

THE ELECTRIC CONSTITUTION OF THE SOLAR SYSTEM.

BY JACOB ENNIS.

The zodiacal light, the aurora borealis, the corona of the sun, and the tails of comets, are all different forms of the same thing. They are electrical brushes, precisely the same as the electric brushes which in the night are seen to fly off from a highly charged electric machine. On the electric machine the electric fluid is developed by friction. On our great globe, on the sun, and on the comets, the electric fluid is developed by evaporation. Put a little saline water in a metallic vessel shaped like a watch crystal, then if heated, or if a hot pebble be dropped in the water, the vapor arising will be charged with the electric fluid. All the waters of our globe are more or less saline, and the ocean is very much saline, and the rising vapors are charged with electricity. A gill of water is changed into about 30 gallons of electrified vapor. All around our globe the average rainfall is about 36 inches a year. This shows the amount of water evaporated; and the amount of vapor and of the electric fluid rising daily high up in our atmosphere, is great beyond conception. A very small portion of the electric fluid comes down as lightning. The brilliant light and the loud explosions are simply indications of the resistance offered by the dense lower atmosphere to the downward progress of the electric fluid. But high up the air is very rare, and the electric fluid easily rises upwards; therefore the higher regions of the atmosphere are always highly charged with electricity. Ordinarily the ground is negative, and the air is positively electrified. As a balloon mounts up, a cord let down, say a hundred yards, shows that its lower end is always negative and the upper positive. This is proof that the upper strata of the air are more highly charged than the lower. As those upper strata float toward the poles they carry thither an ever-increasing accumulation of the electric fluid. What becomes of this fluid? It cannot descend to the ground through the dense atmosphere; there are no thunder showers in those polar regions, therefore it goes upward through the rare air to the top of the atmosphere, and from thence it is driven off in the form of auroral streamers constantly far away into empty space as electrical brushes.

But what repels this vast daily accumulation of electricity away from our planet off into empty space? The answer is that electricity alone can repel electricity; and in this case the repelling electricity is seen in the corona of the sun. The corona of the sun consists of brushes of electricity. They are so vast that they rise up visibly to our eyes at this great distance a million of miles. How much further they would be visible if our standpoint were nearer, we cannot say. They are caused there, as here, by the evaporation from the intense heat of the sun. They are so powerful as to drive the tails of comets, also electric brushes, in the direction away from the sun. They drive away from the direction of the sun our zodiacal light, and our aurora borealis, and aurora australis, all three of which must be regarded as the perpetual tail of our planet, in many respects similar to the tail of a comet; for the tails of some comets are so short and rare as to be either invisible or almost invisible at our distance.

Our auroral streamers and our zodiacal light are perpetual; they never cease, because evaporation never ceases. There is a zone all around our globe toward the Arctic Circle where the aurora borealis is seen every night. In Europe this zone lies in about 70 degrees of latitude, but in America it comes lower down, as far as about the latitude of 58 degrees. As we go northward from Philadelphia we see the northern aurora more and more frequently. It is easy in summer to go to Quebec, and from there in a steamer up the Saguenay River to Grand Bay and Chicoutimi, where very seldom a night passes without being cheered more or less by the electric lights along the northern sky.

The evidence is complete that an auroral display is a display of electricity. It runs along the telegraph wires, and messages have been dispatched and carried to their destination by the auroral power. During the display of September 2, 1859, it was estimated by telegraphic experts that "the intensity of this power was equal to that of 200 cups of Grove's battery on a line 230 miles long." I need not stop here to detail how telegraph operators have been stunned, how their apparatus has been melted, and how their work has been suspended by an electric storm on their wires coming from the aurora.

When there are extraordinary auroral displays they appear first in Europe and then in America; they travel from east to west around the globe like the dark cone of the night; they are on the dark

side of the globe, and the auroral streamers, sometimes 500 miles high, point away from the sun, like the tails of comets, driven by the sun's electric repulsion. This is illustrated by the hours in which they appear. In lower latitudes, say of 40 degrees, where the zone around the globe from east to west is very long, the aurora appears in the earlier part of the night, and the electric fluid is all driven off generally before midnight. But far to the north, where that zone is shorter, the appearances of the auroras are more often at midnight and later.

The following table shows the times of the appearance of many auroras in Canada, and other stations further north, at Carlton Fort, Athabasca, and Point Barrow, ranging from 48 to 71 degrees of latitude.

Hours.	No. of auroral displays.	Hours.	No. of auroral displays.
6 P. M.	. . . 61	1 A. M.	. . . 323
7 " .	. . . 137	2 " .	. . . 267
8 " .	. . . 220	3 " .	. . . 240
9 " .	. . . 261	4 " .	. . . 182
10 " .	. . . 328	5 " .	. . . 133
11 " .	. . . 358	6 " .	. . . 81
Midnight	. . . 330		

When MM. Lottin, Bravais, and their companions spent the long night of 70 times 24 hours at Alten Bay, in West Finmark, latitude 70, they saw 64 auroras, and perceived some half dozen more by the magnetic needle when the clouds hid the sky. The aurora was not continuous during the long night, but once in 24 hours when the night overshadowed the same meridian in temperate latitudes. If in these lower temperate latitudes the aurora occurred in the daytime, it could not indeed be seen on account of the light of the sun, but it could be perceived by the magnetic needle.

Not only the nightly auroral streamers, often 500 miles long, pointing away from the sun like the tails of comets, but also the eleven years periodicity of great auroras, corresponding with the eleven years periodicity of great solar spots, declares the connection between the sun and our auroras. Then indeed the auroral electricity may be felt on the telegraph wires in the daytime; that is on the sun side of the earth, because by unwonted solar activity the electric fluid is hurried away from the solar to the night side of the earth, and it is felt in its passage; then, in those sea-

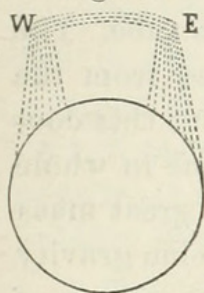
sons of extra large auroras, the tall streamers are seen to arise not only from the north, but all around from the east and the west, and less strongly from the south. Their upper limits seem to come nearly together a little south of the zenith in our latitude, and the near meeting of their tops forms a circle called the auroral corona. This circle is broken, or nearly broken, on the south side, because the streamers rising up from the distant southern latitudes are too far off to be plainly seen. While looking up to the centre of the corona we are really looking out of the far end of a tube—an auroral tube composed of electric streamers. These streamers seem to approach one another, and make the far end of the tube very small, but really they do not approach. Their apparent convergence is like the seeming approach of the two rails on a railroad when the eye can see them far away. These tall auroral streamers, which apparently converge and form the corona, must be several thousand miles high.

Now we can understand why the zone of constant auroras is far this side of the poles, and why the explorers and the whalers in the extreme north have to look southwardly to see the auroras. The polar regions on our globe are not in the direction away from the sun; their zenith is at right angles or perpendicular to the sun's radiations, and the solar electric repulsion drives all the terrestrial electricity away down to lower latitudes.

Now we can understand also why the earth's atmosphere extends so high. Mathematicians have declared that, according to Mariotte's law, it can extend upward only about 40 miles, but the passage of meteors through the air, and their bright ignition, prove that our atmosphere reaches as high as 200 miles. When we stand on an insulated stool charged with electricity, we know how our hairs all stand on end, and reach far out from our heads. Pith balls and tufts of down tied to the ends of threads on the prime conductor of an electric machine, all fly off at the full lengths of the threads. So it must be with the particles of air, only in a far greater degree, because they are so much lighter. The atmosphere, especially its upper surface, is like the prime conductor of an electric machine. This great machine rotating in the sun's rays, is constantly receiving an inconceivable amount of electricity from evaporation, and it must necessarily lift the top of our atmosphere far up—we cannot tell how high.

The Zodiacal Light.—Now first we can understand also the cause of zodiacal light. At the belt of calms in the equatorial region, where the trade winds meet from the north and from the south, there is much evaporation, and as the warm, moist air rises, the vapor is condensed, and it descends in rain. Some, though comparatively little, of the electricity comes down as lightning. During three rainy seasons within the tropics, I heard and saw much thunder and lightning among the clouds, but I never heard of a lightning stroke reaching the ground, though such instances may possibly have rarely occurred without my knowledge. Therefore on the equatorial zone the electricity must accumulate on the top of the atmosphere. This it must the more naturally do because above the unstable strata of the atmosphere, which moves north and south, there is a much taller stable stratum which remains always in the same latitudes. On this curious subject see the latter part of my paper on Meteors, in the Proceedings of the American Association for the Advancement of Science, for 1871. This accumulation of electricity on the equatorial region must meet the same fate as the accumulations near the polar regions. It must be driven off by the solar electric repulsion, and point with tall streamers away from the sun and form the zodiacal light. The zodiacal light has the same color and appearance as a large streamer of the aurora borealis, being brighter below and paling off slowly to the top, the point above where it fails to impress the eye being undefined and uncertain. It is more steady than the aurora, but when watched attentively it is seen on some nights to be broader, or taller, or better defined than on others. Pulsations can sometimes be seen in it, cloud-like movements running upward as in the aurora. Its greater steadiness can be accounted for by the greater steadiness and calmness of the equatorial regions. And the aurora too appears more steady when seen nightly from high northern latitudes than when seen in its extraordinary convulsions from low latitudes. At the equator the zodiacal light can be seen at all times in the year, both in the west in the evening, and in the east in the morning, and sometimes making the complete arch of the heavens. When in great auroral convulsions we see the tall streamers rising up from all around the horizon, I suppose the southern streamers arise from this equatorial region, and that the zodiacal light and aurora are united.

Fig. 1.



The adjoining figure shows a section at the equator of our globe and the departing streamers which form the zodiacal light, the morning or eastern one at E., and the evening or western one at W. At the equator on clear nights they are seen to be continuous by a faint arch all across the sky. The great authority on this subject is the work of Rev. George Jones, Chaplain in Commodore Perry's Expedition to Japan, in 1853-5, printed by the U. S. Government in 1856.

It may be thought that the electric repulsion from the sun should be seen on an ordinary electrometer. But our electrometers are deeply immersed in the bottom of our electric atmosphere, and this being near, overpowers the distant influence from the sun, the same as our moon is controlled by the feeble gravity of the earth, and not by the more powerful gravity of the sun. The sun's electric repulsion is seen in giving a general external direction to the earth's electrical envelop, and not in causing small differences among interior objects.

The Corona of the Sun.—At total eclipses a whitish irregular ring, nearly as broad as the sun's diameter, appears around the sun. It has been compared with the "glory" which in catholic pictures appears around the heads of saints. This is the corona. It is doubtless an effulgence, a constant streaming forth of electricity, like the aurora borealis, or like the zodiacal light, from every part of the sun's surface. It cannot be an atmosphere except in its very lowest border, for some comets have passed through it with their speed unaltered and their bodies unaffected. This impunity could not have happened to such large and extremely rare bodies, with such velocities, through any atmosphere. As it cannot be an atmosphere, we can think of it as nothing but an outflow of electricity, an electrical brush, or as thousands of them united. But what can be the source of this outflow of the electric fluid? We must refer it to the same cause as that from our earth—evaporation. As evaporation from the sun is millions of times greater than from our earth, so the evolution of electricity may be in proportion. On earth the best image of the sun is the crater of a volcano, and no displays of thunder and lightning are equal to those seen and heard in the ascending volcanic emanations. Among our electric machines there is none so powerful as the one which

goes by evaporation. The vapor most highly charged with electricity issues from many small orifices in the sides of a tube. The electric fluid in this case has been supposed to arise from the friction of the vapor against the sides of the orifices; but this conjecture is loose and unsatisfactory. Even if it be true in whole or in part, there is something like it in the sun. The great mass of the sun consists of molten, liquid matters, with a specific gravity one-fourth heavier than water or ice. This is the great source of light and heat. Around this is an envelop of flames from 2000 to 4000 miles high. This height is ascertained by the depressions of the spots, which are solids partially cooled, and floating like cakes of ice on water. This tall envelop of flames is the so-called photosphere, having suspended in it many different solar elements, and the thousands of their fixed spectroscopic lines are dark, because the chief light of the sun comes from the incandescent liquid below. In that liquid chemical action is going on with inconceivable force, and its products are not only heat and light, but red vapors. From the vast amounts of some of these vapor jets, we must suppose that large bubbles of vapor, several hundred miles in diameter, are formed thousands of miles down in the interior of the sun. They must be subject to enormous hydraulic pressure, and in the same proportion they must be ejected upwards with enormous velocities, some more and others less, depending on their sizes and the depths from which they come. Some rise as high as 20,000 or 30,000 miles. Others mount up to 70,000, and some few have been seen to reach 100,000, and according to Prof. Young even 200,000 miles, with velocities proportioned to their heights. The propelling power of these jets has never before been published. They seem to be innumerable, and the red vapor, after rising, falls back like the waters of a fountain. Sometimes the vapor at our distance is invisible in the solar atmosphere where it condenses into visible clouds, and down from the bottom of the clouds some spectroscopists have perceived appearances like the fall of rain from a shower-cloud. What this vapor is composed of we need not now inquire. It is generally said to be hydrogen gas, because some of the hydrogen lines appear in its spectrum. But this cannot be, because it is red, and hydrogen is a colorless invisible gas. It is not permanent, but condenses and falls; whereas hydrogen is a permanent gas, and must accumulate indefinitely on the solar surface unless it takes fire and burns, of

which there is not the least appearance. Hydrogen has only four fixed lines in its spectrum, but Prof. Young has seen nearly 300 in the red vapors of the sun. Probably, therefore, it is a complex vapor consisting of several elements; and, like our vapors here, it may be a source of electricity. Like a hydro-electric apparatus, it may also generate electricity by the friction as the huge bubbles rise up so swiftly from the deep interior of the sun.

In appearance and in action there is a perfect identity between our aurora borealis and the corona of the sun. The lower portions of both are white without any variations of tint. Above their bases begin their radiations—tall streamers reaching upwards. The streamers are brightest below, and gradually pale off towards their tops, and these tops vanish away in space so as to be undefined. In both the largest and brightest streamers reach out the furthest, because they are the fullest and most copious jets or brushes of the electric fluid. Taking them altogether the line of their contours above is a very broken jagged line. Hence around the sun the contour of the corona is often not circular but trapezoidal and otherwise irregular. Between the bright radiations of the corona there are darkish lines extending outwards, not really dark, but faint spaces less brightened by the rays. Wider spaces between the rays are called “rifts;” the same as there may be deep depressions, nearly vacant spaces, in our auroras between two tall streamers. These radiations and rifts in the solar corona have been photographed.

The same rapid changes in our aurora are seen in the solar corona. Sometimes the corona is large, and then it is so bright that the eye can scarcely endure its splendor. It then extends far outward, and is very irregular in its exterior contour—the streamers in some places are seen to rise a million of miles high. At other times the corona is small and pale, and without radiations, or such radiations as are easily perceptible. Then its form around the sun is circular, and nearly even in contour. Prof. Newcomb, describing the total eclipse of 1870, said, “Instead of the gorgeous spectacle I witnessed in the total eclipse of 1869, I saw only the most insignificant corona.” Speaking of the “great changes in brilliancy,” he says, “the corona of 1869 seemed to me many times more brilliant than that in 1870.” “The light of the latter seemed everywhere as soft and diffused as the zodiacal light.” Still even then, other observers, probably with clearer

skies, could detect rays, as Prof. Eastman and Capt. Tupman. Professor Harkness, writing of the eclipse of 1870, said, "I do not think the corona more than half or two-thirds as extensive as that I witnessed in 1869. On that occasion it had a well-marked trapezoidal form, but this time it seemed to me more nearly circular." "Otto Struve, observing at Leipsic, in 1842, found the corona so bright that the naked eye could scarcely endure it. Mr. Airy has been fortunate enough to witness several total eclipses, and he testifies that the corona was much brighter in some than in others. The experience of the officers of this observatory is the same." Here the aurora borealis shows precisely the same differences at different times. It may be large, bright, distinctly radiated, with a rough, uneven contour; or it may be small, faint, without radiations, and perfectly circular on its top.

Not only from year to year, but even during the brief period of a total eclipse, the corona of the sun changes before the eye. In this respect also it is identical with our aurora borealis. Streamers in both shoot up almost with the velocity of light. I have seen in one aurora strong undulations, like white clouds, fly up from our northern horizon to the auroral corona, south of the zenith, in the fraction of a second. The great comet in 1843 passed around the sun in about two hours, and its tail, more than 100,000,000 miles long, must have swept around through an arc of 300 degrees in that short period. It could not have swung around like a stiff lever from the comet; for that, considering the small mass of the comet, would have been contrary to the laws of matter and of motion. It must have darted off from the comet every instant 100,000,000 miles, with the velocity of light. Nothing but electricity can do this. Now the conviction fastens itself on our minds, that the streamers of the solar corona must be capable of the same out-darting velocity. What happens on our own globe and on the comets may happen in the sun. Hereafter observers of total eclipses will watch attentively to see the movements in the solar streamers.

Already we have a beginning in these facts. Captain Tupman, in his report to Professor Harkness about the eclipse of 1870, writes as follows: "The first part of the corona that attracted my attention was a ray or enlargement at the right upper quadrant, a little to the right of the very bright protuberance, A; but by the time you had done with the polariscope, which could scarcely have been

ten seconds, the left and lower parts, B to C in the figure, were the brightest and the largest; and so they remained until near the end of the totality, when the part, D, in the right lower quadrant, almost if not quite rivalled them. The ray, D, did not enlarge suddenly, but very gradually indeed. The upper part of the corona was throughout the faintest. The extreme right was also faint until quite at the end of totality, when it brightened a little. No part increased in brilliancy without extending itself further from the moon at the same time, so as to become a more or less pointed ray." Just, in fact, as it should do if it were the action of electricity. A copious outgush of the electric fluid would enlarge and brighten the ray and extend it far outward as an electric brush. The evidence is strong that the corona of the sun varies, like the aurora borealis, not only from year to year, but even during the short space of a total eclipse.

I have now brought together the chief facts about the corona of the sun. They are like those of the aurora borealis. The aurora is well known to be electric. And all the facts of the corona are perfectly explained by the same theory. Regarding the corona as being a great electric brush, we have also an explanation why the aurora and the zodiacal light point, like the tails of comets, away from the sun. They are driven off by the sun's electric repulsion. If the sun's electric brush extends off on every side a million of miles from our stand-point, then if we stood nearer, say at the orbit of Mercury, we would likely be able to see them extend twice as far. The power, the repulsive force, of such an enormous mass of electricity is beyond our estimation by any reasoning, *à priori*. Facts alone must teach us how far its repulsive force may extend, and such facts we see in the diurnal and in the eleven years' periodicity of the aurora, and in the diurnal periodicity of the zodiacal light. Such facts we see much more impressively in the directions of the tails of comets driven off by the mighty repulsion of the solar corona. To the comets we will now attend.

The Tails of Comets regarded as Electric Brushes.—Here on our earth some materials evolve much more electricity than others. Tin, zinc, and mercury, duly mixed, are found to be the best for friction machines; and a like selection of acids and metals is necessary for the galvanic battery. The materials of the sun and of the comets are very different from ours, and, therefore, they evolve much greater quantities of electricity. The fixed lines

in the solar spectrum are innumerable, and indicate hundreds, probably thousands, of simple elements in the sun. Only about a half dozen of them are terrestrial, and some of these, such as the iron, may have fallen in the sun as meteors. Thousands of solid meteors strike our earth annually, and the iron ones occasionally weigh thousands of pounds. More and heavier meteors must fall in the sun. The materials of comets we know to be very different, because they are such light bodies, and they are easily evaporated and dilated by solar heat. A comet at a distance appears large, but nearer the sun it seems smaller, because much of its mass is so dilated by solar heat as to be invisible. As the cometic and the solar elements are so different from the terrestrial, it is not strange or singular that their evaporation gives out more electric fluid than the saline waters of our ocean.

Comets present appearances so different from the other celestial bodies, that they have been a terror to the world, and even scientific men have regarded them as totally different in their natures from the other stars. But they are precisely similar to the other stars; the only difference being that they carry some few ordinary principles to excess. Their bodies are solid and very small; in modern times they have repeatedly occulted the stars. Their atmospheres are unusually large. They are easily evaporated and dilated by the sun's rays; and in this evaporation they evolve unusual amounts of the electric fluid. This is all. These few facts explain all their wonders without exception.

From their smallness they do not make their appearance in the outer regions of the solar system. Donati's comet in 1858, so magnificent when near, was first seen by the telescope as a faint nebulosity at only half the distance of Jupiter, whose diminutive moons are so easily seen with the smallest telescope. As they approach the sun their peculiar elements are easily evaporated; from this evaporation their electricity is evolved, which, rising up through their atmospheres, produces light; the same as it produces light in our own atmosphere, from the mild glow of the aurora to the brilliant lightning. When first visible they are a faint nebulosity. On coming nearer to the sun, their evaporation is so rapid, and their electric outflow is so abundant, that they are the most splendid objects in the heavens, and often they have been seen in the daytime, even in the close neighborhood of the sun. These facts show that very little of their light is the reflected

radiance of the sun. It is chiefly their own independent luminosity springing from electric excitement.

This light is seen to arise from the side toward the sun, and, therefore, from the most heated and evaporated side. It rises narrowly fan-shaped; very narrow and bright below, and spreading and paling upwards through the cometic atmosphere. It is then, by the repulsion of the sun's corona, driven backward all around like a fountain away from the sun, and it forms the tail, which generally spreads and becomes fainter, until it is lost by dispersion. Its resemblance to our auroral streamers is then complete. In the summer of 1874, when Coggia's comet appeared in our northern horizon, with its large, broad tail projecting straight upward, I was on Mount Desert Island, far up the coast of Maine, where the auroral streamers rise beautifully almost every night. The rise of those streamers, and the rise of the comet's tail, were identical in every particular. Both were of the same color and tint; both were brighter below and gradually paled off upwards. Their tops had the same indefinite ending, and both plainly lengthened and shortened while attentively watched. Tremulous waves ran upwards through them both—whitish, cloud-like appearances—as if they were special gushes of the electric fluid hastening to escape, and carrying out the tops of both to a further distance. The same cloud-like impulses pass through our artificial auroral tubes. But they are plainer to our view in our near auroral tubes, less plain in the aurora brushes, and faintest of all in the tails of comets. These three gradations depend on the distance. I remarked that the general brightness of the comet's tail, so many million miles off, was about equal to that of the aurora borealis, so comparatively near; proving that the amount of the electric fluid from the comet must have been inconceivably the greater.

It is a cardinal fact that the tails of comets do not occult the stars. If their tails were vapors of any kind, the occultations would be decided and constant; therefore the apparent vapor rising up from the sunny side of the comet is really the electric fluid.

The tail of a comet must be a hollow tube, because it springs from the sunward side, and falls back around on every side, like the waters of a fountain, and its own self-repulsion hinders it from coming together. Hence there appears a dark line through the centre of the tail, because from there, less electric light meets the

eye than from the borders whose edges are turned towards us. The dark line cannot be the shadow of the nucleus, because a shadow cannot curve as did Donati's comet.

The fan-shaped jet of light arising through the front of the comet's atmosphere is not always steady, but breaks out at different places, "as from points of least resistance." Hence the tail is sometimes described as unsteady, and to "sway to and fro like a willow branch."

Auroral arches arise over our northern horizon and hover there for a while, occasionally two or three above one another, and then dart off in streamers. Exactly the same luminous arches rise in front of the comet, and the streamers then become the tail. But there is this difference. The streamers of the aurora rise from the convex side of the arch; those of the comet are driven backward by the solar corona, and seem to depart from the concave side.

The head of a comet is solid, with perhaps some exceptions, and the bright glow of light all around it is called the nucleus. The broader and paler atmosphere is called the coma or hair. But some writers call the tail the coma. In the coma or atmosphere there may be clouds, as in our own; and these clouds have been seen to be lit up by the electric passage. A comet may have many tails, as many as six. This is because in the solid nucleus there may be many points of least resistance, out of which the streams of vapor and electricity flow.

The greatest wonder about comets is the length of their tails; some of them are 120,000,000 miles long and even more. The diameter across the tail has been known to be 15,000,000 miles. But is it possible that there could have been so much electric force in a comet as to send out such an electric brush? We may as well ask how it is possible for our sun to send out such a mass of heat and light uninterruptedly during hundreds of millions of years? The answer is, that the materials of the sun and of comets are so very different from those in our earth. The enormous heterogeneity of matter should be more studied by the scientific men of our day. This neglect is now their great fault. All matter was once many billion times more rare than hydrogen; not dilated by heat, but by its own native repulsion. This we know from the teachings of the nebular theory. Even yet hydrogen is a million and a quarter times less condensed than platinum. What differences there may be in the heat-giving power, or in the electric-

producing power, of the materials of other celestial orbs, we are perfectly unable, *à priori*, to tell. All that we know is from what we see.

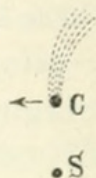
The electric composition of these great tails becomes manifest from the way they go around the sun. Some great comets go around the sun in about two hours, as that of 1843, the tail all the while pointing away from the sun. Its outer end could not have swung around like a stiff lever through a space of 700,000,000 miles in so short a time. That would have been inconsistent, as I have already said, with the laws of matter and of motion. The tail must, therefore, have darted out continuously from the comet as an electric brush, and it must have been repelled in its direction away from the sun by the sun's more powerful electric mass. There is something clearly defined and decided in the huge tail pointing away from the sun in its approach, and then apparently swinging around with the velocity of lightning, and on its departure pointing away from the sun again. The electric theory of the constitution of the solar system explains the wonder clearly and easily, and nothing else can.

Evaporation explains why the tails of comets have become shorter on successive visits. The tail of Halley's comet was first described as being excessive. In 1682, it was 30° in length; in 1835, its greatest length was only 20° . For the first two months in 1835 it had no tail. It began on October 2d. On the 5th, it was 4° or 5° long. On the 15th, it had gained its greatest length, 20° . On the 29th, it was only 3° . Afterwards, at its perihelion passage, it had no tail. The explanation is that all these elements, whose evaporation evolved the electric fluid, had turned into vapor before perihelion, and then there could be no further evaporation with evolution of the tail. But a condensation of much of that vapor must again take place in the cold outer region away from the sun; and this recondensed material must furnish another tail on its next visit—a smaller tail, however, for a portion of the vapor must be carried away with the electric fluid, and scattered into distant space. When comets have no tails, it may be that they have never possessed any of those peculiar elements on whose evaporation the tail depends, or that by repeated visits to the sun all their powerful electric elements have been lost.

The electric theory explains the various forms of the tail. That of 1843, which was more than 100,000,000 miles long, appeared

like a straight cylinder of light with very little difference in thickness through the whole length. I remember it well. It was very near the sun, whose large electric mass and powerful repulsion drove off the smaller mass in right lines. The sun was the great prime conductor fully charged, and the comet was only like a small highly-charged pith ball. The tail of Coggia's comet, being much further from the sun, was more spreading and fan-like. On account of greater distance, the sun's force was less, and the self-repulsion widened the tail. The tail of Donati's comet was spreading on account of the distance from the sun, and gracefully curved. This curving was because the comet was moving nearly at right angles to the direction toward the sun, and as the tail was not repelled out rapidly, it fell behind the comet in its progress. In our figure S represents the sun, and C the comet moving in the direction of the arrow, and getting in advance of the extreme end of its tail.

Fig. 2.



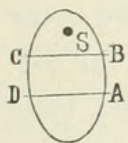
Our theory tells why some comets have been split in two or three parts, and finally into thousands of meteors. Although they are solid bodies, their cohesion is very slight. With a cotton string I tied in a bundle a handful of the downy tufted seeds of the milk-weed, *Asclepias incarnata*, which is abundant here. The other end of the string I connected with the prime conductor of a large electric machine. On turning the crank my bundle was soon dissipated, torn by electric repulsion into many parts, which flew away. The repulsion was too strong for my tying. So it may be too strong for the weak cohesion of a comet. It may divide the comet first into two parts, and then into shreds, which may form meteor streams like those of August and November. When Biela was divided into two, it is significant that each part was still a perfect comet, having a head, a nucleus, and a tail. The two alternated several times in brightness, according as the electric fluid was liberated more freely from one than from the other. In a thunder-storm we see the lightning leap suddenly from cloud to cloud. This violence is from the resistance of the air. But the two portions of Biela were in a vacuum, and a pale band of the electric fluid was seen to pass from the brighter to the fainter portion, the same as we see it pass through an exhausted auroral tube.

The two parts of Biela continued steadily to separate as though driven apart by their electric repulsion. Before their disappear-

ance the distance between them was 160,000 miles, and by their next return that distance had grown to be 1,250,000 miles. On the night of the 13th and 14th of November, 1857, the officers of the Observatory at Washington counted 3000 meteors in an hour. Professor Newcomb calculated that on an average every meteor occupied as its own territory 900,000 cubic miles. The gravity of the sun could separate them only in one direction; but their nearly even diffusion every way seems like the work of electric repulsion. The meteors of the August stream are still more widely dispersed.

We can now see how comets may shorten their periods without the theory of a terrible ponderable resisting medium ex-

Fig. 3. isting everywhere. That is a most violent theory, and threatens to break down the entire solar system on the sun. Let the curve A, B, C, D be the elliptic orbit of a comet, and S the sun in a focus. Let the comet on its approach move any distance from A to B in a day, and an equal distance from C to D in the same time on



its departure. The electricity of the sun repels the comet, because both are clothed with electricity; the same as a charged prime conductor repels a charged pith-ball. For simplicity of conception let the repulsive influence from the sun move just as fast as the comet in these two regions of its orbit; that is, from B to A, and from C to D, in one day. Then on its approach the comet must suffer resistance in moving from A to B; but it finds no influence at all in moving from C to D. The same principle must apply nearly all around the orbit. Whatever the difference between the velocity of the comet and that of the repulsive force from the sun, it must remain true that from aphelion to perihelion the comet must lose more velocity from the electric repulsion of the sun than it gains by that repulsion, in moving from perihelion to aphelion. Therefore, upon the whole, the comet must suffer resistance from the electric repulsion of the sun, and its period must be shortened. This resistance is all the more effective from the great size and small mass of the comet. Encke's comet, which gave rise to the "resisting medium" theory, is highly electric, as is shown in the drawings of Professor Asaph Hall, made on its return in 1871, printed in 1872. For one, I am happy in being relieved from the dangerous, cumbersome, and highly improbable "resisting medium" theory.

It has before been surmised by some that the solar corona is electric. Others have thought that the tails of comets are electric. The aurora has been proved to be electric. But no one has conjectured the origin of these electricities, except that evaporation has been regarded as one of the origins of terrestrial atmospheric electricity. No one has assigned evaporation as the cause of the solar corona. Sir John Herschel believed the tails of comets to be vapors of some kind, raised by the heat of the sun, and driven away by some unknown repulsion from the sun. But his vapors were not the electric fluid, and his repulsion was not electric repulsion. See his "Outlines." No one has said that the zodiacal light is electric, and that this and the auroral streamers, always like comets, point away from the sun. No one has regarded all these phenomena as emanating from a common cause: the solar heat causing evaporation. No one has supposed that the far distant solar corona, by mere electric repulsion, drives off the tails of comets, the auroral streamers, and the zodiacal light. A highly-charged electric machine affects a delicate electrometer far off on the opposite side of a wide room; but this wonder, until now, was not fruitful in originating our theory. Now, first, all these distant facts have been brought together, and they are seen to form a harmonious system. A new spiritual influence is found to pervade our entire solar system. If, in this system, the solar repulsion drives off the tails of comets 120,000,000 miles with nearly the velocity of light, why should it not reach, like gravitation, to the nearest fixed stars? What and where is to be the end of this new advancement?



1878. "The Electric Constitution of the Solar System." *Proceedings of the Academy of Natural Sciences of Philadelphia* 30, 102–118.

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