbit makes an angle with the ecliptic, varying from 5° to 5°18′, one half of it is on one side of the ecliptic, and the other on the other side, and she only coincides with it when at the points of intersection, called

her nodes, which coincidence cannot happen less than twice, but sometimes happens thrice, between change and change. For as the moon goes almost a whole sign more than round her orbit from change to change, if she passes through either node at, or a little before the time of change, she will pass by the other about fourteen days afterwards, and come round to the former node before the next change. When the motion is northward of the ecliptic, she rises sooner and sets later than if she moved in the ecliptic; and when she is southward of the ecliptic, she rises later and sets sooner. This difference is variable, even in the same signs, because the nodes shift backwards about 19° in the ecliptic every year, and so go round it, contrary to the order of the signs, in eighteen years two hundred and twenty-eight days.

When the ascending node is in Aries, the southern half of the moon's orbit makes an angle of $5\frac{1}{3}°$ less with the horizon than the ecliptic does when Aries rises in northern latitudes; for which reason, the moon rises with less difference of time when she is in Pisces and Aries, than if she moved in the ecliptic, and will differ only one hour and forty minutes for the whole of seven days. But in nine years one hundred and fourteen days afterwards, the descending node comes to Aries, and then the moon's orbit makes an angle of $5\frac{1}{3}°$ greater with the horizon when Aries rises, than the ecliptic does at that time; which causes the moon to rise with greater difference of time in Pisces and Aries, than if she moved in the ecliptic; this difference, in the course of a week, will amount to full three hours and a half. Hence, though we observe the phenomenon of the harvest-moon every year, yet it is not every year equally remarkable, but alternately, for a period of nearly

nine years and a half, it is greatest and least; from 1813 to 1815 is the remainder of a period during which the harvest-moon varies most in the time of rising; from 1816 to 1825, includes a period during which the difference is the least.

The principal phenomena of the *tides*, in which the moon is so material an agent, may be thus illustrated.

1. The sea is observed to flow for about six hours from south to north, gradually swelling; after this it seems to rest for a quarter of an hour, and then to ebb, or retire back again from north to south, for six hours more. Then after another pause of about a quarter of an hour, the sea again begins to flow; and so on alternately.

2. The time of a flux and reflux is, on an average, about twelve hours and twenty-five minutes, and twice this time, or twenty-hours and fifty minutes, is the period of a lunar day, or the time between the moon's passing a meridian, and coming to the same point of it again. So that the sea flows as often as the moon passes the meridian, that is, as well when she comes to the arch above the horizon, as when she comes to that below the horizon; and ebbs as often as the moon passes the horizon, both on the eastern and western side.

3. The elevation of the waters on that side of the earth immediately under the moon, somewhat exceeds the elevation of the opposite side, and in all cases the elevation diminishes from the equator to the poles.

4. The sun raises and depresses the sea twice every day, in the same manner as the moon; but the solar influence in this respect is less than that of the moon, in the proportion of 1 to 3.

5. The tides which depend on the actions of the sun and

moon, are not distinguished, but compounded; and thus they form, to appearance, one united tide, which, increasing and decreasing, produces *neap* and *spring* tides.

6. In the syzygies, that is, when the moon is either new or full, the action of both luminaries concur, and the tides are highest; but they are least in the quadratures, or when the lines of their action are ninety degrees apart; for where the water is elevated by the moon, it is depressed by the sun, and *vice versa*. Therefore, while the moon passes from the syzygy to the quadrature, the daily elevations are continually diminished; on the contrary, they are increased, while the moon passes from the quadrature to the syzygy. At the new moon, also, the tides are the greatest, because the sun and moon are not only in the same line, but on the same side of the earth; and at this time the tides of the same day are more different than those at full-moon.

7. The greatest elevations and depressions take place on the second or third day after the new and full moon; and they are the greater, the nearer the luminaries are to the plane of the equator; they are therefore greatest in the syzygies at the time of the equinoxes.

8. The actions of the sun and moon are greater, the nearer these bodies are to the earth; and the greatest tides happen when the sun is a little to the south of the equator; but this does not happen regularly every year, because some variation may arise from the situation of the moon's orbit, and the distance of the syzygy from the equinox.

9. As the mean force of the moon to move the sea, is to that of the sun nearly as 3 to 1; if the action of the sun alone would produce a tide of two feet, which it is said to do, then that of the moon will be six feet; hence, the

spring-tides will be eight feet, and the neap-tides four feet.

We have seen that the waters of the ocean must rise at the same time at that part of the ocean which is immediately under the moon, and at the opposite point. Consequently, at ninety degrees from these points on each side, the water must be lowered. In the same manner, the solar action must elevate the waters in that part which is immediately under the sun, and at the part diametrically opposite. Combining the two actions, we shall find that the elevation of the water at the same place must be subject to some variations, both with respect to quantity and time, according as the solar and lunar actions are combined, or according as these forces act differently, or against each other. In general, in conjunctions and oppositions of the sun and moon, their forces are combined. In conjunctions, these bodies act on the same meridian; and in opposition, they still act in the same line, and each raises the water on that side which is immediately under it. In the quadratures, on the contrary, the water which is elevated by the sun, is depressed by the moon's attraction, for the moon is then ninety degrees from the sun. This, then, is the time of the lowest, or neap-tides; and the highest, or spring-tides, happen at new and full moon, when the two luminaries are in conjunction, or opposition. In the course of every day there are two tides, which depend upon the action of the sun, as in every lunar day there are two, which depend on that of the moon; all follow, however, the same laws. The effect of the sun, as has been stated, is, however, much feebler than that of the moon; as the mass of the sun is much greater than that of the earth and the moon together, yet its immense distance lessens its force most materially.

In general, the nearer the moon happens to be to the earth, the greater is its attraction; and the same may be said of the sun. Laying aside, for the present, the action of the sun on the ocean, the highest tide would be at the moment when the moon passed the meridian, if the waters had not, like all other bodies in motion, a *vis inertiæ*, by which they are inclined to retain the impression they have received. But this force must necessarily produce two effects. It must retard the time of high water, and it must in general diminish the height of the tide. As a proof, let us for a moment suppose the earth at rest, and the moon above it in a certain point. Abstracting, then, the action of the sun, the force of which upon the tides is much less than that of the moon, the water would unquestionably rise in that part which was under the moon. Let us suppose again that the earth turns upon its axis, on one side it turns very rapidly as to the motion of the moon; and on the other, the water which has been raised by the moon, and which turns with the earth, endeavours (if we may use the expression) to preserve by its *vis inertiæ*, the elevation which it has acquired, though in withdrawing from the moon, it loses somewhat of that elevation. Thus, the water carried forward by the motion of the earth on its axis, will be elevated more to the east of the moon than it would have been without this motion; yet it will at the same time be less elevated than it would have been directly under the moon, had the earth continued immovable. The motion of the earth on its own axis, then, has in general a tendency to retard the time of high water, and to lessen its elevation. Both after the flux and reflux, the ocean continues some time quiescent, neither disposed to rise or fall;

because the waters have a tendency to preserve the state of rest and equilibrium in which they are at the flood and ebb tide; and because the motion of the earth, displacing the waters with relation to the moon, lessens the intensity of the action of that luminary. These two efforts counterbalance each other for some moments. We must add also, that the attraction of the particles of the fluid to each other, and obstacles of different kinds, which must retard their motion, prevent them from passing all at once from the tide of flood to that of ebb. The moon passes above the eastern parts of the globe before the western. The flood-tide, therefore, always proceeds in this direction.

From the lightness of the air, its freedom of motion, and its greater nearness to the moon than the ocean, it may be supposed that there are aërial tides of great elevation; but experience seems to contradict this supposition when we find that there are no changes of the barometer satisfactorily indicating this to be the case. A little consideration, however, will show, that such a change of the barometer is not to be expected. By the preceding theory of the tides, it appears that water is higher immediately under the moon, and at the same time to the antipodes of the point immediately under her, that is, at those two places on the earth where her attraction is greatest and least. Now, though the water is higher at these two points than elsewhere, yet it does not follow that the water, from its increased quantity, presses with a proportionably greater weight on the bottom of the ocean than before it was thus raised up, because the moon's attraction has diminished that tendency to the centre of the earth, which constitutes the weight of bodies. Hence we may suppose, that though the moon draws up the atmosphere to a great

height, yet a higher column of mercury is not supported through this circumstance, because the actual weight of the atmosphere remains but little affected.

The motion of the planetary bodies by intercepting the sun's rays, occasionally produces an eclipse of that luminary.*

With reference to the phenomena of *eclipses*, it may be observed that new moon is that situation of the earth's satellite, in which it has exactly the same longitude as the sun. This phase may take place at any part of the lunar orbit, either in the nodes, or any distance from them. In the first case, she will appear to pass over the disc of the sun ; but if at the conjunction, or time of the new moon, she should be at some distance from the node, as is usually the case, she will be invisible to us; but were she visible at this time, we should see her directly over, or under the sun; and the distance would be the greater, the farther the moon was from the node: but this distance never could much exceed 5°, or the angle expressing the inclination of the two orbits.

Full moon is that position of the moon when her longi-

* The words *transit*, *occultation*, and *eclipse*, are all employed to designate the same general phenomenon, of one heavenly body being lost sight of, either wholly or in part, by the interposition of another ; but they are not used indiscriminately. The word *transit* denotes the passage of the inferior planets, Venus and Mercury, over the sun's disc ; *occultation*, the disappearance of the stars or planets by the interposition of the moon ; and *eclipse*, 1st, to the obscuration of the moon, when this luminary falls into the earth's shadow, called an *eclipse of the moon* ; 2nd, to the obscuration of the sun, when the earth falls into the moon's shadow, called an *eclipse of the sun* ; and 3d, to the obscuration of the satellites of any of the planets, by their coming within the shadows of their respective primaries. One of the two first of these three phenomena is always meant when the word eclipse is used alone.

tude differs exactly half a circle from that of the sun; that is, its longitude is the same as the longitude of the centre of the earth's shadow, if we suppose it extended till it meet the ecliptic. This phase of the moon may take place likewise in any part of her orbit; she may therefore be above, below, or in the centre of the earth's shadow; in which latter case, being deprived of the light of the sun, by the interposition of the earth, she will be eclipsed.

When the moon passes the conjunction, or becomes new, near to the node, she eclipses the sun, and when she is full, or in opposition, in similar circumstances, she herself enters the earth's shabow. The earth's shadow consists of two parts; the true shadow, within which none of the sun's surface is visible, and the penumbra, which is deprived of a part only of the sun's light; the true shadow forms a cone terminating in a point, at a little more than 3½ times the mean distance of the moon; the penumbra, on the contrary, constitutes, together with the shadow, a portion of a cone diverging from the earth without limit; but the only effect of this imperfect shadow is, that it causes the beginning of a lunar eclipse to be incapable of very precise determination; for the limit of the darkened part of the moon, as it appears in the progress of the eclipse, is that of the true shadow, very little enlarged by the penumbra. The true shadow, where the moon crosses it, is about 80 minutes in diameter, as seen from the earth, while the moon herself is only 30. This shadow is not, however, wholly deprived of the sun's light; for the atmospheric refraction inflects the light passing nearest to the earth, in an angle of 66 minutes, and causes a great part of the shadow to be filled with light of a ruddy hue, by means of which the moon remains still visible to us, the cone of total darkness extending to somewhat less than two-thirds of the

moon's distance. But it has sometimes happened, probably from the effects of clouds occupying the greatest part of our atmosphere, that the moon has totally disappeared.

When the sun is eclipsed, it depends on the situation of the earth and moon in their orbits, whether the sun or moon subtends the greatest angle as seen from the earth; since at their mean distances, their apparent diameters are each about half a degree. If the sun's apparent diameter is the greater, the eclipse, when the centres coincide, must be annular, the margin of the sun's disc being still visible in the form of a ring: when the moon's apparent diameter is greater than the sun's, the eclipse, if central, becomes total; but still a ring of pale light is seen round the disc, which has been attributed to the effect of the sun's atmosphere, since that of the moon is probably too inconsiderable to produce the appearance: a red streak is also sometimes observed at the margin, before the actual emersion of the sun. The degree of darkness depends on the situation of the place of observation within the shadow, on account of the greater or less illumination of the atmosphere within view: sometimes a considerable number of stars may be seen during a total eclipse of the sun.

To complete the above view of the solar system, it will be necessary now to examine another class of bodies, differing very considerably in their arrangement from the planets. These are the *comets*: they generally appear attended by a nebulous light, either surrounding them as a comma, or stretched out to a considerable length as a tail; and they sometimes seem to consist of such light only. Their orbits are so eccentric, that in their remoter situations, the comets are no longer visible to us, although at other times they approach much nearer to the sun than any of the planets: for the comet of 1680, when in its peri-

helion, was at the distance of only one-sixth of the sun's diameter from its surface. Their tails are often of great extent, appearing as a faint light, directed always towards a point nearly opposite to the sun: it is quite uncertain of what substance they consist; and it is difficult to determine which of the conjectures respecting them can be considered as the least improbable: it is possible that, on account of the intense cold to which the comets are subjected in the greatest part of their revolutions, some substances, more light than any thing we can imagine on the earth, may be retained by them in a liquid, or even in a solid form, until they are disengaged by the effect of the sun's heat. But we are still equally at a loss to explain the rapidity of their ascent; for the buoyancy of the sun's atmosphere cannot possibly be supposed to be adequate to the effect; and on the whole, there is, perhaps, reason to believe that the appearances are derived from some cause, bearing a considerable analogy to the fluid supposed to be concerned in the effects of electricity. It is probable that the density of the nucleus, or the body of the comet itself, is comparatively small, and its attraction for the tail consequently weak, so that it has little tendency to reduce the tail, even if it consists of a material substance, to a spherical form; for since some comets have no visible nucleus at all, there is no difficulty in supposing the nucleus, when present, to be of a very moderate density, and perhaps to consist of the same kind of substance as constitutes the tail, or comma, in a state of somewhat greater condensation. If, therefore, it should ever happen to a planet to fall exactly in the way of a comet, of which there is but very little probability, it is to be supposed that the inconvenience suffered by the inhabitants of the planet might be merely temporary and local: the chances are, however, much greater, that a comet

might interfere in such a manner with a planet, as to deflect it a little from its course, and retire again without coming actually into contact with it.

The number of comets is very much greater than that of the planets which move in the vicinity of the sun. From the reports of former historians, as well as from the observations of late years, it is ascertained that more than four hundred and fifty have been seen previous to the year 1771; and when the attention of astronomers was called to this subject, by the expectation of the return of the comet of 1759, no fewer than seven were observed in the course of as many years. From this circumstance, and the probability that all the comets recorded in ancient authors, were of considerable apparent magnitude, while the smaller were overlooked; it is reasonable to conclude that the number of comets is considerably beyond any estimation that might be made from the observations we now possess. But the number of comets whose orbits are settled with sufficient accuracy to ascertain their identity when they may appear again, is no more than fifty-nine, reckoning as late as the year 1771. The orbits of most of these are inclined to the plane of the ecliptic in large angles, and the greater number of them approached nearer the sun than the earth ever does. Their motions in the heavens are not at all in the order of the signs, or direct, like those of the planets; but the number whose motion is retrograde, is nearly equal to that of those whose motion is direct.

The analogy between the periodical time of the planets, and their distances from the sun, discovered by Kepler, takes place also in the comets. Hence, the mean distance of a comet from the sun may be found by comparing its period with the time of the earth's revolution round the

sun : thus, the period of the comet that appeared in 1531, 1607, 1682, and 1759, being about seventy-six years, its mean distance is found by this proportion : as the square of one year, the earth's periodical time, is to 5776 the square of 76, the comet's periodical time; so is 1,000,000 the cube of 100, the earth's mean distance from the sun, to 5,776,000,000 the cube of the comet's mean distance, the cube root of which is 1794, the mean distance itself, in such parts as the mean distance of the earth contains 100. If the perihelion distance of this comet, 58, be taken from 3588, double the mean distance, we shall have the aphelion distance 3530 of such parts as the distance of the earth contains 100 ; and this is little more than 35 times the distance of the earth from the sun. By a like method, the aphelion distance of the comet of 1680, comes out 138 times the mean distance of the earth from the sun, supposing its period to be 575 years ; so that this comet in its aphelion, goes to more than 14 times the distance from the sun that Saturn does.

Comets, in describing their elliptic orbits round the sun, have been found to be disturbed by the action of the larger planets, Jupiter and Saturn ; but the great eccentricity of their orbits makes it impossible, in the present state of mathematical science, to assign the quantity of that disturbance for an indefinite number of revolutions, though it may be done for a limited portion of time, by considering the orbit as an ellipsis the elements of which are continually changing. This method was suggested by La Grange, and is followed in the Mécanique Céleste. Dr. Halley, when he predicted the return of the comet of 1682, took into consideration the action of Jupiter, and concluded that it would increase the periodic time of the comet a little more than a year ; he therefore fixed the

time of the reappearance to the end of the year 1758, or the beginning of 1759. He professed, however, to have made this calculation hastily, or, as he expresses it, *levi calamo.*—(Synopsis of the Astronomy of Comets.)

The effects both of Jupiter and Saturn, on the return of the same comet, were afterwards calculated more accurately by Clairaut, who found that it would be retarded 511 days by the action of the former planet, and 100 by the action of the latter; in consequence of which, the return of the comet to its perihelion would be on the 15th of April, 1759. He admitted, at the same time, that he might be out a month in his calculation. The comet actually reached its perihelion on the 13th of March, just thirty-three days earlier than was predicted; affording, in this way, a very striking verification of the theory of gravity, and the calculation of disturbing forces. The same comet may be expected again about the year 1835.

In some instances, the effects which the planets produce on the motion of comets, are far more considerable than in this example. A comet which was observed in 1770, had a motion which could not be reconciled to a parabolic orbit; but which could be represented by an elliptic orbit of no great eccentricity, in which it revolved in the space of five years and eight months. This comet, however, which had never been seen in any former revolution, has not been seen in any subsequent one. On tracing the path of this comet, Mr. Burkhardt found that, between the years 1767 and 1770, it had come very near to Jupiter, and had done so again in 1779. He therefore conjectured, that the action of Jupiter may have so altered the original orbit, as to render the comet for a time visible from the earth; and that the same cause may have so changed it, after one revolution, as to restore the comet to the same

region in which it had formerly moved. This, if a true conjecture, is the greatest instance of disturbance which has yet been discovered among the bodies of our system, and furnishes a very happy as well as an unexpected confirmation of the theory of gravity.

Though the comets are so much disturbed by the action of the planets, yet it does not appear that their re-action produces any sensible effect. The comet of 1770 came so near to the earth as to have its periodical return accelerated by two days; two hundred and forty-six, according to La Place; and if it had been equal in mass to the earth, it would have augmented the length of the year by not less than two hours and forty-eight minutes. It is certain that no such augmentation took place, and therefore that the disturbing force by which the comet diminished the gravity of the earth is insensible, and the mass of the comet, therefore, less than 1-500th of the mass of the earth. The same comet also passed through the middle of the satellites of Jupiter. Hence, it is reasonable to conclude, that no material, or even sensible alteration, has ever been produced in our system by the action of a comet.

M. Fatio has suggested that some of the comets have their nodes so very near the annual orbit of the earth, that if the earth should happen to be found in that part next the node, at the time of a comet's passing by, as the apparent motion of the comet will be incredibly swift, so its parallax will become very sensible; and the proportion thereof to that of the sun will be given; whence such transits of comets will afford the best means of determining the distance of the earth and sun.

The comet of 1472 had a parallax above twenty times greater than the sun's: and if that of 1618 had come down in the beginning of March to its descending node, it

would have been much nearer the earth, and its parallax much more obvious. But, hitherto, none has threatened the earth with a nearer approach than that of 1680; for, by calculation, Dr. Halley found that on the 11th of November, that comet was not above one semi-diameter from the earth, to the northward of the earth's path; at which time, had the earth been in that part of its orbit, the comet would have had a parallax equal to that of the moon.

If the earth had been at this time in that part of her orbit nearest to that node of the comet, through which it passed, their mutual gravitation must have caused a change in the plane of the orbit of the earth, and in the length of our year. Dr. Halley adds, that if so large a body, with so rapid a motion as that of this comet near its perihelion, were to strike against our earth, the shock might reduce this beautiful frame to its original chaos.

It would be a waste of time to detail the various wild and extravagant opinions which have been entertained respecting these interesting bodies. During the ages of barbarism and superstition, they were regarded as the harbingers of awful convulsions, both in the political and in the physical world. Wars, pestilence, and famine, the dethronement of kings, the fall of nations, and the more alarming convulsions of the globe, were the dreadful evils which they presented to the diseased and terrified imaginations of men. As the light of knowledge dissipated these gloomy apprehensions, the absurdities of vague speculation supplied their place, and all the ingenuity of conjecture was exhausted in assigning some rational office to these wandering planets. Even at the beginning of the eighteenth century, the friend and companion of Newton regarded them as the abode of the damned. Anxious to know

more than what is revealed, the fancy of speculative theologians strove to discover the frightful regions in which vice was to suffer its merited punishment; and the interior caverns of the earth had, in general been regarded as the awful prison-house in which the Almighty was to dispense the severities of justice. Mr. Whiston, however, outstripped all his predecessors in fertility of invention. He pretended, not only to fix the residence of the damned, but also the nature of their punishment. Wheeled from the remotest limits of the system, the chilling regions of darkness and cold, the comet wafted them into the very vicinity of the sun; and thus alternately hurried its wretched tenants to the terrifying extremes of intolerable cold and devouring fire.

By other astronomers, comets were destined for more scientific purposes. They were supposed to convey back to the planets, the electric fluid which is constantly dissipating, or to supply the sun with the fuel which it perpetually consumes. They have been regarded, also, as the cause of the deluge. The transient effect of a comet passing near the earth, could scarcely amount to any great convulsion; but if the earth were really to receive a shock from one of these bodies, the consequences, as La Place has shown, would be awful. A new direction would be given to its rotatory motion, and the globe would revolve round a new axis. The seas, forsaking their ancient beds, would be hurried by their centrifugal force to the new equatorial regions; islands and continents, the abode of men and animals, would be covered with the universal rush of the waters to the new equator, and every vestige of human industry and genius at once destroyed.

Proceeding onward, to the more distant regions of space,

we come to the *fixed stars.* Prior to a notice of their classification, however, a few preliminary remarks will best explain their nature and arrangement.

The fixed stars are farther distant from the earth than the farthest of the planets; as we frequently find the fixed stars hid behind the most distant of those bodies; and they are supposed to have no parallax, which the planets have. It is inferred that the fixed stars are greater than our earth; for if that was not the case, they could not be visible at such an immense distance.

It is evident also, that the fixed stars shine with their own light; for they are much farther from the sun than the remotest planet, and appear much smaller; but since, notwithstanding this, they are found to shine much brighter than such planet, it is evident they cannot borrow their light from the same source.

Astronomers divide the heavens into three regions; a northern and a southern hemisphere, and the zodiac. Stars of various magnitudes are seen in all these regions, and are classed into what are called constellations, or systems of stars, according as they lie near one another, so as to occupy those spaces which the figures of different sorts of animals would take up, if they were delineated on what appears to be the concave surface of the heavens. Those stars which the ancients could not bring into any particular constellation, they called unformed stars, but most of these are comprehended in the new constellations of the moderns.

This mode of dividing the stars into different constellations, serves to arrange them in such a manner that any particular star may be readily found in the heavens by means of a celestial globe, on which the constellations are so delineated as to put the most remarkable stars into

those parts of the figures, which may be most easily pointed out. This may be illustrated by a reference to the classification already alluded to.

CONSTELLATIONS OF THE ZODIAC.

Constellations.	No. of Stars.	Principal stars and their magnitudes.	
Aries	66		
Taurus	140	Aldebaran	1
Gemini	85	Castor 1, Pollux	2
Cancer	83		
Leo	95	Regulus	1
Virgo	110	Spica Virginis	1
Libra	51	Zubenich Meli	2
Scorpio	44	Antares	1
Sagittarius	69		
Capricornus	51		
Aquarius	108	Scheat	3
Pisces	112		

CONSTELLATIONS ON THE NORTH SIDE OF THE ZODIAC.

Ursa Minor	24	Stella Polous	2
Ursa Major	87	Dubhe	1
Cassiopeia	55		
Perseus	59	Algenib	2
Auriga	56	Capella	1
Bootes	54	Arcturus	1
Draco	60	Rastaben	2
Cepheus	35	Alderamin	3
Canes Venatici, viz. Asterion and Chara	25		
Cor Caroli	3		
Triangulum	16		
Triangulum Minus	5		
Musca	6		
Lynx	44		
Leo Minor	24		
Coma Berenicis	40		
Camelopardalus	58		
Mons Mœnalus	11		

Constellations.	No. of Stars.	Principal stars and their magnitudes.	
Corona Borealis	21		
Serpens	50		
Scutum Sobieski	8		
Hercules, cum Ramo et Cerbero	113	Ras Algethi	3
Serpentarius sive Ophuichus	67	Ras Alhagus	2
Taurus Poniatowski	7		
Lyra	22	Vega	1
Vulpecula et Anser	37		
Sagitta	18		
Aquila	40	Altair	1
Delphinus	18		
Cygnus	73	Deneb Adige	1
Equulus	10		
Lacerta	16		
Pegasus	85	Markab	2
Andromeda	66	Almaach	2

CONSTELLATIONS ON THE SOUTH SIDE OF THE ZODIAC.

Phœnix	13		
Officina sculptoria	12		
Eridanus	76	Acherner	1
Hydrus	10		
Cetus.	80	Menekar	2
Fornax Chemica	14		
Horologium	12		
Reticulus Rhomboidalis	10		
Xiphias	7		
Cela Praxitelis	16		
Lepus	19		
Columba Noachi	10		
Orion	78	Betelgeux	1
Argo Navis	50	Canopus	1
Canis Major	30	Sirius	1
Equuleus Pictorius	8		
Monoceros	31		
Canis Minor	14	Procyon	1
Chamaeleon	10		

Constellations.	No. of Stars.	Principal stars and their magnitudes.	
Pyxis Nautica	4		
Piscis Volans	8		
Hydra	60	Cor Hydræ	1
Sextans	4		
Robur Carolinum	12		
Machina Pneumatica	3		
Crater	11	Alkes	3
Corvus	9	Algorab	3
Crux	6	Crucis	1
Musca	4		
Apus	11		
Circinus	4		
Centaurus	36		
Lupus	24		
Quadra Euclidis	12		
Triangulum Australe	5		
Ara	9		
Telescopium	9		
Corona Australis	12		
Pavo	14		
Indus	12		
Microscopium	10		
Octans Hadleianus	43		
Grus	14		
Toucan	9		
Piscis Australis	20	Tomachaut	

The stars vary very materially in their apparent magnitude and number at different periods of time.

The first new star that we have any good account of, was discovered by Cornelius Gemma, in 1572, in the chair of Cassiopeia. It surpassed Sirius in brightness and magnitude; and was seen for sixteen months successively. At first, it appeared larger than Jupiter, and then it gradually diminished both in magnitude and lustre, until 1573, when it became invisible.

On the 13th of August, 1596, David Fabricius observ-

ed the Stella Mira, in the neck of the whale; which has since appeared and disappeared periodically.

In the year 1600, William Jansenius discovered a changeable star in the neck of the swan; which, in time, became so small as to be thought to disappear entirely; till the year 1657, when it recovered its former lustre and magnitude.

In the year 1604, Kepler and several of his friends saw a new star near the heel of the right foot of Serpentarius, so bright, that it exceeded any thing they had ever seen before; and they state, that it was every moment changing into some of the colours of the rainbow, except when it was near the horizon, at which time it was generally white. It surpassed Jupiter in magnitude. It disappeared between October 1605, and the February following, and has not been seen since that time.

In July 1670, Hevelius discovered a new star, which was scarcely perceptible in October. In April following, it still retained its lustre, but wholly disappeared in August. In March 1672, it was seen again, but very small; and has not been visible since. It may be proper to add, that the star Algol, in the space of rather more than two days, changes from the second to the fourth magnitude.

M. Maupertuis, in his Dissertation on the Figures of the Celestial Bodies, is of opinion, that some stars, by their prodigious swift rotation on their axes, may not only assume the figures of oblate spheroids, but that by the great centrifugal force arising from such rotations, they may ultimately attain the figure of a mill-stone, or be reduced to flat circular planes, so thin, as to be quite invisible when their edges are turned towards us, as Saturn's ring is in such a position. But when very eccentric planets, or comets, go round any flat star in orbits much inclined to its equator,

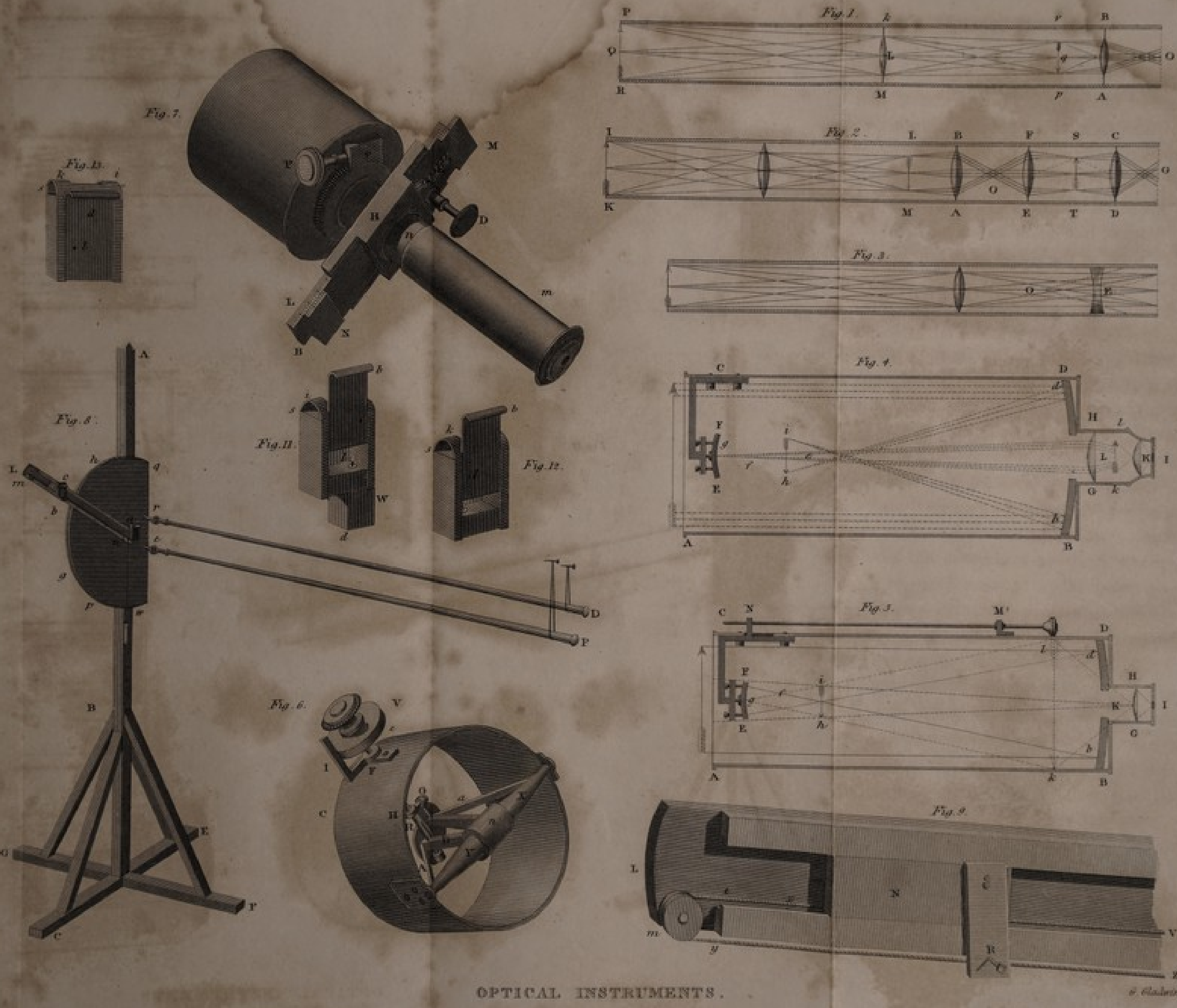
the attraction of the planets, or comets, in their perihelions must alter the inclination of the axes of the star; on which account it will appear more or less large and luminous, as its broad side is more or less towards us. And thus he imagines we may account for the apparent changes of magnitude and lustre of these stars, and likewise for their appearing and disappearing.*

Dr. Herschel's success in examining the milky-way, induced him to turn his telescope to the nebulous parts of the heavens. Most of these yielded to a Newtonian reflector, of twenty feet focal distance, and twelve inches aperture; and he ascertained that they were composed of stars, or at least contained stars, and afforded very strong indications of their consisting of them entirely. "The nebulæ," says he, "are arranged into strata, and run on to a great length, and some of them I have been able to pursue, and to guess pretty well at their form and direction. It is probable enough that they may surround the whole starry sphere of the heavens, not unlike the milky-way, which undoubtedly is nothing but a stratum of fixed stars; and as this immense starry bed is not of equal lustre in every part, nor runs in one straight direction, but is curved, and even divided into two streams along a very considerable portion of it; we may likewise expect the greatest variety in the strata of the cluster of the stars and nebulæ. One of these nebulous beds is so rich, that, in passing through a section of it in the time of only thirty-six minutes, I have

* Hevelius apprehends, that the sun and stars are surrounded with atmospheres, and that, whirling round their axes with great rapidity, they throw off great quantities of matter into those atmospheres; and thus, he adds, it may happen that a star, which, when its atmosphere is clear, shines out with great lustre, may at another time, when it is full of clouds and thick vapours, appear greatly diminished in brightness and magnitude, or even become quite invisible.

detected no less than thirty-one nebulæ, all distinctly visible upon a fine blue sky. Their situation and shape, as well as condition, seem to denote the greatest variety imaginable. In another stratum, or perhaps a different branch of the former, I have often seen double and treble nebulæ variously arranged; large ones, with small seeming attendants; narrow, but much extended lucid nebulæ, or bright dashes; some of the shape of a fan, resembling an electric brush issuing from a lucid point; others of the cometic shape, with a seeming nucleus in the centre, or like cloudy stars, surrounded with a nebulous atmosphere; a different sort of orb again, containing a nebulosity of the milky kind, like that wonderful, inexplicable phenomena about Orionis; while others shine with a fainter mottled kind of light, which denotes their being resolvable into stars."

Plate 1. Vol. 2.



OPTICAL INSTRUMENTS.

Published Jan. 1823 by J. Taylor High Holborn.

G. Gladwin sculp.

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THE END.

LONDON:
PRINTED BY S. AND R. BENTLEY, DORSET STREET.