sun on the materials of the comet, and that of the comet on the nebulous atmosphere by which it was surrounded.

Olbers was driven to consider the repulsive action of the comet on its atmosphere in order to explain the many luminous sectors visible in the comet in question. To this he also ascribed the gradual rise of successive envelopes, so well illustrated subsequently by the comet of Donati.

The energy of electrical repulsion depends upon the amount of surface of the bodies concerned, whereas the attraction of gravity depends upon the masses of the bodies. Small things have more surface in proportion to their masses than large ones, and there will therefore be attraction or repulsion between the sun and the particles composing comets according as the differential effect of the two opposite forces is repulsive or attractive. In the very small particles, the electrical repulsion will be stronger than the attraction due to gravitation, while in the larger particles the two forces may balance each other, or gravitation may preponderate. Only the finest particles composing the head of a comet are therefore repelled to form the tails.

Bessel[1] considerably modified this hypothesis. He considered that the action of the sun on the comet represented a polar force.

M. Faye has more recently held that this repulsive action is due to the radiant energy of the sun, and that it has an intensity inversely as the square of the distance, and proportional to the surface and not to the mass of the moving particles. Its action would therefore be in the inverse ratio of the density of the particles upon which it acted; it would vary with every difference of cometary constitution; it would be inappreciable on the nucleus itself; (the idea being, of course, that the nucleus was a solid body); and it would be most effective in the case of the rarest vapours. The important part of M. Roche's later memoir consists in testing these views of repulsion, to determine whether the forms of comets could be explained by its introduction.

One result is very striking: the tail towards the sun demanded by gravitation alone at once disappears. The limiting surfaces which Roche's calculations demand are so very like some of the surfaces actually observed in the head of a comet, where they can be best seen, that it is suggested that the movement of the particles takes place in the precise direction where they would flow according to M. Roche's mathematical investigations.

Hence we are justified in attributing some cometary phenomena to the flow of matter acting under the influence of attraction and solar repulsion.[2] In concluding his memoir Roche points out (p. 393) that the hypothesis of a repulsive force acting along a radius vector, and varying inversely as the square of the distance, and only acting on matter reduced to a state of great rarefaction, gives figures identical with those observed. We see the germ of the tail is the part of the atmosphere the furthest removed from the sun, and it is easy to explain the enormous development of the emission of cometary particles near perihelion. The existence of a repulsive force which counterbalances the solar attraction M. Roche therefore considers established by his researches.

It must, however, be at once stated that much remains to be done before all the help that M. Roche's work can afford can be

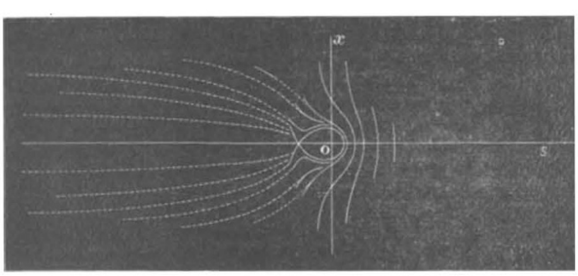

FIG. 26.—M. Roche's theoretical construction of the head of a comet, a repulsive force being taken into account.

utilized, and there is little question that the outflow in the solar direction has not been so entirely abolished as his figures indicate. This, however, may to a certain extent depend upon the fact that the observations of comets have been made at some distance from perihelion. But there may be another reason. If the outflow along the limiting surface is an outflow of solid particles, the solar repulsion will not be effective until collisions have reduced this dust to vapour. We shall still therefore have the quasi-conical surface *turned towards the sun*,[1] though it will be soon destroyed. Many of the phenomena presented by jets and excentric envelopes may be thus caused, and the very complicated phenomena presented by Coggia's comet, and others in which the section of the cone presents the appearance of birds with their wings more or less extended, do not seem opposed to this view.

J. NORMAN LOCKYER.

(*To be continued.*)

[1] Bessel's paper "On the Physical Constitution of Halley's Comet" is printed in the *Connaissance des Temps*, 1840.

[2] See *Annales de l'Observatoire de Paris*, vol. v.

[1] Although this does not figure in Roche's diagrams, Faye gives it in his lectures on the "Forms of Comets."

PRELIMINARY NOTE ON KEELING ATOLL, KNOWN ALSO AS THE COCOS ISLANDS.

MR. JOHN MURRAY, of the *Challenger* Expedition Office, has forwarded to us the following letter, which he has received from Dr. Guppy:—

DEAR MR. MURRAY,—

During my sojourn of nearly ten weeks in these islands, I was able to make a fairly complete examination of them. Here, I can only refer to some of the new features of this atoll which my investigations have disclosed, and must leave the details to be subsequently worked into a general description of the islands. Regarding myself as very fortunate in being able to examine the only atoll visited by Mr. Darwin—the atoll, in fact, which gave rise to the theory of subsidence—I at once set about making observations, without reference to any particular view of the origin of coral-reefs. I examined all the islands and islets, more than twenty in number, making a separate description of each, and reaped the benefit of the fact that this atoll has been occupied for more than half a century by residents interested in their surroundings The result has been to convince me that several important characters of these islands escaped the attention of Mr. Darwin, partly owing to his limited stay, partly also due to his necessarily defective information of the past changes in the atoll. The features, in fact, that escaped his notice, throw considerable light on the mode of origin of these lagoon islands, and give no support to the theory of subsidence.

In the first place, I have ascertained that Keeling Atoll consists essentially of a ring of horse-shoe or crescentic islands inclosing a lagoon and presenting their convexities seaward. The crescentic form is possessed in varying degrees by different islands: some of the smaller ones are perfect horse-shoe atollons, and inclose a shallow lagoonlet; others, again, exhibit only a semi-crescentic form; whilst the larger islands have been produced by the union of several islands of this shape. The whole land-surface, however, is subject to continual change. The extremities of islands are often being gradually swept away or extended. Some islands are breached during heavy gales, others are joined, so that by the repetition of these changes the island in the course of time loses its original form. Hence it is that, although the crescent is the primitive shape of each island this structure is partly disguised in the case of some of the larger islands by the union of several of smaller size. The Admiralty chart gives but an imperfect idea of the true shape of the islands; but, notwithstanding, its inspection will prove very instructive.

In truth, Keeling Atoll exhibits in an incomplete manner the features of the large compound atoll of the Maldive Group. If it was considerably larger and possessed a less protected lagoon, so that open-sea conditions prevailed in its interior, it would have all the features of a compound Maldive atoll—that is, an atoll consisting of a circle of small atolls or atollons. In its original condition, however, it was an atoll consisting of a circle of crescentic islands. Such it is essentially now, but extensive changes have often partly disguised this feature.

Before proceeding to explain the origin of the incompleted compound atoll of the Keeling Islands, it will be necessary to dwell on the exaggerated prevailing notion of an atoll. This kind of coral-reef is usually described as a circular reef inclosing a deep basin or lagoon; but this description only applies to very small atolls less than a mile across. By drawing a section on a true scale of an atoll of average size, like Keeling Atoll, it will at once become apparent that such a description gives a very misleading idea of the real nature of this class of reef. A section of Keeling Atoll, drawn from the 1000-fathom line on a true scale of an inch to the mile, and intended to illustrate a breadth of six miles, and a depth in the lagoon of 9 or 10 fathoms, would represent to the naked eye a flat-topped mountain, the depth of the so-called basin on the summit being merely represented by a slight central depression of about 1/100 of an inch. If the lagoon possessed a depth of 30 fathoms, the inclosed basin so-called would only be indicated in this section by a central depression of about 3/100 of an inch. So trifling a proportion does the depth of an atoll of ordinary size bear to the breadth, that such a reef can only be accurately described as possessing a broad level surface, with very slightly raised margins. A correct model of Keeling Atoll would at once convey a just idea of the true relative dimensions of a reef of this class. The lagoon would be there only represented by a film of water occupying a slight hollow in the level mountain-top. By thus grasping these facts, we at once perceive that by reason of our failing to view an atoll in relation to its surroundings, and through our misconceptions of its dimensions, we have been led to introduce a great cause to explain a very small effect. The slightly raised margins can be easily explained by causes dwelt upon by Murray, Agassiz, and others. No movement of the earth's crust is necessary for this purpose. The mode of growth of corals, the action of the waves, and the influence of the currents, afford agencies quite sufficient to produce the slightly raised margins of an atoll.

The development of the islands of an atoll into horse-shoe or crescentic islands, as in the instance of Keeling Atoll, or into perfect small atolls or atollons, as in the Maldive Group, is a subsequent process to be shortly explained. These small atolls and horse-shoe islands only assume their characteristic forms *after the island has been thrown up by the waves*. Such was the conclusion I arrived at concerning small atolls and crescent-shaped coral islands in the Solomon Islands (Proc. Roy. Soc. Edin., 1885–86, p. 900); and as just stated I have formed the same opinion concerning the islands of Keeling Atoll. There is in the first place the island from which "lateral extensions grow out on either side so as to ultimately form a horse-shoe reef," which itself under favourable conditions may develop into a small atoll. In the Solomon Islands I imperfectly grasped the method by which these changes in form are effected. In Keeling Atoll I saw the process in operation, and I arrived at the conclusion that wherever a coral island stems a constant surface-current, the sand produced by the breakers on the outer edge of the reef will mostly be deposited by the current on each side of the island in the form of two lateral banks or extensions, giving the island ultimately a horse-shoe form, with the convexity presented against the current. The process may be aptly compared to the formation of a V-shaped ridge of sand when a stake or some other obstacle is placed in a river-bed. The stake represents the original small island thrown up by the waves. The V-shaped ridge of sand represents the arms of the horse-shoe island which are subsequently formed. The back-wash or eddy may in the river-bed join the arms of the V-shaped ridge of sand. In a similar manner a horse-shoe island may have a bank thrown up across the mouth, and thus a small atoll is formed. Such is the process, imperfectly disclosed to me in the Solomon Islands, that I found illustrated in all its stages in Keeling Atoll. In the Keeling Islands, however, it was necessary to satisfy myself of the reality of the agencies chiefly concerned in this process. For instance, I had to ascertain how and to what extent the surface-currents acted, and to discover the source of the sand. It was also necessary to observe what changes in the form and extent of the islands had occurred in the experience of the residents during the half-century of their occupation.

The westerly equatorial drift or south-east trade current, striking the south-east angle of the atoll, there divides and sweeps around the coasts, the two branches meeting and forming an eddy off the north-west island, a spot where drift timbers are often detained and stranded after having been swept around half the circumference of the atoll. Advantage of this current is taken by the proprietor of the islands, who directs his men to mark any logs of valuable timber thrown up on the weather or south-east coast, and then to launch them again outside the breakers. In this way huge logs are transported by the current to any particular island. If left alone, the logs, whether drifted around the north or south side of the atoll, arrive finally in the eddy off the north-west angle. This current finds its way into the lagoon through the several passages between the islands its rate there varying usually from half a knot to two knots in the hour. Only rarely is there any check to the inflow of water through the passages, as, for instance, during north-west gales.

The current in these passages carries daily a large amount of sand into the lagoon. I discovered this accidentally whilst using the tow-net for catching the pelagic animals brought in by the current. The source of this sand is the weather edge of the reef on the outer side of the islands, where the breakers are unceasingly at work in keeping up the supply. After several measurements under varying conditions of current, tide, and depth, I estimated that during every day of ordinary weather at least 10 tons of sand are carried through the passages into the lagoon. During gales and cyclones this amount is greatly increased; and probably the estimate for an ordinary year would not be less than 5000 tons. The bulk of this sand is deposited by the current near the inner mouths of the passages and on the margins of the lagoon, where it goes to extend the islands in the form of banks stretching into the lagoon. In this manner an island obtains a horse-shoe shape, just as the V-shaped ridge is formed by placing a stake in a river-bed. The first stage is represented by an island with two sand-banks extending into the lagoon, one from each extremity. The second stage is that in which the island has attained a semi-crescentic shape by the encroachment of its vegetation on the newly formed banks. In the course of time, when the vegetation of the island has entirely occupied the banks, the third stage, that of the horse-shoe island, is reached. In some instances, there is yet a further stage, when during a long continuance of westerly winds another bank is thrown up across the mouth of the horse-shoe, and a small atoll with a shallow lagoonlet is produced. Thus the currents are the principal agencies in forming the horse-shoe islands of Keeling Atoll. In large atolls, where more open-sea conditions prevail in the lagoon, and especially where, as in the Maldives, there are two opposite sets of winds and surface-currents, each prevailing in its own half of the year, we should expect to find the horse-shoe island replaced by an atollon. Keeling Atoll, however, lies for eleven months out of the twelve within the region of the constant trade-wind and westerly drift current, so that the situation is only one favouring the formation of horse-shoe islands facing to the southward and eastward. The protected character of the lagoon, also, is not a condition that would assist the growth of a circular island or atollon.

Another important feature in this atoll is to be found in the existence outside the seaward edge of the present reef of a series of submerged lines of growing corals separated from each other by sandy intervals. Unfortunately, I was not able to examine these to the extent I desired, since it can only be satisfactorily done later in the year, when the sea is sufficiently smooth to allow boats to approach the breaker edge of the reef. This feature, however, is familiar to the residents, who have supplied me with information on the subject. It would seem that all around the circumference of this atoll there is a space outside the present edge of the reef varying from 200 to 500 or 600 yards in width, where ships have anchored, and where boats in the calm season go with fishing parties. Here the submarine slope slopes gradually down to 20 or 30 fathoms; but beyond this the descent is precipitous. It is on this gradual slope that the lines of growing coral occur, separated by sandy intervals from each other. There may be two or three of these lines, the innermost covered by 4 or 5 fathoms, and the outer by from 20 to 30 fathoms.

We are thus able to perceive that the outward extension of the reef is effected, not so much by the seaward growth of the present edge of the reef, as by the formation outside it of a line of growing corals, which when it reaches the surface reclaims, so to speak, the space inside it, which is soon filled up with sand and reef-*débris*. The evidence, in fact, goes to show that a reef grows seaward rather by jumps than by a gradual outward growth. This inference is of considerable importance, since it connects all classes of reefs together in the matter of their seaward growth, the degree of inclination of the submarine slope being the chief determining factor.

Following Le Conte, I have previously shown (Proc. Roy. Soc. Edin. 1885–86, p. 884) that where there is a very gradual submarine slope the deposition of sand and the presence of much sediment in the water will prevent the growth of corals in the shallow water outside the seaward edge of the reef, and that in consequence a line of living corals will spring up in the clearer and deeper waters a considerable distance beyond. The appearance of this line of coral at the surface will result in the production of a barrier-reef with a lagoon-channel inside. In a similar manner the submerged line of growing corals immediately outside the weather-edge of the reef of Keeling Atoll would form a barrier-reef, if it was removed some miles from the shore instead of being only about 100 yards distant. As it is now situated, it lies too close to the edge of the present reef to prevent the obliteration of the channel inside it after it has reached the surface. Its lagoon-channel would be very quickly filled with sand and reef-*débris*, and as a result we should merely have a permanent addition to the present reef-flat, which, when the process was complete, would be 100 yards wider. The process is the same as in the case of a barrier-reef, the difference in the result being due to the submerged line of corals being too close to the edge of the reef for the preservation of the interior channel; and this circumstance is due to the fact of the submarine slope being greater than in the case of a coast fronted by a barrier-reef. These remarks are merely intended to be suggestive. They may, perhaps, direct the attention of of other observers to the examination of the outer slopes of atolls and to their mode of seaward growth. This can only be done during unusually calm weather.

I have discovered many other new features of minor interest in connection with Keeling Atoll, to which I will refer in my full description of these islands. The island of North Keeling, lying fifteen miles to the north, is a small atoll connected with Keeling Atoll by a bank. I hope to describe it at some future time.

In conclusion, I may state that most of my observations in these islands were directed towards estimating the age of Keeling Atoll. These data have yet to be worked up, and I am fairly confident of getting a satisfactory estimate. The lagoon is rapidly filling up with sand and coral, but it is almost impossible to state in precise terms the changes since the visit of the *Beagle*, as the survey then made was little more than a sketch. The present Admiralty chart is of but little service in inquiring into past changes, for in it the original survey of the *Beagle* in 1836 has received several later additions, and there is nothing to distinguish the one from the other. For the purpose of navigation, and for the advantage of science, a complete examination of these islands should be made. The best season for surveying is during the calm weather of the months of January and February, when boats can venture close to the edge of the reef, and a satisfactory examination of the outer shores, as well as the interior of the atoll, can then be made. In collecting information from the residents, it will be necessary to remember that no records are kept in the islands; and in studying past changes the observer will have to receive what may at first sight appear to be very interesting facts with scientific caution. Some corroboration of such facts should always be looked for.

Yours faithfully,

Batavia, November 8. H. B. GUPPY.

SOCIETIES AND ACADEMIES.

LONDON.

Royal Society, December 20, 1888.—"Correlations and their Measurement, chiefly from Anthropometric Data." By Francis Galton, F.R.S.

Two organs are said to be co-related or correlated, when variations in the one are generally accompanied by variations in the other, in the same direction, while the closeness of the relation differs in different pairs of organs. All variations being due to the aggregate effect of many causes, the correlation is a consequence of a part of those causes having a common influence over both of the variables, and the larger the proportion of the common influences the closer will be the correlation. The length of the cubit is correlated with the stature, because a long cubit usually implies a tall man. If the correlation between them were very close, a very long cubit would usually imply a very tall stature, but if it were not very close, a very long cubit would be on the average associated with only a tall stature, and not a very tall one; while, if it were *nil*, a very long cubit would be associated with no especial stature, and therefore, on the average, with mediocrity. The relation between the cubit and the stature will serve as a specimen of other correlations. It is expressed in its simplest form when the relation is not measured between their actual lengths, but between (*a*) the deviation of the length of the cubit from the mean of the lengths of all the cubits under discussion, and (*b*) the deviation of the mean of the corresponding statures from the mean of all the statures under discussion. Moreover these deviations should be expressed on the following method in terms of their respective variabilities. In the case of the cubit, all the measures of the left cubit in the group under discussion, and which were recorded in inches, were marshalled in the order of their magnitude, and those of them were noted that occupied the first, second, and third quarterly divisions of the series. Calling these measures Q_1, M, and Q_3, the deviations were measured from M, in terms of inches divided by $\frac{1}{2}(Q_3 - Q_1)$, which divisor we will call Q. Similarly as regards the statures. [It will be noted that Q is practically the same as the probable error.] This having been done, it was found that, whatever the deviation, y, of the cubit might be, the mean value of the corresponding deviations of stature was $0·8y$; and, conversely, whatever the deviation, y', of the stature might be, the mean value of the corresponding deviations of the cubit was also $0·8y'$. Therefore this factor of 0·8, which may be expressed by the symbol r, measures the closeness of the correlation, or of the reciprocal relation between the cubit and the stature. The M and Q values of these and other elements were found to be as follow:[1] left cubit, 18·05 and 0·56; stature 67·2 and 1·75; head length, 7·62 and 0·19; head breadth, 6·00 and 0·18; left middle finger, 4·54 and 0·15; height of right knee, 20·50 and 0·80; all the measures being in inches. The values of r in the following pairs of variables were found to be: head length and stature, 0·35; left middle finger and stature, 0·70; head breadth and head length, 0·45; height of knee and stature, 0·9; left cubit and height of right knee, 0·8. The comparison of the observed results with those calculated from the above data showed a very close agreement. The measures were of 350 male adults, containing a large proportion of students barely above twenty-one years of age, made at the laboratory at South Kensington, belonging to the author.

These results are identical in form with those already arrived at by the author in his memoir on hereditary stature (Proc. Roy. Soc., vol. xl, p. 42, 1886), when discussing the general law of kinship. In that memoir, and in the appendix to it by Mr. J. D. Hamilton Dickson, their *rationale* is fully discussed. In fact, the family resemblance of kinsmen is nothing more than a special case of correlation.

The general result of the inquiry was that, when two variables that are severally conformable to the law of frequency of error, are correlated together, the conditions and measure of their closeness of correlation admits of being easily expressed. Let x_1, x_2, x_3, &c., be the deviations in inches, or other absolute measure, of the several "relatives" of a large number of "subjects," each of whom has a deviation, y, and let X be the mean of the values of x_1, x_2, x_3, &c. Then (1) $y = r$X, whatever may be the value of y. (2) If the deviations are measured, not in inches or other absolute standard, but in units, each equal to the Q (that is, to the probable error) of their respective systems, then r will be the same, whichever of the two correlated variables is taken for the subject. In other words, the relation between them becomes reciprocal; it is strictly a correlation. (3) r is always less than 1. (4) r (which, in the memoir on hereditary stature, was called the ratio of regression) is a measure of the closeness of correlation. Other points were dwelt upon in the memoir, that are not mentioned here: among these was as follows: (5) The probable error, or Q, of the distribution of x_1, x_2, x_3, &c., about X, is the same for all values of y, and is equal to $\sqrt{(1 - r^2)}$ when the conditions specified in (2) are observed.

It should be noted that the use of the Q unit enables the variations of the most diverse qualities to be compared with as much precision as those of the same quality. Thus, variations in lung-capacity which are measured in volume can be compared with those of strength measured by weight lifted, or of swiftness measured in time and distance. It places all variables on a common footing.

"Preliminary Account of the Morphology of the Sporophyte of *Splachnum luteum*." By J. R. Vaizey, M.A., of Peterhouse, Cambridge. Communicated by Francis Darwin, F.R.S.

[1] The head length is here the maximum length measured from the notch below the brow. The cubit is measured with the hand prone, from the flexed elbow to the tip of the middle finger. The height of knee is taken from a stool, on which the foot rests with the knee flexed at right angles; from this the measured thickness of the heel of the boot is subtracted. All measures had to be made in the ordinary clothing. The smallness of the number of measures, viz. 350, is of little importance, as the results run with fair smoothness. Neither does the fact of most of the persons measured being hardly full grown affect the main results. It somewhat diminishes the values of M, and very slightly increases that of Q, but it cannot be expected to have any sensible influence on the value of r.