

THE
AMERICAN
JOURNAL OF SCIENCE AND ARTS.
[THIRD SERIES.]

ART. XXI.—*Coggia's Comet—its Physical Condition and Structure. Physical Theory of Comets*; by Prof. W. A. NORTON.

COGGIA'S Comet (Comet III, 1874), the last that was conspicuously visible to the naked eye, was attentively observed at observatories in both hemispheres. The reported results of the diverse series of observations and determinations made with the telescope, spectroscope, and polariscope, appear to reveal the essential features of its physical condition and structure, and to afford important indications with regard to the probable physical theory of comets in general. The following are the elements of the parabolic orbit of the comet, computed by M. Schulhof (Astr. Nachr., No. 2003). $T=1874$, July 8·85664, G. M. T., $\Pi=271^{\circ} 6' 19''\cdot5$, $\Omega=118^{\circ} 44' 25''\cdot3$, $i=66^{\circ} 20' 58''\cdot6$, $\log. q=9\cdot829826$, which gives, per. dist. $q=0\cdot67581$. Motion direct.

Nature and Condition of the Cometic Matter.—The following are the general results of the observations made with the spectroscope and polariscope* with the view of ascertaining the nature and condition of the matter of the comet; in the nucleus and coma or envelopes, and as more widely diffused in the tail.

(1.) The light of the tail and coma was partially polarized in a plane through the axis of the tail.

(2.) The spectrum of the comet consisted of three or more bright bands on a continuous spectrum. This continuous spectrum was faint on July 7, but became much brighter by July 14. The three bright bands were identical with those obtained by passing a spark from an induction coil through gaseous-

* Month. Not. of Royal Astr. Soc., 1873-4, pp. 489 to 491; 1874-5, p. 83. Astr. Nachr., No. 2018, pp. 18 to 32.

dioxide of carbon (carbonic acid gas). Other experiments have shown that the volatile hydro-carbons give, with the electric spark, the same spectroscopic bands; and that these are wholly due to the momentary incandescence of the carbon molecules of the compound. Several other comets have given the same "carbon bands." Brorsen's comet, a faint circular nebula, invisible to the naked eye, proved to be an exception. Three bright bands were observed in its spectrum, but they differed in position and other features from the carbon bands.

(3.) "The spectrum of the nucleus was continuous, but it appeared to have traces of numerous bright bands, and three or four dark lines also were seen."

(4.) The light from the tail gave a continuous spectrum, without superimposed bright bands.

From these results we may draw the following conclusions:

(1.) From the bright bands observed we may infer that the coma consisted in a large measure of matter in the gaseous state; and that the actual gaseous substance was either dioxide of carbon (i. e. carbonic acid gas), or oxide of carbon, or the vapor of some hydro-carbon.

(2.) The light of incandescence of the gaseous particles, which furnished the bands, must have been of electric origin; since the heat of the sun could not have been sufficient to ignite the most inflammable vapor.

(3.) The continuous spectrum on which the three carbon bands were seen, affords no decisive evidence of the presence in the coma of discrete solid particles, since it may have resulted from the solar light reflected from the gaseous particles. Such light would not have been sufficiently intense to give the dark solar lines.

(4.) The "traces of bright bands" seen in the spectrum of the nucleus reveal the presence of vapors at its surface shining by electric light. The bright continuous spectrum may have been wholly due to reflected solar light (since dark solar lines were not wanting), or partly to discrete solid particles rendered luminous by electric discharges. The light reflected from the solid nucleus, or from dense vapors or clouds near its surface, may well have been of sufficient intensity to make the gaseous carbon bands resulting from electric discharges inconspicuous.

(5.) The spectroscope did not give any decisive evidence with regard to the state of the matter in the tail—whether gaseous or composed more or less of discrete solid particles; but since the tail was formed of matter flowing in continuous streams from the head, we must suppose that it was made up chiefly of gaseous particles, like the head.

(6.) The light of the tail was exclusively reflected solar light.

The experiments of Professor Arthur W. Wright, of Yale College, on the gases from stony meteorites,* have furnished strong evidence in support of the hypothesis first propounded by him, that the cometic substance is gaseous carbon dioxide. He found that "in meteorites of the stony kind, the characteristic gas is carbon dioxide, and this, with a small proportion of carbonic oxide (oxide of carbon), makes up more than nine-tenths of the gas given off at the temperature of boiling water, and about half that evolved at a low red heat." The spectrum of the gases, obtained by passing an electric spark through a small tube containing the gases at a low tension, consisted of the hydrogen and carbon spectra together. The three bright bands of the carbon spectrum were coincident in position with those in the spectra of comets, and had the same relative order of intensity. The close relationship now known to subsist between comets and meteors renders it highly probable, as suggested by Professor Wright, that the cometic matter is identical with the gaseous matter found associated with stony meteorites, and consists chiefly of carbon dioxide disengaged from the nucleus of the comet by the heat of the sun.

If we adopt this hypothesis with regard to the nature and origin of the cometic substance, the question arises in what condition does the carbon dioxide exist, in its association with the matter of the nucleus? We may at once admit, with Professor Wright, the high probability that it has become intimately associated with it by interpenetration, or by surface concentration upon small metallic grains, as it is found in meteoric stones. But it is also to be observed, that at the temperature of free space, which must prevail on most comets throughout the greater part of their periods of revolution, a large accumulation of carbon-dioxide might exist on their surface in the solid condition, or as a layer of detached solid particles. This may be inferred from the results of Faraday's experiments on the condensation of this gas into a liquid at extremely low temperatures. He found at the temperature of 80° C., below the freezing point, a pressure of one atmosphere sufficed to condense it into a liquid. 80° C. is, according to Fourier, 20° C. below the temperature of free space, but, according to the more reliable determination of Pouillet 60° C. above it. At this temperature, -140° C., a small fraction of one atmosphere of gaseous pressure should suffice to condense the gas into a liquid.

Now, when a comet, supposed to have an accumulation of solid carbonic acid at the surface of the nucleus, is in the act of approaching the sun, the increasing amount of heat received from the sun should give rise to copious evolutions of the

* This Journal, III, vol. ix, July, 1875, p. 44.

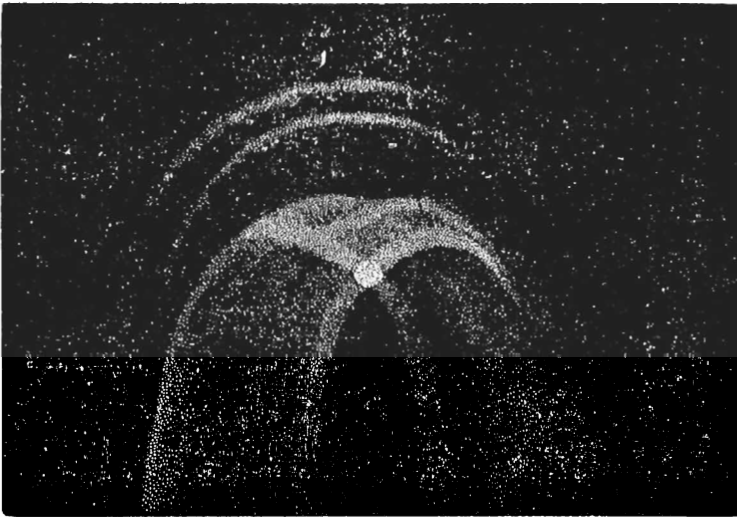
carbon-dioxide in the gaseous form—either continuously or intermittently—and these may occur either simultaneously over large areas, or in limited streams or jets. A portion of the vapor evolved may be condensed into solid particles by the cold resulting from the rapid evaporation. In so far as the gas is in intimate physical association with the solid matter of the nucleus, it would seem that the heat of the sun would not at the perihelion distance of either Coggia's Comet, the great comet of 1861, Donati's Comet, or, indeed, of any of the conspicuous comets with a few exceptions, be intense enough to occasion such copious evolutions of gaseous matter as have been actually observed. Evolutions of occluded gas may, however, constitute the chief phenomena, produced by the solar heat, in the cases of the inconspicuous comets of short period, which, in retreating from the sun do not pass beyond the limits of the planetary system.

The conclusions that have now been reached apply strictly only to the comets that have been spectroscopically observed, but they may be regarded as probably applicable also to other comets that do not differ greatly from these in the circumstances of their approach to the sun and recess from him, and in the physical phenomena they have presented. The great comets of 1843 and 1860, that approached very near the sun, may have given off, in great abundance, aqueous or other forms of vaporous matter, derived from the liquefaction and subsequent vaporization of frozen liquids.

The important question here presents itself, what is the probable origin of the free electricity that plays so important a part in the luminous phenomena which conspicuous comets have presented? We might rest on the assumption that the solid nucleus of a comet is surrounded by a gaseous atmosphere like the earth, permeated by free electricity increasing in tension from the surface of the nucleus upward; and that whatever may be the unknown origin of the electric state of the earth's atmosphere, the same may be the origin of the atmospheric electricity of the comet. But, I will add, from my special molecular stand-point, that the ethereal electric atmospheres by which, as I conceive, the gaseous or vaporous atoms ascending from the nucleus are surrounded, should expand as these atoms recede from the nucleus, and come under diminished gaseous pressure, and so give off a certain overplus of free electricity. The outward flow of such disengaged electricity along the lines of best vaporous conduction should disengage more or less light.

Physical Aspects of the Comet.—From numerous published drawings of the comet, I select that in which its peculiar features are most conspicuous. The cut is a copy of a drawing

communicated by R. S. Newall to A. C. Ranyard, showing the aspect of the comet, as seen at Ferndene on July 12th. In the accompanying description* it is stated that "the nucleus was very bright, with a disk tolerably well defined. In front of the nucleus (i. e. on the side toward the sun) was a fan-shaped light which seemed to arise from the overlapping or duplication of the two tails, which streamed away behind (the nucleus) for a length of about 15° , forming, as it were, two luminous veils, delicate, transparent and flickering, having between them a black space well defined up to the nucleus. The edges of these tails appeared to be brighter than the middle part, and crossing over the nucleus they formed the sides of the fan; the outside edges also crossing over formed the top of the fan and head of the comet. In front of this was another covering semicircular and brightest in the preceding part, and in front of that was again another fainter envelope or cloud." This outer faint envelope, or duplex envelope, has been a noticeable feature in the aspect of other comets (e. g. Donati's).



1.

Physical structure and condition of the Comet.—Upon the various drawings made by different observers, Mr. Ranyard has the following remarks:† "The drawings that were made of Coggia's comet during the early part of July, 1874, show that although there was but one small almost stellar nucleus, there were two sets of parabolic envelopes situated side by side, and apparently overlapping one another just in front of the nucleus. These

* Month. Notices of Astr. Soc., 1875-6, p. 279.

† Ibid.

were shown in the drawings made by Mr. Huggins and Mr. Christie. They are also to be seen in Mrs. Newall's drawing (see cut, p. 165), and they were described by Mr. Lockyer in a letter published in the Times, of July 16th, on the structure of the comet. When the comet was again visible in the Southern hemisphere, the inner duplicate structure was still visible, but the outer arcs had been dissipated." The *duplicate structure* here referred to is a highly significant fact. That it may be duly appreciated it must be borne in mind that at the period when this structure was observed, the line of sight from the earth to the nucleus was inclined under a small angle to the plane of the orbit, and under a large angle to a line through the nucleus perpendicular to the plane of the orbit. A few days later (July 21) the earth was in the plane of the orbit: the line of sight to the nucleus was in this plane, and perpendicular to the line just mentioned. We must, therefore, infer that at the period when the observations were made *the luminous jets which made up the structure observed were situated in the plane through the radius vector perpendicular to the plane of the orbit, or were seen as projected on this plane.* The lateral dispersion and lines of jet-discharge shown in the drawings, must then have been in the direction of this plane, and not in that of the plane of the orbit. Shall we then conclude that the head and first portions of the tail were flat, or approximately so, and consisted entirely of jets lying in this plane or but moderately inclined to it, or regard the drawings as showing sections of a hollow paraboloid by this plane. We must adopt the former hypothesis, since the strong contrast between the dark space behind the nucleus and the two comparatively broad bright streams on either side of it, and the sharp lines of demarcation between them cannot be reconciled with the latter.

This conclusion suggests at once the inference that the nucleus of the comet must have rotated about an axis approximately at right angles to the plane of the orbit, and that the outstreaming from diverse points of the surface, had some physical relation to the latitudes of these points (i. e. their angular distance from the plane of the orbit or equator). This idea being once admitted we readily perceive that we have a plausible explanation of the duplicate structure of the comet in the hypothesis that separate streams, or systems of jets, proceeded from the two hemispheres lying on opposite sides of the plane of the orbit; and that the overlapping of the envelopes just in front of the nucleus, signalized by Mr. Ranyard, may have been the result of an initial inclination toward the radius vector of the jets issuing from each hemisphere. The prevalent notion that the outstreaming is everywhere in directions normal to the surface of the nucleus, and decreases in intensity

from the region exposed to the normal incidence of the sun's rays, it appears, then, altogether fails of application to Coggia's comet. It gives the single hollow paraboloidal tail without duplication, which is entirely at variance with the facts of observation.

Physical Theory of cometary phenomena.—Now, if there be, in fact, two systems of jets, emanating from opposite hemispheres of the nucleus, and passing over from one to the other, we can look for the origin of such a state of things only in a supposed magnetic condition of the nucleus, and in the hypothesis that the lines of initial discharge lie in the direction of the lines of the magnetic force; or in lines having a certain relation to these. This consideration brings us to the proper point of view for the presentation of the definite physical theory of cometary phenomena which I have been led to form, from a detailed study of Coggia's comet and other comets. It is briefly this: that the direct effect of the action of the sun on the side of the nucleus exposed to the solar rays, is to form an envelope of gaseous carbon dioxide extending a certain distance from the nucleus. This envelope, consisting of a diamagnetic gas, is traversed by the ideal lines of magnetic force proceeding from the nucleus, which are also lines of electric conduction through the diamagnetic gas. The electricity set free by the ascending currents of the gas, by reason of the diminished gaseous pressure, is propagated along these lines; and the impulsive force of the electric currents detaches streams of successive molecules of the gas, in the direction of the lines of conduction. De La Rive's well-known experiment of transmitting electricity through an attenuated gas or vapor surrounding a magnet, showed that the lines of force in the magnetic field were also lines of electric conduction, rendered luminous by the propagated electricity. The outstreaming cometic matter moves away subject to the combined action of the nucleus and sun. Both bodies exert repulsive forces upon the escaping molecules, the probable origin of which I shall consider soon. But their effective actions may be either repulsive or attractive, according as the repulsion prevails over the attraction of gravitation, or the reverse. The repulsion of the nucleus takes effect in directions normal to its surface, or nowhere deviating much from this direction. It should be observed that besides taking effect on the gaseous molecules detached by the electric discharges, it may operate on other molecules not thus detached, with an intensity sufficient to overcome their gravitation toward the nucleus.

In my mathematical discussion of Donati's comet* I reached the result that the tail of the comet was made up of matter of which a portion was solicited by an effective solar repulsion,

* This Journal, II, vol. xxxii, No. 94, July, 1861.

varying in intensity from 0 to 1.213 A (A representing the intensity of the sun's attraction of gravitation at the same distance); and another portion was subject to an effective solar attraction, varying between the limits 0 and 0.455 A. I also showed that the "columnar structure" of the tail, signalized by Prof. Bond, was attributable to considerable variations, at short intervals, in the quantity of matter detached from the head of the comet; while the limits of variation of the effective solar force remained sensibly the same for several days. The varying intensity of the solar repulsion, in its operation on different molecules or particles escaping from the head, was the determining cause of their subsequent wide lateral dispersion in the plane of the orbit. Professor Bredichin, Director of the Observatory of the Moscow University, in a memoir on Coggia's comet, assigns for the effective solar force in operation on that comet, average attractive values varying from 0.118 A to 0.530 A. The values obtained in single determinations come between the limits, repulsion = 1.415 A and attraction = 0.736 A.

Force of Cosmical Repulsion.—Several hypotheses have been propounded with regard to the nature and origin of this force. But none of them appear to be free from serious objections. Several years since (1861) I suggested the hypothesis that the solar repulsion might consist in the repulsive action of free statical electricity. We have abundant evidence of electric excitation both at the surface of the sun and in the cometary envelopes; but it may reasonably be doubted whether the free electricity at the sun's surface can exert, at cosmical distances, an energy as great as that which the operative cause of the wide dispersion of cometic matter displays—especially when it is considered, as suggested by Dr. W. Zenker, that a positive electric state at or near the surface of the sun implies a corresponding negative state at some lower depth.* While not prepared to admit the impossibility of a sensible electric repulsion, it appears to me that another and much more probable view may be taken of the character and origin of the solar force. This is that it is a *diamagnetic repulsion exerted by the sun as an electro-magnet † on the gaseous molecules of the comet.*

* Prof. F. Zöllner, in two elaborate papers published in the *Astronomische Nachrichten*, No. 2057–2060 and No. 2082–2086, has endeavored to remove the force of the several objections urged by Dr. Zenker to the electric theory of the solar repulsion, and establish the adequacy of this theory. Dr. Zenker has published a detailed reply to Prof. Zöllner's arguments. As one result of the discussion, it does not appear that the above-mentioned objection has been set aside. It must be admitted, I think, that at present the electric theory rests under a cloud of doubt. As for Dr. Zenker's own reaction theory, to mention no other objections, it is certainly wholly inapplicable to the case of a comet coming as near the sun as did the comets of 1843 and 1860; and it obviously affords no explanation of the duplicate structure of Coggia's comet.

† By the term electro-magnet is meant a magnet which derives its magnetic condition from the continued operation of some external cause.

It was conclusively established by Faraday, by a series of careful experiments, that the gases, with the exception of oxygen, are diamagnetic; that is, that their molecules are repelled by both poles of a magnet. That the body of the sun is in a state of magnetic excitation there is abundant evidence. In a former publication* I have undertaken to show that the electric currents in which this must consist, may be ascribed to the impulsive action of the ether of space on the ethereal atmospheres of its molecules, resulting from the combined motion of rotation and progression. If the nucleus of a comet has a motion of rotation, as well as of revolution, the same operative cause should make it an effective magnet. It should accordingly diamagnetically repel the molecules of any diamagnetic gas or vapor that may be posited at or near its surface. The force thus exerted should increase in intensity with the augmenting magnetic intensity, up to the time of the perihelion passage, when the orbital velocity is the greatest; and subsequently decrease. The maximum of magnetic intensity may, however, be reached a certain interval of time after the perihelion passage, by reason of the persistence of currents previously developed. The magnetic condition of the nucleus would be a rapidly changing one, in approximate correspondence with the varying rate of the orbital motion. The circular magnetic currents developed would have diverse directions, in planes lying between the plane of the equator and the plane of the orbit. The effective force exerted by the nucleus on a diamagnetic gaseous molecule, would be the difference between its diamagnetic repulsion and its attraction of gravitation. The solar force of diamagnetic repulsion should vary according to the inverse square of the distance. The mathematical discussion of Donati's comet, already alluded to, served to establish that the effective solar force taking effect on the particles of the tail of the comet varied according to this law. From this fact we may infer that it probably consists of radial impulses propagated in waves through the ether of space.

Inequality of the Solar Repulsion.—Faraday established that the diamagnetism of a gas increased with its temperature. But the separate gaseous molecules of a comet being equally exposed to the sun's rays could not differ materially in temperature. Any single molecule, in receding from the sun, should, however, experience a gradual diminution of temperature, and therefore become less diamagnetic. The inequality of the solar repulsion, taking effect on different gaseous molecules, cannot then be ascribed to changes of diamagnetic condition produced by changes of temperature. But may not material variations of diamagnetic condition result from the electric discharges to which the gaseous molecules are exposed?

Looking at the matter from the general point of view I have taken in my papers on Molecular Physics, it appears that such dis-

* This Journal, II, vol. xli, Jan., 1866.

charges should condense the electric atmospheres (or envelopes) of the molecules, and so augment their absorptive action on the radial impulses of the diamagnetic repulsion. In proportion as the condition of the molecular atmospheres is favorable to such absorption, will the condition of the molecules be unfavorable to the reception of an impulsive action from the diamagnetic force. The tendency of electric discharges should then be to diminish the molecular susceptibility to diamagnetic repulsion from the sun or nucleus of the comet. The varying intensity of such discharges might well occasion large variations in this susceptibility. While a portion of these effects should pass off, as their originating cause ceases to operate, a certain portion may abide as permanent changes of molecular condition. This is a legitimate deduction from my general molecular theory; from which the variability of the physical condition of the ultimate molecules under varying conditions, is one prominent inference, and the key to the satisfactory explanation of a multitude of phenomena.

The only other view that can be reasonably entertained of a possible origin of an inequality of solar repulsion, is that the cometic particles may differ greatly in size or mass. This might be allowed if we could admit that they are solid particles, or that a large number of different gases are present in the coma. But both of these suppositions seem to be irreconcilable with certain facts of observation.

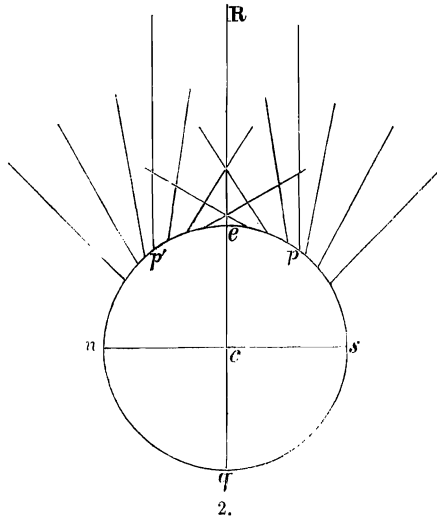
Explanation of General and Special Phenomena.—It should be understood at the outset, that it is not essential to the explanation of cometary phenomena, that the force of cosmical repulsion be regarded as having a diamagnetic origin—that is, as I view the matter, consists of radial impulses propagated in ethereal waves proceeding from all points of the magnetic currents of the cosmical body. The essential feature is that a repulsion, whatever may be its origin, is exerted normally, or approximately so, to the surface of the body, and that the radial impulses of this force take effect unequally on different gaseous molecules; by reason of unequal absorption, resulting probably from certain effects produced by electric discharges—but possibly on solid cometic particles differing in size or mass. A magnetic condition of the nucleus, sufficiently decided to determine lines of electric conduction through its diamagnetic gaseous envelope, coincident with the lines of force in the magnetic field, is however an essential feature of the theory.

The precise character of the phenomena should depend, to some extent, on the position of the axis of rotation of the nucleus. We may regard as the normal position that in which it is perpendicular to the plane of the orbit; and the attendant phenomena as the general phenomena. If the axis deviates from this position there will be two efficient causes of special phenomena to be considered: (1) the point of maximum evap-

orating effect of the sun's rays will probably fall at some point of either the northern or the southern hemisphere of the nucleus, instead of on the equator; (2) the magnetic poles will not coincide with the poles of rotation, and the magnetic equator will be more or less inclined to the plane of the equator of rotation, as well as to that of the orbit. From this it follows that the lines of force will, in general, be more or less inclined to the astronomical meridian planes of the nucleus; and hence that the initial directions of the jets of cometic matter will be inclined to these planes.

Let us first take the axis in its normal position. We at once perceive that there may be two general varieties in the process of evaporation under the influence of the sun's rays. (1.) A continuous evaporation most abundant at the equator, and extending into both hemispheres. (2.) A more copious evaporation occurring only at certain intervals, beginning in each instance at the equator, and subsequently extending both north and south. A tendency to such intermittence at each point of a meridian should result from the cold produced by a copious evaporation and the intercepting action of the vapors already generated. The vapor or gas developed by either of these special processes becomes subject to an expulsion to an indefinite distance, either by an effective repulsion exerted by the nucleus, or by the impulsive force of electric discharges combined with the effective force exerted by the nucleus, whether attractive or repulsive. In both of these modes of expulsion the gaseous molecules, in their motion *relative to the nucleus*, are subject to the full force of the sun's repulsion, undiminished by his attraction of gravitation. Those which experience the first mode of expulsion, not having suffered any diminution of susceptibility to diamagnetic repulsion by reason of electric discharges (p. 170), are energetically repelled both by the nucleus and sun. They become separately visible in the straight "secondary tails" (e. g. Donati's comet). On the other hand, the gaseous matter expelled by electric discharges, serves to form the envelopes that rise in succession from the nucleus (e. g. Donati's comet; great comet of 1861). In the formation and expulsion of each successive envelope, whichever of the two processes of evaporation may occur, the evolution of gaseous matter will be most abundant at the equator, and electric discharges may reasonably be supposed to begin near the equator, and extend gradually both north and south. The varying directions of the discharges, and therefore also of the initial directions of the jets, from diverse points of a single meridian, are shown in Fig. 2. At about 35° from the equator, on either side, the direction becomes parallel to the equator (*ecq*), and thus to the radius vector (*ceR*). From 0° to 35° it tends toward

this line, and beyond 35° diverges from it under a larger and larger angle. If the initial velocity is constant, as well as the solar repulsion, the escaping molecule should attain to its greatest distance from the nucleus when the discharge occurs from the latitude of 35° , and in the precise direction of the sun. If then the process of electric discharge begin near the equator, and extend gradually to the north and south, the outer surface of the envelope formed will gradually move away from the nucleus, and attain its greatest distance when the process reaches the latitude 35° . The jets that issue from latitudes greater than that (about 35°) at which the direction is parallel to the radius vector, do not pass sensibly beyond the boundary line of the jets that proceed from points between 0° and 35° of the other hemisphere, unless for such jets the projectile velocity is greater, or the solar repulsion less.*



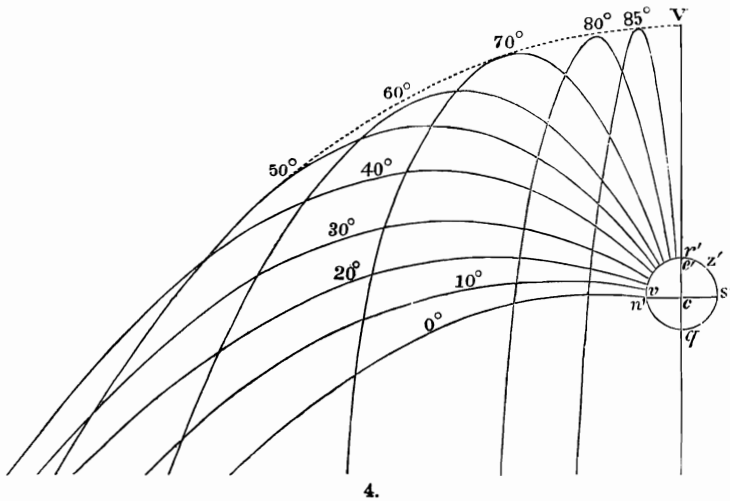
What has now been stated should be the precise result if the molecules after receiving a projectile velocity were exposed only to the retarding force of the solar repulsion. The effective action of the nucleus would obviously modify somewhat the curve for each initial direction, and alter the limiting latitude for which the recess in the assumed direction is a maximum. If this effective action is attractive, this latitude will exceed 35° , if it is repulsive, it will be less than 35° .

We may infer from the great dimensions of the head of a comet in comparison with the nucleus, that the action of the nucleus becomes practically insensible at a small fraction of the

* See remark about recess of envelopes on p. 176.

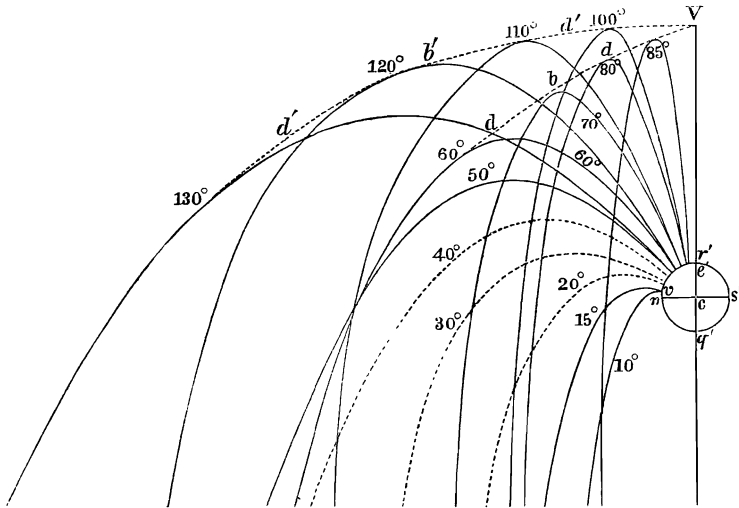
form the following side. The time required for any receding particle receiving an initial velocity in the line of direction of the sun, to reach its point of greatest recess, must have been less than twenty-four hours, in the case of the two comets (Donati's and Coggia's) for which the intensity of the actual solar repulsion has been determined.

Let $nesq$ (Fig. 3) represent the nucleus, or more strictly the surface of projectile discharge, and $n'e's'q'$ the sphere of sensible action of the nucleus; eq being the equator and ceR the direction of the sun. The point p is at lat. 35° , and r is the point of projection of the jet which issues from the sphere $n'e's'q'$ in the direction $r'R'$ parallel to ceR . The jets proceeding from the arc er issue from this sphere at various points near e will have at v a direction at right angles to ceR .



If the jet discharge extend beyond r to some point z the jet proceeding from z will emerge from the sphere $n'e's'q'$ at z' , in a direction $z't$, having a certain inclination to ceR . The cometic matter outstreaming from the arc rz will emerge from the same sphere between r' and z' . Now let $n'e's'q'$ (Fig. 4) answer to $n'e's'q'$ in Fig. 3, and let a denote the inclination of any jet emerging from this sphere to the line $n'c's'$ perpendicular to the radius vector $ce'R$. Suppose a (estimated from left to right) to increase by 10° from 0° to 90° , and let us regard the initial velocity, on leaving the sphere $n'e's'q'$, as constant, (p. 173) and also the solar repulsion as constant for each jet. The parabolic curves that would be pursued are

shown in the diagram. The jets proceed from $n' v e' r'$, and were projected from the lower latitudes of the right hemisphere, or between e and r (Fig. 3). Jets issuing from the corresponding arc $e r$, of the other hemisphere, would form a similar set of curves to the right of $c e' R$. Other sets of parabolic jets are projected from latitudes above 35° , or from the arcs $r z$ and r, x (Fig. 3); but these will have sensibly the same outer boundary as those from $e r'$ and $e r$, unless the initial velocity or the solar repulsion is different. It is to be observed that $c e$ is so small a fraction of $c e'$ (Fig. 3) and $c e'$ so small a fraction of $c V$ (Fig. 4) that we may without material error regard v as coincident with n' , and r' as coincident with e' .



The hypothesis made in the construction of Fig. 4, that the solar repulsion is constant for all values of a , or in other words that the force of electric discharge on which the intensity of this repulsion theoretically depends, is independent of the initial angle of direction of the jet, is not the most probable one under the circumstances. In fact, the electric discharges at the nucleus should apparently increase in intensity and impulsive action, with the inclination of the line of discharge to the surface, and hence the solar repulsion should, according to the theoretical principle before stated (p. 170) diminish as this angle of inclination increases. This angle corresponds to the dip of a magnetic needle on the earth's surface, and varies, we may suppose, with the latitude according to a similar law. Let it be denoted by β .

In Fig. 5 the solar repulsion is assumed to be inversely proportional to $\sin \beta$. The change of direction of the jet while passing through the sphere of sensible action of the nucleus is neglected in the application of this law. Two systems of curvilinear jets are shown—one answering to values of a varying by 10° from 50° to 90° , and emanating from latitudes less than 35° of the right hemisphere, or from a portion of the arc er (Fig. 3); and another answering to values of a varying by 10° from 90° to 130° , and estimated from right to left. These emanated from latitudes greater than 35° of the left hemisphere, or from a portion of the arc rx (Fig. 3). The other corresponding systems of jets, emanating from portions of er , and rz , would form the other half of the comet. If we consider all the jets issuing from the right hemisphere as forming one system, and all those issuing from the left hemisphere as forming another system, then for each system a will vary from 50° to 130° : and will increase from left to right for the first, and from right to left for the second. They answer to the supposition that the outstreaming extends from latitude $17\frac{1}{2}^\circ$ to $57\frac{1}{2}^\circ$, in each hemisphere. It will be seen that the jets proceeding from the latitudes higher than 35° , for which a varies from 90° to 130° , recede to greater distances from the nucleus than those emanating from latitudes less than 35° , for which a varies from 50° to 90° . This of course results from the greater values of $\sin \beta$ that obtain for the first-mentioned set of jets. Thus, for the 130° jet $\sin \beta = 0.953$, while for the 50° jet $\sin \beta = 0.534$. The envelope, $Vabd$, or outer boundary of the latter system of jets thus falls within that, $Va'b'd'$, of the other system. The overlapping of the two systems of jets should accordingly be conspicuously visible, and an appearance presented similar to that of Coggia's comet on July 12th, as shown in the drawing on page 165.

This drawing indicates that the evolution of cometic matter was much less for angles a from 0° to about 50° than from 50° to 130° . Not to confuse the drawing too much I have shown in full lines only two jets between 0° and 50° , answering respectively to 10° and 15° ; as showing that the boundaries of the dark space behind the nucleus were probably formed by jets issuing from low latitudes on the nucleus.

It ought to be added, as an important feature of the general theory, that the recess of a cometary envelope, or system of jets from the nucleus, should continue after the jet discharge has reached the latitude 35° and upward, until the electric discharges at these latitudes have attained to the maximum intensity.

Certain comets have presented peculiarities of appearance which I find, on a careful examination, admit of satisfactory explanation on the hypothesis that the equator of the nucleus was inclined to

the plane of the orbit, and in consequence the two magnetic hemispheres were unequally exposed to the influence of the sun's rays. The special features alluded to, are the unsymmetrical position of the envelopes thrown off in succession from the nucleus (e. g., the envelopes of Donati's comet in their earlier stages, and especially the five separate envelopes of the great comet of 1861, as seen by Dr. Schmidt on June 30th); and great differences in the length of the two branches of the normal tail, in connection with an anomalous curvature of the first portion of the longer branch, when the comet was viewed from certain positions of the earth relative to the plane of the orbit, observed in the case of Comet II, 1862, and elaborately discussed by Prof. Schiaparelli and Prof. Bredichin. In this case we have only to suppose that the sun was vertical to points of one of the hemispheres, and as a consequence the jet discharges were mostly confined to that hemisphere. The longer branch of the tail was composed of jets issuing from the lower latitudes, while the less copious and more fluctuating discharges of matter subject to a diminished solar repulsion (p. 176) from the higher latitudes, formed the shorter branch of variable length.* The anomalous curvature of the former system of jets, and their interlacing with the other system, was a simple consequence of the greater intensity of the solar repulsion in operation on the former than on the latter.

The curious phenomenon of the *oscillation of jets* first observed by Bessel in the head of Halley's comet, and of which he offered in explanation the improbable hypothesis of a polar attractive force exercised by the sun upon the nearer portion of the nucleus, may be seen to be another probable consequence of an inclination of the equator to the plane of the orbit. It has already been intimated (p. 171), as one theoretical result of such a state of things, that there should be two magnetic poles in each hemisphere, and that the lines of magnetic force should be variously inclined to the planes of different local meridians on the nucleus. As the planes of these different local meridians are brought successively by the rotation into coincidence with the meridian plane through the sun, the lines of jet discharge, which are coincident with the lines of magnetic force, should oscillate with respect to this plane.

* To illustrate, if the outstreaming were confined to the right hemisphere, (Fig. 3) the jets proceeding from $e r$ would pass over to the left side of the nucleus, and those proceeding from $r z$ would curve around to the other side.

AM. JOUR. SCI.—THIRD SERIES, VOL. XV, No. 87.—MARCH, 1878.