a strong vertical support fastened to the brass lid of the jar MM (fig. 9), and passes through a slit in the hollow cylinder. This vertical piece is fitted on one side with two V notches, into which the hollow cylinder is pressed by a spring fastened to the lid and bearing half way between the Vs, and on the other side with a rectangular groove in which slides the vertical part of a knee-piece D, in rigid connection with the hollow cylinder. D prevents the cylinder from turning round, but allows it to move vertically; it also carries a fiducial mark running opposite a graduation on one edge of the groove, by means of which whole turns of the screw are read off, fractions being estimated by means of a drum head. The nut AC is arranged in two parts, with a spring between them, to prevent "lost time" and secure steadiness (for details, see paper cited above.)

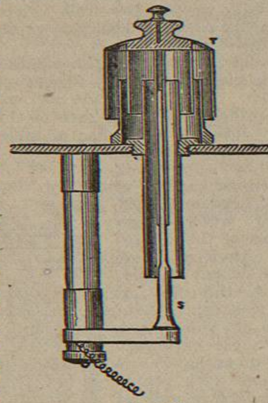

Fig. 11.

The disc G is connected by a spiral of fine platinum wire with the main electrode S, which is insulated from the lid of the box by a glass stem. The arrangement of this electrode is worthy of notice, and will be understood from fig. 11. The dome T is called the umbrella; its use is obvious. A similar, only less perfect, device was noticed in Cavallo's electroscope. The vital parts of the instrument are all inside the coated jar, and therefore removed from disturbing influences; only it is necessary to remove some of the tinfoil opposite the hair in order to see it. The effect of this is counteracted by means of a screen of fine wire.

The use and the theory of the instrument are very simple. The body whose potential is to be measured is connected with the umbrella, which is raised in order to insulate the main electrode from the case, the last being supposed to be in connection with the earth. Let v be the potential of the inner coating of the jar, the disc, and guard plate, V that of the body and G, and d the distance between G and H when the hair is in the sighted position. Then, since F may be regarded as forming part of an infinite plate,[1] if its surface be S its potential energy will be $\frac{1}{2}S\sigma(v - V)$ (see ELECTRICITY, p. 34), *i.e.*,

$$\frac{S(v-V)^2}{8\pi d}.$$

Hence the attraction f on F will be given by

$$f=\frac{S(v-V)^2}{8\pi d^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).^1$$

Here f is a constant, depending on the torsion of the suspending wire of the aluminium balance; hence, A^2 standing for $8\pi f \div S$, *i.e.*, A being a constant depending on the construction of the instrument, we have

$$v - V = Ad \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

If we now depress the umbrella, so as to bring G to the potential of the earth, and work the screw till the hair is again in the sighted portion, we have, d' being the new reading of the screw,

$$v = Ad' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Hence, from (2) and (3),

$$f = A(d' - d) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

We thus get V in terms of A and the *difference* of two screw readings, so that uncertainties of zero reading are eliminated. The value of A must be got by comparison with a standard instrument, if absolute determinations be required.

Thomson's absolute electrometer (fig. 12) is an adaptation of the attracted disc principle for absolute determinations. We give merely an indication of its different parts, referring to Thomson's paper (*l.c.*) for details. B is an attracting disc, which can be moved parallel to itself by a screw of known step ($\frac{1}{50}$ in. or thereby). A is a guard plate, in the centre of which is a circular balance-disc of aluminium suspended on three springs, and connected by a spiral of light platinum wire with A. The disc can be raised or depressed into definite positions by means of a screw (the kinematical arrangements in connection with these screws are similar to that in the portable electrometer). A hair on the disc, an object lens h, a fiducial mark, and an eye lens l enable the observer to tell when this disc is in such a position that its lower surface is plane with lower surface of A. y y are the halves of a box which screens the disc from electric disturbances. An idiostatic guage (consisting of an aluminium lever with guard plate, hair, and lens, as in the portable electrometer), placed over a plate F in connection with the guard plate, enables the observer to tell when the guard plate and the inside coating of the instrument (which forms a Leyden jar as in the portable instrument) are at a certain definite potential. And finally, a small instrument called the "replenisher" enables him to raise or lower the potential of A till this definite potential is reached.

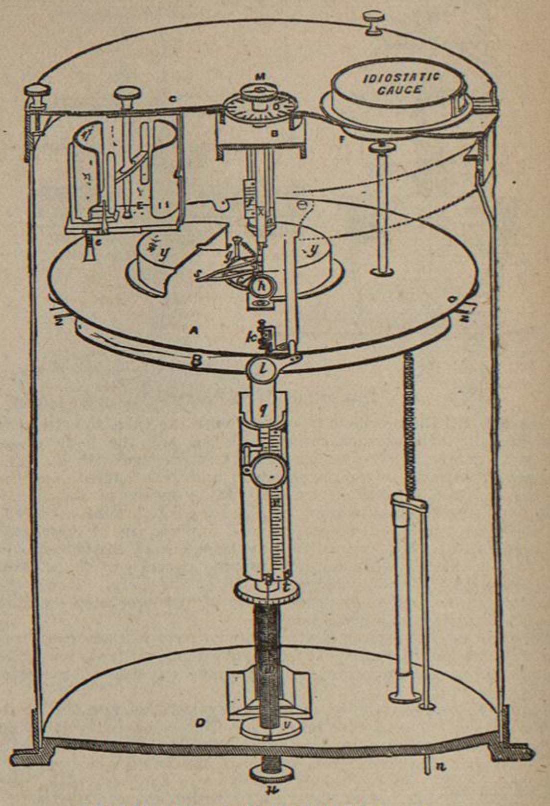

FIG. 12.—Thomson's Absolute Electrometer.

A short description of the replenisher will be in place here. It is represented pretty clearly at E (fig. 12). Two metal shields, in the form of cylindrical segments, are insulated from each other by a piece of ebonite; the left hand one is in connection with the guard plate, the right hand one with the case of the instrument (and therefore with the outer coating of the jar). A vertical shaft, which can be spun round by means of a milled head, carries two metal flies on the ends of a horizontal arm of vulcanite. Two small platinum springs (the front one is seen at e) are arranged so as to touch the flies simultaneously in a certain position just clear of the shields. Let us suppose the left shield along with A to be positively electrified, and the flies to be in contact with the springs; e being close to the left shield, the front fly will be electrified − and the back fly +. Suppose the shaft to revolve against the hands of a watch lying face up on the cover of the electrometer. The front fly carries off its − charge, and, when near the middle of the right shield, comes in contact with a spring connected with the shield. Being thus practically inside a hollow conductor, it gives up its − charge to the shield. At the same time the back fly gives up its + charge to the left shield. The result of one revolution therefore is to increase the + and − charges on the respective shields, or, in other words, to increase the difference of potential between them. By giving the machine a sufficient number of turns, the potential of A may be raised as much as we please; and, by spinning in the opposite direction, the potential can be lowered; so that, once A is charged, it is easy to adjust its potential till the hair of the gauge is in the sighted position.

To work the instrument, the electrode n of the lower plate B is connected with the guard plate to avoid all electrical forces on the balance; the hair of the balance is brought to the sighted position,

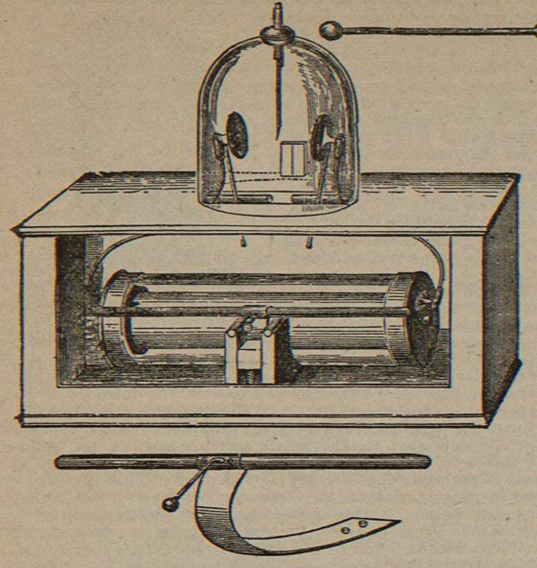

FIG. 13.—Dry Pile Electroscope.

and the upper screw reading taken; then a weight of w grammes is distributed symmetrically on the disc, the balance brought up again by working the screw, and the reading again taken. We thus ascertain how far the weight of w grammes depresses the balance. The weight is now removed, and the balance left at a distance above A equal to that just found. A is now charged, and its potential adjusted till the hair of the gauge indicates that the standard potential v is reached. Let it now be required to measure the difference between the potentials V and V′ of two conductors. Connect first one and then the other with n, and work the lower screw till the hair of the balance is sighted in each case, and let the screw readings reduced to centimetres be d and d'. Then, since the force on the disc in each case is gw, where g is the acceleration produced by gravity in a falling body in centimetres per second, we have by (1)

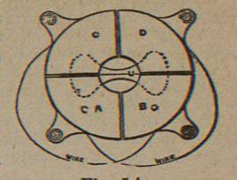

Fig. 14.

$$V - V' = (d' - d)\sqrt{\frac{8\pi gw}{S}} \quad . \quad . \quad . \quad . \quad (5),$$

where S denotes the area of the balance disc, or rather the mean of the areas of the disc and the hole in which it works. We thus get the value of V − V′ in absolute electrostatic C. G. S. units.

Dry pile electroscope.

III. *Symmetrical Electrometers.*—Two instruments fall to be described under this head,—the dry pile electroscope, and Thomson's quadrant electrometer. The idea common to these instruments is to measure differences of potential by means of the motions of an electrified body in a symmetrical field of force. In the dry pile electroscope, a single gold leaf is hung up in the field of force, between the opposite poles of two dry piles, or, in later forms of the instrument, of the same dry pile. The original inventor of this apparatus was Behrens, but it often bears the name of Bohnenberger, who slightly modified its form. Fechner introduced the important improvement of using only one pile, which he removed from the immediate neighbourhood of the suspended leaf. The poles of the pile are connected with two discs of metal, between which the leaf hangs. This arrangement makes it easier to secure perfect symmetry in the electric field, and allows us to vary the sensitiveness of the instrument by placing the metal plates at different distances from the leaf. In order to make the attainment of perfect symmetry still more easy and certain Riess[1] added a metal rod to the apparatus, which can be made to touch the two metal caps of the dry pile simultaneously, and then be removed, leaving the pile symmetrically electrified. This form of the electroscope, with the various improvements, is represented in fig. 13.

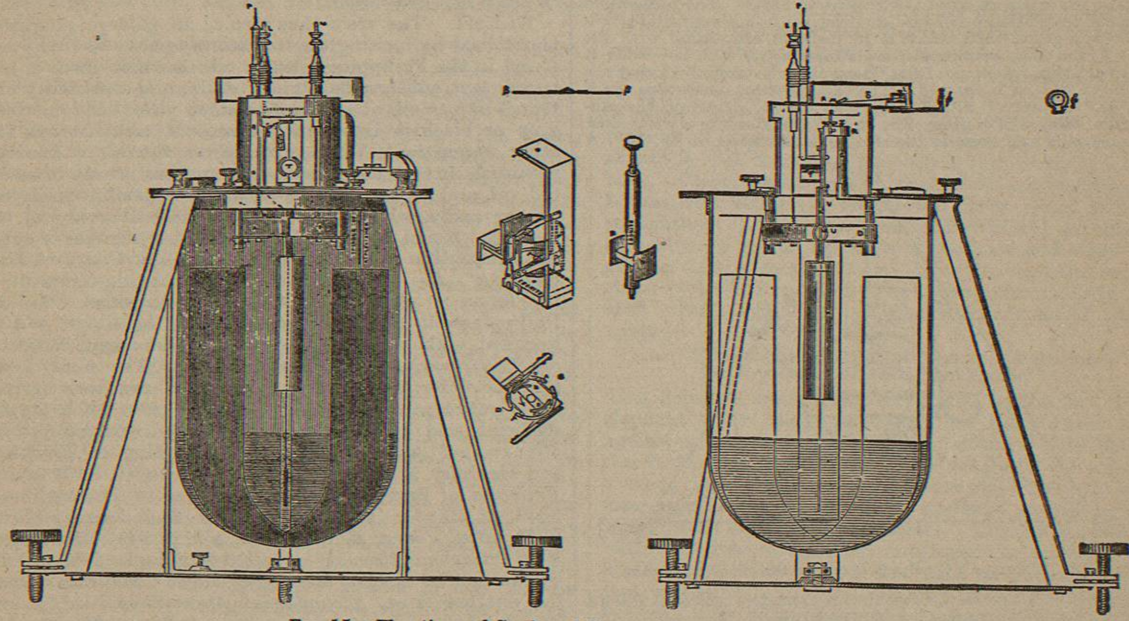

FIG. 15.—Elevation and Section of Thomson's Quadrant Electrometer.

Hankel[2] still further improved the dry pile electroscope by giving a micrometric movement to the plates, by substituting a galvanic battery with a large number of cells for the uncertain and varying dry pile, and by using a microscope with a divided scale to measure the motions of the gold leaf. With these improvements it became an *Electrometer* of great delicacy and considerable range. Some of the

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[1] Those who desire to know the degree of approximation here should consult Maxwell, *Electricity and Magnetism*, vol. i. § 217.

[1] *Reibungselectr.*, § 16.

[2] Mascart, § 272, or *Pogg. Ann.*, 1858.

experiments in which Hankel used it are alluded to in the article ELECTRICITY.

In the quadrant electrometer of Sir Wm. Thomson, which is the most delicate electrometric instrument hitherto invented, the moving body is a horizontal flat needle of aluminium foil, surrounded by a fixed flat cylindrical box (fig. 14), which is divided into four insulated quadrants A, B, C, D. The opposite pairs A, D and B, C are connected by thin platinum wires. The two bodies whose potentials are to be compared are connected with the two pairs of quadrants. If A and B be their potentials, and C the potential of the needle, it may be shown (see Maxwell, *Electricity and Magnetism*, § 219) that the couple tending to turn the needle from A to B is

$$\alpha(A-B)\{C-\tfrac{1}{2}(A+B)\} \quad . \quad . \quad . \quad . \quad (6),$$

where α is a constant depending on the dimensions of the instrument. If C be very great compared with $\tfrac{1}{2}(A+B)$, as it usually is, then the couple is

$$\alpha C(A-B) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

simply; in other words, the couple varies as the difference between the potentials of the quadrants. Some idea of the general distribution of the parts of the actual instrument may be gathered from fig. 15, which gives an elevation and a section of the instrument. The case forms a Leyden jar as usual in Thomson's electrometers; the internal coating in this instance is formed by a quantity of concentrated sulphuric acid, which also keeps the inside of the instrument dry. The quadrants are suspended by glass pillars from the lid of the jar, and one of these pillars is supported on a sliding piece, arranged on strict kinematical principles, so as to be movable in a horizontal direction by means of a micrometer screw Y. This motion is used to adjust the position of the needle, when charged, so that its axis may fall exactly between the quadrants A, C, and B, D. A glass stem C, rising from the lid of the jar into a superstructure called the "lantern," supports a metal piece Z, to which is fastened a metal framework fitted with supports and adjustments for the bifilar suspension of the needle. A fine platinum wire drops from the needle into the sulphuric acid, thus connecting the needle with the inside coating of the jar. This tail wire is also furnished with a vane, which works in the acid and damps the oscillations of the needle. A stout aluminium wire rises from the needle, carries a light concave mirror T, and ends in a cross piece to which are attached the suspension fibres. The aluminium stem and the platinum tail wire are defended from electrical disturbances by a guard tube, which is in metallic connection with the piece Z, and also, by means of a platinum wire, with the acid; it is through this, by means of the "temporary electrode" P, that the inside of the jar is charged. The two principal electrodes are P and M. Connected with Z is a metal disc S, attracting the aluminium balance of a gauge like that of the absolute electrometer. This gauge is well seen in the bird's-eye view given in fig. 16. A replenisher, like that in the absolute electrometer, is fitted to the lid of the jar, and by means of it the potential of the needle can be adjusted till the hair of the guage is in the sighted position.

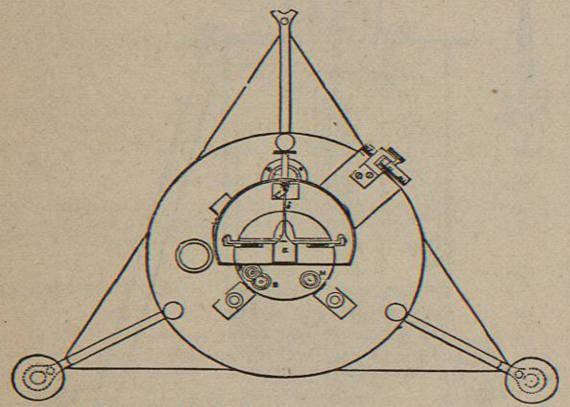

FIG. 16.—Thomson's Quadrant Electrometer—Bird's-eye view.

The deflections of the instrument are read off by means of an image formed by the mirror T on a scale at the distance of a metre or so, the object being a wire which is stretched below the scale in a slit illuminated by a lamp. Within certain limits the deflections are proportional to the deflecting couple, *i.e.*, to the difference between the potentials of the quadrants A, D and B, C; but where this is not so, the instrument can easily be graduated experimentally.

For many purposes, especially in the lecture room, an instrument so complicated as the above is unnecessary and undesirable. simpler form (fig. 17) of quadrant electrometer is now manufacture by Elliot Brothers, and answers most ordinary purposes very well.

Capillary Electrometers.—Electrometers have recently been constructed by taking advantage of the fact that the surface tension of mercury is greatly affected by the hydrogen deposited on it when it is the negative electrode in contact with dilute sulphuric acid (see ELECTROLYSIS, p. 109). A quantity of mercury is placed in the bottom of a test tube, and communicates with a platinum electrode let in through the bottom of the tube; on the mercury is poured dilute sulphuric acid, and into this dips a tube drawn out into a capillary ending. This tube contains mercury down to a certain mark on the capillary part, the remainder being occupied with acid which is continuous with that in the test tube. So long as the mercury in the test tube is simply in metallic connection with that in the upper tube, the position of the mercury in the capillary part is stationary; but if an electromotive force be introduced into the external circuit, acting towards the test tube, then hydrogen is deposited on the small mercury surface, its surface tension increases, and the pressure in the tube must be considerably increased to maintain the mercury at the mark. This increase of pressure is proportional to the electromotive force within certain limits, hence we can use this arrangement as an electrometer.

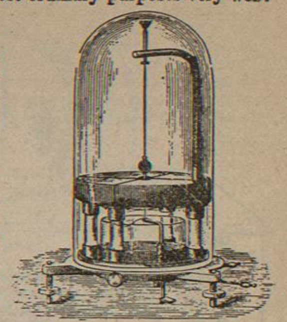

FIG. 17.—Quadrant Electrometer.

Electrometric Measurement.—Several examples of electrometric measurement will be found in the article ELECTRICITY (pp. 18, 37, 38, 42, 46, &c.). We recommend in this connection the study of the sections on atmospheric electricity in Sir Wm. Thomson's *Reprint of Papers on Electricity and Magnetism*, and sections 220 and 229 in Clerk Maxwell's *Electricity and Magnetism*. We have been drawing throughout on Thomson's *Report on Electrometers and Electrometric Measurements*, but it will not be amiss to draw attention to it once more. (G. CH.)

ELEMI. The resin thus termed in modern pharmacy is obtained by incising the trunk of a species of *Canarium* found in the Philippine Islands. It is a soft, more or less translucent, adhesive substance, of granular consistency and fennel-like smell, and colourless when pure, but sometimes grey or blackish from the presence of carbonaceous and other impurities. When exposed to the air it becomes yellowish in tint, and harder. It consists mainly of essential oil, and of an amorphous and a crystalline resin, the former easily soluble in cold, and the latter only in hot alcohol. Elemi is used chiefly in the manufacture of spirit and turpentine varnishes, which it enables to dry without cracking. As a constituent of a stimulating ointment, it has found a place in British pharmacopœias. In the Philippines it is employed for caulking ships, and is kneaded with rice-husks for torches (see Jagor, *Reisen in den Philippinen*, p. 79, Berlin, 1873). The word elemi, like the older term *animi*, appears to have been derived from *enhæmon* (Greek, ἔναιμον), the name of a styptic medicine said by Pliny to contain tears exuded by the olive-tree of Arabia. This tree, according to Flückiger and Hanbury, is probably to be identified with the *Boswellia Frereana* of Birdwood, which flourishes in the neighbourhood of Bunder Marayah, west of Cape Gardafui (see S. B. Miles, *Journ. R. Geog. Soc.*, xlii. p. 64). Mexican or Vera Cruz elemi, formerly imported into England, is afforded by the species *Amyris elemifera*, Royle; Mauritius elemi by another tree, *Colophonia Mauritiana*, D.C.; and Brazilian elemi by several species of *Icica*. For a paper "On the Chemistry of Elemi," see Flückiger, *Year-Book of Pharmacy*, 1874, p. 496.

ELEPHANT (*Elephantidæ*), a family of pachydermatous mammals belonging to the order Proboscidea, containing only a single existing genus and two species—the sole surviving representatives of the entire order. The elephants are characterized by great massiveness of body, constituting

them the largest of living terrestrial mammals, by peculiarities in their dentition, and by the possession of a lengthened proboscis or trunk. The latter organ is a huge prolongation of the nose and upper lip, measuring usually from 6 to 8 feet in length, and almost wholly composed of a mass of muscles, numbering, according to Cuvier, nearly 40,000, and curiously interlaced, so as to produce the greatest diversity of motion. Its extremity contains the two openings of the nostrils by which the elephant breathes when swimming, as it sometimes does, with only the tip of its trunk above the surface, and through which it can fill the channels of its trunk with water, the flexibility of that organ enabling it to pour the liquid into its mouth or to squirt it over the surface of its body. By a peculiar valvular arrangement the water is prevented from penetrating into the bony nostrils. The extremity of the trunk is produced on the upper surface into a finger-like process, and ends beneath in a thick tubercle which acts the part of thumb to the prolongation above, while the whole is exquisitely endowed with the sense of touch, and so forms an organ of prehension comparable in many respects to the human hand. With it the elephant collects its food and drink, discovers the snares that are often set in its path, strikes its antagonist to the ground, and gives vent to its rage in a shrill trumpet-like sound, hence the French name of *trompe* for the proboscis, corrupted in our language into *trunk*. Without it the animal is helpless, being unable even to feed itself; and, as if conscious of the vital importance of this organ, the elephant is exceedingly cautious in using it, preferring when in combat with the tiger to fight with its trunk carried aloft, out of reach of its antagonist's claws. When the trunk is injured the elephant becomes furious with rage and pain, and can no longer be controlled by its rider.

The teeth of the elephant consist of two incisors, or tusks, as they are called, in the upper jaw, and six molars on each side of either jaw. The permanent tusks are preceded by small milk teeth, which, however, give place to their successors before the end of the second year. The tusks, proceeding from a permanent pulp, continue to grow during the elephant's lifetime, and sometimes attain enormous size, examples having been known to weigh from 150 to upwards of 200 ℔ each. They consist almost entirely of ivory—a remarkably fine and elastic form of dentine—and are hollow for a considerable part of their length. They are also deeply imbedded in the skull; thus a tusk, about 8 feet long and 22 inches in girth, was found by Sir Samuel Baker to be imbedded to a depth of 31 inches. The tusks are invariably best developed in the male sex, and are regarded by Darwin as sexual weapons. Their almost vertical position, however, and the inability of the elephant to raise its head above the shoulder, render their use as offensive weapons somewhat difficult; nevertheless they are certainly employed as such in fighting with the tiger, the mode of using them depending, says Darwin, "on their direction and curvature"—thus the elephant has been known to toss a tiger to a distance of 30 feet with its tusks, when these were turned upward and outward, while it seeks to pin its foe to the ground when these organs have the usual downward direction. The tusks are largest in the African species, which feeds principally on the foliage and the succulent roots of trees, and in this species they are often used as levers in uprooting mimosa trees, whose crown of foliage is beyond the reach of the upturned trunk. In Ceylon, on the other hand, where the elephant lives chiefly on grass and herbage, tusks are generally absent in both sexes. The bullets occasionally found imbedded in the solid ivory have evidently been shot into the upper part of the tusk, and, getting lodged in the pulp cavity, have been carried down by the growth of successive layers of ivory into the solid part of the tooth. The molar teeth consist of a series of transverse plates, composed of dentine, and coated with a layer of enamel, the whole bound together by the substance known as *crusta petrosa*, or cement. Each of these materials, possessing a different degree of hardness, wears away at a different rate from the others, and the uneven surface necessary for the proper trituration of the food is thus produced. Although the elephant may be said to have altogether six molars on each side of either jaw, at no time can more than one and a portion of a second be seen. These molars are not deciduous in the ordinary sense, but they grow from behind forward, and as the anterior part of the front molar gets worn away by degrees, its successor is gradually cutting its way through the gum, from which, however, it does not wholly emerge until the tooth in front has almost disappeared. This progression of the molar teeth continues throughout the greater part of the elephant's life, so that it may be said to be always teething. Six of such molars, each composed of a greater number of plates than its predecessor, are said to suffice it for life. The massiveness of the skull, and its height in front, to which the elephant owes something of its sagacious aspect, is due not to the great size of the brain—which is relatively small—but to the enormous development of the bones of the cranium, rendered necessary in order to give attachment to the powerful muscles of the head and trunk. The presence of large air cells, however, in the cranial bones, renders the skull light in proportion to its enormous bulk. The eyes in the elephant are small, and its range of vision, owing to the shortness and slight flexibility of its neck, is somewhat circumscribed; this, however, is of secondary importance to an animal living generally in dense forests, where the prospect is necessarily limited, and in the elephant is compensated for by exceeding keenness in the senses of hearing and smell. Its stomach resembles that of the camel in having a chamber which can be cut off from the proper digestive cavity for the storing of water; this is capable of holding 10 gallons. The contents of this chamber it is able to convey into its trunk, should it wish to indulge its body in the luxury of a shower bath. The elephant is an unwieldy creature, weighing fully 3 tons, and supported on colossal limbs, which from their straightness and apparent want of flexibility—an effect produced by the greater nearness of the knee and elbow to the ground than in most animals—were for centuries supposed either to be jointless, or to have such joints as could not be used. Such evidently was Shakespeare's belief when he wrote—

> "The elephant hath joints, but not for courtesy;
> His legs are for necessity, not flexure."

This delusion was further supported by the fact that the elephant often sleeps standing, its huge body leaning against a tree or rock. In lying down it does not place the hind legs beneath it, as is generally the case, but extends them backwards after the manner of a person kneeling. By this method the elephant can raise its huge weight with little perceptible effort. The feet are furnished with five toes, completely enveloped in a tegumentary cushion, and with four or five nails on each of the front feet, and three or four on the hind ones, according to the species. The skin of the elephant is thick and soft, and of a dark brown colour. With the exception of a few hairs on certain parts of its body, it is naked, although individuals found in the elevated districts of Northern India are said to be more hairy than those inhabiting warmer regions, while the young everywhere, according to Tennent, are at first covered with a woolly fleece, especially about the head and shoulders, approximating in this respect to the mammoth which inhabited the alæarctic region during Pleistocene times. From such facts Darwin regards it as