VI.—*Some remarks on Theories of Cometary Physics.* By C. PIAZZI SMYTH, Esq.,
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While the physical appearances of comets have ever excited such intense curiosity and interest, all the theories concerning them are generally confessed to be insufficient to explain them; and, certainly, if we may judge from the various views advocated by different writers, and the anomalous forces gratuitously brought in to support the different hypotheses—it is so.

This unsatisfactory state of things, so different from that in which is the theory of the motions of comets,—seems to be owing partly to the difficulty of making the necessary observations by reason of the undefinable nature of the bodies themselves, and partly from the untoward circumstances under which the observations must be made, as well as the rareness of any opportunities offering. Hence, theories are built upon accounts handed down from old astrological times, when men's prejudices would have prevented them, even if their means had been ample, which they were not, from giving any satisfactory and trustworthy accounts of the phenomena displayed by the heavens of their day.

Then, again, the theories appear to have failed from attempting too much, attempting things not legitimately within their reach; it would have been enough to determine the laws of the changes which the tail undergoes during the orbit of a comet; but in place of this, they attempted to shew why the tails were there, and how they came into existence. This is as much as in the planetary theory to attempt to determine why Saturn has rings; a problem which would have eluded the grasp even of NEWTON, and will for ever remain wrapped up in the mystery of creation; enough for us that the rings are there; we can measure their diameter and thickness, approximate to their weight, and determine the laws of their rotation, and alternate appearance and disappearance to the earth, and to their own planet; and something of the same sort we may expect to be able to do in the case now before us.

It has been remarked that theory and fact sometimes unite, and that something of theory is necessary to enable us to speak correctly of facts. Many instances of this occur in the history of most of the sciences, but in none have the facts been more misinterpreted by the vulgar feeling of the senses, in the absence of correct theory, than in the case of the physical characteristics of comets. No phenomena were so likely to be misinterpreted by reason of the strong prejudices almost innate in men's minds, as well as the specious and inexplicable character of the appearances themselves. Accordingly, because the tails of

comets were seen chiefly at or about the perihelion passages, they were said to be produced then; to have been shot out, and then drawn in again, or dissipated; and numerous have been the theories to explain this creation and extinction. And yet of all the facts that have been ascertained, if any of them can be so considered, with regard to the physical appearances of comets, of none may we be more sure than that the tails of comets, in place of being *largest*, or existing only at the perihelion point of the orbits, are then the *smallest*. Comets of every size, (the distinction of those said to be with and without tails is visionary, or rather the tail is equally a part of the general body of the comet, as the so-called head, and obeys the same laws), when accurately observed, have always been found to decrease in coming to perihelion, and to increase in size in retreating therefrom; this condensation of substance, producing more power to reflect light at that period of the orbit, when, from the closer proximity to the sun, there is more light to reflect. These two causes combining, and both increasing most rapidly with comets of great excentricity and small perihelion distance, occasions the sight, all of a sudden, of a long cometric ray in our skies, when the previous night, or at least the previous clear night, there was none bright enough to catch men's eyes. As the comet leaves the sun, the tail or body expands, and partly from its consequent greater rarity, and the diminishing intensity of its solar illumination, is lost to our sight; and only the denser roundish portion about the head remains visible. This is likewise expanding, and is at length also lost sight of for the same reason. In like manner a comet reappears, first the oval mass about the head, and then the tail gradually strengthens; but its aspect will materially depend not only on its distance from the sun, but on our distance from it, and the direction of our line of sight with the longer axis of the body.

Having had the good fortune to see a rather large number of comets, both great and small, and under circumstances favourable above the average, I hope that I may be of some service to theorists, by stating what data may be looked upon as well fixed with regard to these phenomena; by pointing out some corrections which are absolutely necessary to be made upon the observations, before any good and safe grounds for theorizing can be procured, but which corrections never have been made; and by pointing out the most probable method of improving the observations themselves, which, as at present conducted, are by no means satisfactory.

With regard then to the physical nature of comets, we may take the following as axioms:—

1. A comet consists of a nucleus, and one or more gaseous envelopes.

(1.) No instance has ever been recorded, at least since the fabulous days of astronomy, of a comet having ever been seen without some gaseous appendage, forming, indeed, a distinctive feature at a distance from every other body of the solar system; at a distance, because very close to one of the planets, especially one or two of the asteroids, something of its atmosphere might be ob-

served ; but, at the actual distances at which they are viewed, the most powerful telescopes never show these atmospheres in the same manner as those of a comet ; they are indicated only by a very different order of phenomena.

When Uranus was first discovered, and no one dreamt of planets beyond Saturn, it was called a comet ; not because its form was like that of any recognised comet, but because it was expected that its orbit would prove similar ; when, however, the real nature of its path was discovered, the appellation of comet was quickly retracted.

So much for the necessity of a gaseous envelope ; of the equal importance of a nucleus, it may be remarked, that although some comets are described as having nuclei, and others as having none : this turns out to be but negative testimony, inasmuch as these latter bodies have always been the fainter, smaller, and more distant ones, in which the nucleus should have been so much the more difficult to distinguish ; and if it has not been actually observed itself, there has at least been invariably noticed in every recorded comet, some one point where the gaseous matter was visibly more concentrated than in other parts, indicating thus a virtual or a dark nucleus, if not an actual and a reflective one : while observation, combined with calculation, has satisfactorily shewn, that in comets of every degree of size and excentricity, the mass is so very nearly concentrated in this nucleoid centre, that that need alone be referred to in all determinations of the orbit.

2. The nucleus if solid and material, is exceedingly small.

(2.) Every advance of our knowledge has tended to diminish the possible size of the solid nuclei of comets, planetary perturbation has shewn them to have no sensible mass, and telescopic observation no sensible size ; and in the cases of comets of all sizes, observers have witnessed them pass over stars in every position, except, perhaps, exactly centrically with the nucleus, without perceiving any obscuration of the stellar rays.

The old observers have certainly spoken of very large nuclei, but they evidently meant rather the head, which, in some comets at certain parts of the orbit, presents in small telescopes an appearance of planetary opacity and definition.

Such was the case with the great comet of 1843, for three or four days after having passed its perihelion ; in small telescopes it was difficult to avoid believing in the existence of an actual planetary nucleus of very notable size ; but the fourteen feet reflector of the Cape Observatory shewed the borders of this head to be filmy, and exhibited small stars shining through it ; day after day it expanded and became less defined, until at last it ceased to present a solid appearance in any telescope ; and at no time was there anything larger than a stellar point, to which the attribute of hard or heavy matter might be expected to apply.

3. The nucleus is excentrically situated in the gaseous body.

(3.) The nucleus actual or virtual, has never been observed in the middle of the envelope, but always nearer one end than the other, the envelopes too, never being round, but invariably more or less elongated.

4. Comets of longest period have the largest bodies.

(4.) This is the general result of cometary statistics, but need not be any more strictly true, than that the largest planets are all at the greatest distances from the sun ; they are not strictly ranged in the order of distance agreeably with size, but as a general rule merely, the smaller are closer to the sun than the larger planets. In the same way the telescopic comets, when sufficiently numerous observations have been obtained, have almost always been found to have short periods, and those very brilliant ones, with not only long but broad and dense tails, have invariably been found to be of long period.

5. Those comets whose orbits have the greatest excentricity, are the most excentrically situated in their envelopes, or, vulgarly speaking, have the longest tails.

(5.) This may not be strictly true, but yet is assuredly a very marked feature in the statistics of the question. The great comet of 1843, whose orbit was the most excentric ever known, *i. e.*, had the least perihelion, but great aphelion, distance,—had also the longest and narrowest tail, and the smallest head; consequently the nucleus situated near the centre of the latter was most excentrically situated in the gaseous envelope. HALLEY'S comet, and that of 1811, of less excentricity of orbit, had shorter and broader tails and larger heads; and their nuclei, consequently, less excentric: while the telescopic comets of short period, and aphelion not extraordinarily greater than their perihelion distances, exhibit merely somewhat oval masses of vapour.

6. A comet revolves on an axis passing through the nucleus, and at right angles to the major axis of the envelope, in the same period of time that it takes to revolve about the sun: hence, the tail being turned away from the sun in the normal position, is turned away from him in all other parts of the orbit also.

(6.) Every comet has invariably been observed to have its tail turned away from the sun in every part of its orbit; this was the first notable fact established in cometary physics, and the axiom is but a different statement of it.

7. This axis is not at right angles to the plane of the orbit, but variously inclined in the case of different comets, as with the planets.

(7.) There is no reason to expect the contrary; indeed, analogy rather leads us to this conclusion, and it may, if admitted, be sufficient to explain the apparent want of symmetry observed in the tail of HALLEY'S comet, that of 1819, and most, if not all, which have been the subject of special attention; and it may tend to account for some of the differences in the appearance of the former body in approaching and leaving its perihelion, at considerable but equal distances on either side of that point.

8. A quicker rotation round the longer axis of the body also appears to exist.

(8.) This seemed to be almost proved by some of the changes which took place in the head of the great comet of 1843, night after night, in the earlier part of its apparition; for instance, a double-winged head, laterally, one night, becoming a single and centrically winged, or rather a tailed-head the next night; but when a body is seen for so very short a space of time, for a few minutes only in twenty-four hours; and sometimes, perhaps, for several days, even that short glimpse is prevented by clouds,—it becomes extremely difficult to separate in such a body as a comet, in which there is nothing decided and tangible, and fixed either in size or brightness, any indications of revolution from those of the other motions and changes which are going on simultaneously. But it seems a point well worthy of attention, and to be proved or disproved.

9. A comet shines by reflected light, and shews a sensible phase; the quantity, form, and position, therefore, of its component matter, cannot be judged of by the eye alone.

(9.) That comets shine by reflected light, is considered to have been proved by ARAGO'S polarizing experiment; and was inferred before by every analogy in the planetary system; but all appearance of *phase* has been denied, this, therefore, requires a little explanation. The supposed absence of phase has been attributed to the excessive tenuity of the matter of the comet, and the case has been illustrated by reference to the thin clouds often seen in the west after sunset, or in the east before sunrise, glowing in the solar rays, literally drenched with light, and exhibiting no distinction of light and dark side. A little examination of this instance would have shewn that the conclusion is not so safe; the whole of the cloud being so bright, the difference of illumination of the two sides of it is

merely so much the more difficult to distinguish, by reason of the well-known optical or physiological law, that a small difference in the brightness of two objects is more difficult to perceive in proportion to their absolute brightness. If our sensation and means of measurement are not sufficiently accurate in this case of the thin cloud, we have only to turn to a thicker cloud (of the same species, and in a similar part of the sky with regard to the sun), and there we shall see the same law which must obtain in the former case now visibly developed; and then we come to the necessary conclusion, that the illuminated side of every cloud must be brighter than the other, *i. e.*, that it must shew some phase.

The comets are undoubtedly far rarer than any description of cloud floating in our atmosphere, but they are seen under far more favourable circumstances for exhibiting a phase; for, they are illuminated by the sun from one *end*, so that there must be a much greater difference of intensity of light at the two ends than there would be at the two sides, if transversely lighted, as with the long thin films of bright cloud alluded to; and, further, the comet being of the last degree of faintness, the eye is much better able to detect small differences of luminosity. Then again, comets, though they be exceedingly rare, are very voluminous, so that the rays of light have to traverse a great space of matter in passing through them; and if some is reflected in the anterior parts of the body, as we see is the case by the fact that the body is rendered visible to us, there cannot possibly be so strong an illumination on the posterior parts; therefore, we shall either see them fainter than the others; or not at all, if the anterior portions themselves are but just visible.

With these preliminaries then, we may ask, what comet has ever been seen without some phase? for in every single instance, the anterior part of the head, or the denser portion of the envelope, has been brighter than the posterior, exhibiting sometimes the appearance of a luminous sector in front; and the anterior half only, of the body, has been seen, the comet presenting as a general rule two diverging and slightly curved tails. This has been generally held to be merely the effect of looking transversely through a conical envelope of luminous matter, when the ray of light passing through the central portions would meet with less substance, and that part would therefore appear darker than the limbs. This, doubtless, prevails to a great extent, but then we must further remember, that the exterior coats of the envelope will be more strongly illuminated than the interior; and the dark axis of the comet's tail becomes therefore a particular character of phase. Further, as we proceed to the posterior portions of even the outer coats of the envelope, they will be illuminated by a weaker light from the sun, by reason of their greater distance; and if any convergence of them towards the axis should occur, as has actually been observed in some cases, their illuminating rays being then still further diminished in intensity by absorption and reflection, they will hardly be enabled to make themselves visible to us. Thus, the diverging limbs of the tail, and its forked or many-pointed termination, becomes an effect of phase on a body which may be of a symmetrical and rounded, and complete character.

This point, it is of the greatest importance to determine, for if the actual forms of comets be as we see them, they are altogether anomalous in the heavenly regions; and merely on the score of the form of these supposed conical envelopes and diverging streamers, equally anomalous forces have been introduced to explain the phenomena; electricity and polarity, which have no place in any other department of astronomy, being allowed precedence here.

Granting, that a comet is always a prolate spheroidal mass of vapour of different degrees of prolateness, and of actual length in various cases, but always illumined from one end, then we may expect in the larger and denser comets to see but the anterior half of the body; the posterior half being so much further off from the sun, and the rays of light which reach it, being further so much weakened by having passed through the first half; consequently, in this description of comet, we might expect, and we absolutely do find, the phenomenon of the forked tail most marked. In the smaller and fainter comets, on the other hand, the rays of light which reach the posterior half of the body are not much dimmed either from having passed through the excessively tenuous anterior portion, or from having travelled through any notably greater distance from the centre of radiation; in such cases we may expect to see more completely the whole form of the comet; and in them we do actually find nearly, and sometimes quite oval forms, and all gradations from these, through truncated ovals to the forked tails.

These facts induce us to admit the possibility of the bodies of comets being of a far more regular geometric form than has hitherto been suspected, if we allow that conclusions derived from small comets may be safely so extended, *mutatis mutandis*, to large ones; but this view is further confirmed by a notable observation of one of the largest and most excentric of comets.

As already observed, comets decrease in size and increase in density on approaching the perihelion, and the reverse on receding therefrom; hence the phase ought to be most evident, or the tail

most forked about the perihelion, both on account of the greater absorption and reflection of light in passing through the denser anterior half, and on account of the greater ratio which the difference of distance of the anterior and posterior ends bear to that of the former and the sun; and at a distance from the perihelion, the effects being reversed, we might expect to see less phase, a less dark axis in the tail, and something of a convergence in the limbs of it. Now, both of these phenomena were distinctly and markedly observable in the great comet of 1843; near the perihelion the tail being forked, the axis almost as dark as the sky round about, and the limbs intensely bright and sharp; but long before it was lost on its retreat to aphelion, the oval darkness was almost obliterated, the whole tail was diffuse, and the posterior portion for fully one-third of the whole visible length shewed a convergence inwards.

But the notable phenomenon is still to come; allowing the above increase of phase in approaching perihelion, it is also evident, that if the perihelion distance be very small, the sun may present a very large angle as viewed from the comet; and in this way rays of light may reach every part of the external coats of the body, and these may be also illumined to that intense degree, that as with the sunrise and sunset clouds already referred to, no phase may be seen; so that, with such comets the maximum of phase will occur a short distance on either side of the perihelion, at and very close to it there will be little or none.

As the comet of 1843 almost touched the sun's surface in passing round it, it must have presented as satisfactory and conclusive a proof as man could have wished for. But although it must have been visible to the naked eye, and to nearly the whole world, in this critical part of its orbit, no mortal man is known to have seen it. Rather a melancholy fact of the imperfection of the astronomical watching of the present age; and it appears all the stronger, from ARAGO having, in his report to the Academy, descriptive of the discovery of a small comet, enlarged on the perfection of the system of search organized at the Parisian Observatory; by which it appeared that nothing could escape detection; for the assistant who made the discovery, having purposely kept silence when he was relieved in his watch by another person, this one discovered the same comet before having been an hour at his post. But to return to the comet of 1843, it was seen while still not very far from the perihelion, when the sun was still subtending a very large angle, viz., on February 28, the perihelion passage being February 27, 1843; but then only by three persons, or rather parties, and none of them have given sufficiently accurate accounts of what they saw, or have attempted what would have been so invaluable, if effectually and faithfully executed, a *drawing* of the appearances; but their statements, as far as they go, decidedly confirm the views above enumerated. The first of these happy three, with whose account I became acquainted, was a person at the Cape of Good Hope, who (decidedly no scientific person, and having no prejudice in favour of any theory), described the comet as he and his shepherd boy saw it at noonday, a bright hazy star, with the hazy matter streaming off on one side, and *collected into a focus* about two feet *behind it*. Allowing him to have estimated the sun's diameter at one foot, the apparent length of the comet's tail is well given; and the comet itself being spoken of as a bright star in the hazy matter, which streamed off, and collected into a focus at a certain distance behind the head; this certainly may be interpreted into a somewhat symmetrical elliptic figure, having the nucleus in the focus nearest the sun.

The next testimony is from the ship Owen Glendower, the crew and passengers of which ship, when off the Cape on February 28, saw the comet plainly about sunset, "as a short dagger-like object close to the sun." This is not particularly explicit, but yet we may certainly conclude from it, that the comet was broad in the middle of its length, and pointed towards each end, and had little or no axial darkness, which sufficiently conforms with our idea of the perfect shape of the envelope of a comet seen under such circumstances.

The last witness is from the United States, where Mr CLARKE, of Portland, saw the comet at 3^h P.M., on the same day, and examined it telescopically, and describes it in these words:—"The nucleus, and also every part of the tail, were as well defined as the moon on a clear day. The nucleus and tail bore the same appearance, and resembled a perfectly pure white cloud without any variation, except a slight change near the head, just sufficient to distinguish the nucleus from the tail at that point." The first sentence well describes the increase of density and definition we have already insisted on as a consequence of so near an approach to the sun; and the second paragraph as perfectly describes the absence of axial darkness, a consequence partly of the increased brightness of the illumination of all the external portion, and partly of its being seen in daylight, and so close to the sun; for then, as every one knows, even the darkest shadows amongst the mountains, and in the craters of the moon, those which appear absolutely black at night, are, under those circumstances, barely distinguishable from the brightest portions. As to the shape, Mr CLARKE says,—that the

whole body of the comet was seen, but what his idea of the true complete form of its body was, he does not give; but, as he states, that a slight change of brightness near the head was “the only thing to distinguish the nucleus from the tail at that point;” and, further, “that every part of the tail was as well defined as the moon on a clear day;” it would appear to be quite safe to infer, that the tail was not forked; and that the base, instead of a broad or forked, or many-pointed indistinct termination, was as well and sharply outlined as the limbs. A notable distinction this to every subsequent view obtained on succeeding days; and, indeed, in the case of every other comet whatever observed at a great distance from the sun,—when, whatever the definition of the limbs of the tail, the termination or the base has always been so excessively uncertain, that different persons have varied several degrees in assigning the place of it.

Alas! indeed, that the practical astronomy of the present day did not take better account of this unique and critical instance which was offered by the skies of our times; centuries may elapse before another such instance may occur, and this question of the real and complete form of a comet may be in abeyance as long. Something may, doubtless, be done by rigid examination of all the persons who did witness the phenomenon in the comparatively imperfect form of the day after the perihelion passage; but their answers would not be very safe now, so many years after the event, and after the promulgation of a particular theory. Something might also, perhaps, be done, by careful and photometrical observation of the faintest nebulae, while the darker part of a comet's tail, if it exists, must be passing across them. But this is a very unpromising method, for comets, at all periods, attenuated, become so exceedingly diffuse by the time that they have reached a sufficient distance from the sun, to be viewed for any length of time in a dark sky, and contrasted therein with very faint nebulae,—that we can hardly expect to obtain any certain indication in this manner. The only sure way is for the comet to be so very close to the sun, that rays from some part or other of his surface will reach every portion of the body of the comet directly, *i. e.*, without having to pass through any other part in order to arrive there.

The fact of this great and invaluable opportunity having been lost, would seem to shew that it is highly desirable that extra meridian observations should be made and watched for by some public observatory in its official routine, instead of being abandoned altogether to amateurs. It is high time that our observatories should be placed in the clearer climates of some of the colonies, and that the most favourable geographical positions should be sought for, rather than the most convenient places in a social point of view; for this results in smoky towns in our own beclouded country being selected as the places where the stars are if possible to be observed.

10. The gaseous envelope is of extreme tenuity, is elastic, and with regard to light is slightly reflective and imperfectly transparent; it decreases in size, but increases in density, and light reflective power in approaching the perihelion, and the reverse when receding from it; and this occurs in a degree proportioned to the excentricity of the orbits of the comets.

(10.) That the gaseous envelope of a comet is of extreme tenuity, and is elastic, slightly reflective and imperfectly transparent, is apparently confessed on all hands, and is proved by the phenomena presented by every comet. That it increases in density and light-reflective power with its proximity to the perihelion, and that this occurs in a degree proportioned to the excentricity of the orbit, requires, at least the latter part does, that the instances on which it is founded should be mentioned; for though the contraction in size of small comets on approaching the sun had been remarked, yet some had maintained it to be accompanied by a decrease in density, by an actual evaporation and disappearance at perihelion; and no one that I am acquainted with had applied it to the larger comets also, or compared the degree of it, with the excentricity of the orbit.

With regard to the effect of excentricity of orbit, a small proportion of it should make a comet visible for a long period on either side of the perihelion, from the lesser degree of attenuation and expansion of its substance at a distance therefrom; and it should also be lost in the sun's rays for a considerable time at and about the perihelion passage, from the matter never being compressed into a sufficiently dense body to be visible in the blaze of day. This rule appears well borne out by both small and large comets; the small ones, for instance ENCKE'S, BIELA'S, and FAYE'S, which have for the ratio of the excentricity to the semiaxis major, the numbers respectively, 0.847, 0.755, 0.555, shew no very

well marked changes or even characteristics at any part of their orbits, and are soon lost in the twilight even in their densest states ; there being little compression, and by axiom 4, little substance to compress, the mean distances being only 2·216, 3·502, and 3·812, the earth's distance being unity.

In the case of HALLEY's comet, however, the appearances are very different, the excentricity being 0·967, and the semiaxis major 17·988 ; hence, on this large body approaching the sun and undergoing such a much more intense degree of compression, distinctly marked changes were seen almost from day to day, and at a certain distance from the perihelion it was of great brightness. But the perihelion distance being still large, about half that of the earth, or near fifty millions of miles, the condensation was not sufficient to enable the comet to be seen in moderate twilight, and hence it was not seen after the perihelion passage for more than two months, but then remained visible for nearly four months, so that it was lost sight of at about six months after perihelion passage.

The great comet of 1844-5 had a less perihelion distance, viz., about 25 millions of miles, and a mean distance probably much greater, hence it was sufficiently concentrated in the neighbourhood of the sun to force itself on the notice of men within a week after perihelion : which implies a very much greater degree of brightness, than if HALLEY's comet had been seen as early, when powerful telescopes, directed by means of an accurate ephemeris, were employed in the search. This comet remained in sight between three and four months, and when last seen was a faint nebulosity with little or no apparent concentration in any part.

But the great comet of 1843 is again the decisive test, as this had a perihelion distance of only half a million miles, 60,000 only from the surface of the sun : here, therefore, we might expect to see the brightness excessive at and about the perihelion ; but the subsequent expansion, on account of the great mean distance, would be so rapid that the comet would be soon lost sight of by reason of faintness. Accordingly, we find that this comet pressed itself on men's attention one day only after the perihelion passage ; and from its being so very bright then, and yet seen by so few, there can be little doubt but that it might have been observed the day before, if it had been looked for ; and would have been so seen, were not staring into the sun's face and immediate vicinity rather a trying, and, consequently, an unpleasant occupation to most eyes, and seldom indulged in, especially in the warmer countries of the south, when the sun might have been that day unveiled from cloud, and was high in the sky. But, however, even the day after the perihelion passage, when the comet must have been much less dense than at that epoch, it was quite bright enough to be seen throughout the day within two degrees of the sun, and was then about one degree in apparent length ; four days after it had increased to 25 degrees, in a fortnight to double that ; in a month it was so faint and distended as to be lost to most person's eyes, and powerful telescopes only kept it in sight a few days longer. Its meteor-like brightness and short ephemeral existence were subjects of general remark in the south.

This instance may be considered to settle the matter, but Mr HIND's interesting comet of 1847 as a later instance, and a well-marked one also, is very deserving of mention. He discovered this on February 6, 1847, as an exceedingly faint nebulous body approaching perihelion ; he observed the gradual condensation in the head and appearance of nucleus and tail, this last being about a degree long on March 9 ; and having computed the orbit and found the time of perihelion passage to be March 30·269, Gr. M. T., and that the distance from the sun was then only four millions of miles, he called general attention to the circumstance under the hope that, 1st, the comet might be seen in daylight on that day ; and, 2^d, that a long tail might be visible in the evening after sunset. In the former he was borne out by the fact, for he observed the comet himself with a refractor of 7 inches aperture at 11^h A.M., within two degrees of the sun, and three other persons are recorded to have witnessed it too. I examined that part of the sky myself on the occasion, but with a telescope of only 3·7 inches aperture could see nothing : Mr HIND himself found it a very difficult object to observe, so that the sizes of the two instruments may be taken as giving some measure of its visibility. In the latter supposition he was not confirmed ; for no person saw a tail after sunset, and he himself says that the tail which he saw, exceedingly faint certainly, in the telescope in the day time, very nearly at the epoch of the perihelion passage, was only 40" long,—but the 90th part of its length 21 days before.

He was led to the first conclusion by the consideration, that the intensity of the light would vary as $\frac{1}{r^2 \Delta^2}$ (when r is the comet's radius vector, and Δ its true distance from the earth), whence the comet should be at the time of perihelion 230 times brighter than that on March 8, when it was just perceptible to the naked eye. (*Royal Astronomical Society's Monthly Notices*, vol. vii., p. 248.) But here it will be seen that with regard to the distance from the sun and perihelion, the intensity of solar illumination alone is taken account of ; but the concentration of the comet at the perihelion must have greatly assisted the effect, and without this it seems pretty certain that the comet would not have

been visible : then the introduction of the distance from the earth does not appear correct, for although this may change the apparent diameter of the body, it does not at all alter the intrinsic brightness of the surface.

The second conclusion he was led to, by the old erroneous idea (to use his own words) that “the close approach of the comet to the sun would be likely to *produce* a tail of considerable length :” but in place of so doing it was contracted in size to a very small compass. This additional instance of the prevalence of an idea so completely the reverse of the fact, will, I hope, excuse me from having attempted in so very crude a manner to establish what appears to me the grand statistical truths of cometary physics. But if I have not been able to agree with Mr HIND in his physical ideas, I must express my testimony of his high standing in the more important question of the motions of comets ; here he has indeed filled an honourable niche, which had been long, if not always, unfilled in the cometary credit and fame of this country.

A general result in cometography, certainly following the establishment of this axiom, is, that when the length of the tail of any comet of celebrity is described in millions of miles, a very favourite method with most writers, it will be absolutely necessary to accompany it with an account of the part of its orbit, where the comet is supposed to have been at the time : without this, the statement of an actual length, is as absurd as the fixation of the place of the magnetic pole, without a date being attached.

11. The axis of the tail of a comet is straight at the perihelion, but at any point between this and the aphelion is curved, and is concave toward the latter, the radius of curvature being inversely as the excentricity.

(11.) This I will not attempt to lay much stress upon ; but certainly the tails of the comets of HALLEY, of 1843, and of 1844–5, were sensibly straight near the perihelion ; and the two latter became curved after it, the former more than the latter, and they were concave to the direction in which they were proceeding ; precisely the reverse of the general belief, which states them to bend backwards at the extremity of the tail, as if experiencing some resistance, when whirled round the perihelion with such exceeding velocity.

The direction in which those two comets were proceeding at the time was towards the aphelion ; and I have not had any opportunity of examining a large comet coming up to the perihelion. The great comet of 1843 would have been sufficient to settle the question, but I have only heard of one person (a Commissariat officer voyaging from New South Wales to the Cape), who saw it in the eastern skies before sunrise and the perihelion passage ; and he had made no observations.

12. The molecules composing the envelope of a comet are only held together by their mutual gravitation, each constituting almost a separate projectile, and describing its own parabola about the sun.

The 12th axiom is Sir JOHN HERSCHEL’S, and taken in conjunction with the others, seems generally to explain all the principal variations in appearance, and affords ground for testing each exactly by calculation, and thereby of ascertaining what residual phenomena may be due to laws others than those of gravitation, mechanics, and optics.

After alluding to the observed concentration of ENCKE’S comet near perihelio, and the error of attempting to account for it by the pressure of a supposed æther in the vicinity of the sun, Sir JOHN says (*Royal Astronomical Society’s Memoirs*, vol. vi.), “It appears to me that the phenomenon is (if not wholly, at least partially) explicable on a much less gratuitous supposition, viz., that of the extremely feeble attractive force by which the matter of a comet must be held together,

owing to the probable minuteness of its mass. Cohesion can hardly be supposed to exist in a gaseous or nebulous body of such tenuity; so that the only bond of union between its molecules must be their feeble gravitation to each other, which is hardly more than mere juxtaposition in space. Hence we must regard each molecule as constituting almost a separate, independent projectile, describing its own parabola about the sun. Now, the interval between two or more parabolas described about a common focus, and having their axes coincident, is a minimum at the perihelion, and increases as we recede from it in the sesquiplicate ratio of the radius vector. The observations of ENCKE's comet, which Sir JOHN treated by this theory, shewed rather a more rapid rate of increase and decrease; which might, he thought, be readily accounted for by the effect of the brighter background of sky on which the comet was projected as it approached its perihelion, and *vice versâ*. But whether any other forces may have part in the entire phenomenon presented, he concludes that the property above pointed out, cannot but be allowed to be a *vera causa*, and to have some share in the production of the effect.

To the latter part of this opinion every one must assent; and with respect to the want of agreement between theory and observation, in the case quoted by Sir JOHN of a small comet, in addition to the observations themselves requiring correction, for the cause he has mentioned, the theoretical quantity requires it also on account of the greater attraction of the molecules upon each other at the perihelion, by reason of their increased proximity; while, moreover, the figure of the comet, and the direction in which it is seen, require also to be taken into consideration. With regard to *large* comets, which seem generally to have been thought to be under the dominion of absolutely different laws, the decrease and concentration of the tail at perihelio, is fully accounted for by this 12th axiom, as well as some other phenomena, the perplexing nature of which, when viewed by the light of any other theory, may be gathered by the account given by Sir J. HERSCHEL himself, at the conclusion of the chapter on comets in his work of last year (*Outlines of Astronomy*.)

“ It is in a physical point of view that these bodies offer the greatest stimulus to our curiosity. There is, beyond question, some profound secret and mystery concerned in the phenomena of their tails. Perhaps it is not too much to hope that future observations, borrowing every aid from rational speculation, grounded on the progress of physical science generally (especially those branches of it which relate to the ethereal or imponderable elements), may ere long enable us to penetrate this mystery, and to declare whether it is really *matter*, in the ordinary acceptation of the term, which is projected from their heads with such extravagant velocity, and if not impelled, at least *directed*, in its course by a reference to the sun, as its point of avoidance. In no respect is the question as to the materiality of the tail more forcibly pressed on us for consideration, than in that of the enormous sweep that it makes round the sun in perihelio, in the manner of

a straight rigid rod, in defiance of the law of gravitation, nay, even of the received laws of motion, extending (as we have seen in the comets of 1680 and 1843)* from near the sun's surface to the earth's orbit, yet whirled round unbroken; in the latter case through an angle of 180° in little more than two hours. It seems utterly incredible that, in such a case, it is one and the same material object which is thus brandished."

This and much more to a similar effect might be quoted from Sir J. HERSCHEL, and other authors, as to the difficulties experienced in the usual method of viewing a comet, as a planetary body at the nucleus, with an appendage attached to, and whirled along with it and by it. No wonder that doubts were expressed as to the attractive force of the small nucleus being able to retain within its grasp portions of matter thrown out to such distances; and that fears were expressed as to the breaking off of the tail; and, because some thought that it ought to bend backwards from the resistance experienced in its course, therefore they said that they did see it bend. Other difficulties also follow from the usual mechanical view of the production of the tail at perihelio, as has been stated by many, from the heat of the sun causing the nucleus to throw out jets of vapour on the side of that luminary, which again has the power to bend them back, and sending them streaming past the nucleus once more, forms the tail. These jets of vapour ought to drive the nucleus away from the sun; for though it may be said that the vapour, being nearly imponderable, should not produce any sensible or visible effect on the nucleus,—yet the nucleus itself is, for anything we know, as imponderable; indeed, if we judge of the masses of the two by the quantity of light reflected, which is almost the only indication we have, and perhaps not a very bad one, then the mass of the tail in most cases exceeds that of the nucleus, *i. e.*, if the quantity of light reflected by the whole envelope were to be concentrated into a single point, it would be brighter than the nucleus. Hence with the extravagant rapidity and the enormous quantity of vapour rush-

* This is not stated with perfect correctness, at least with regard to the comet of 1843, which might have had a tail of that length some days after the perihelion passage, when it had grown with the rapid increase of its radius vector; but the first day after the perihelion passage, the tail was observed to be only double the sun's diameter (excluding inclination), and its distance must then have been 100 times greater than at the perihelion; so that if the sesquuplicate ratio holds good, we shall have for that epoch a size not very different from planetary bodies. (A curious meeting this must be of the molecules brought for an instant into such close proximity, after having been separated for ages by distances so vast and inconceivable as they must be at the aphelion; and when separating for their diverse orbits, what speculations on their next meeting, not in thunder, lightning, and in rain, but in light and heat unspeakable. On the last occasion, February 1843, the heat was equal (according to Sir J. HERSCHEL) to 47,000 of our suns, 1900 whereof are sufficient to melt the very rocks. Such, at least, must have been the heat, if the comet travelled at that part of its orbit only at the mean rate of the earth; but the velocity was really vastly greater, and the heat much modified thereby. The degree to which velocity in the heavenly spaces may modify distance, in respect of heat, is one still open for inquiry; and the result, in the case of our own earth, as far as it may have been very imperfectly examined into, would lead us to expect that the above proportion would be greatly reduced.)

ing forth from one side only of the nucleus, that body should be driven far in the opposite direction: but by comparing its observed daily places during the perihelion passages with the computed, we find that no deviations from any such anomalous causes are ever experienced.

All these difficulties, however, vanish on considering the envelope of a comet to consist of separate molecules, each constituting an independent projectile, and bound together only by their mutual gravitation and the laws mentioned above; for then the size, character, and position of a comet being given at the perihelion, which we must look on as the normal state, all its principal variations of appearance during the rest of the orbit may be readily computed; and the return of every particle of the envelope to perihelion, or, vulgarly speaking, the retention of the tail by the nucleus, will be no more surprising, nor deviating from ordinary laws, than the return of the nucleus itself: certainly there is nothing “in defiance of the laws of gravitation, and even of the received laws of motion,” as stated by a supporter of the other theory to be the case with that.

But following this principle further, we may expect that, in the multitude of molecules moving about amongst each other, occasional conglomerations may occur, after passing the proximity of some large planet, whose attraction acting much more strongly on one part of the envelope than the other, will so much alter the motion of the particles therein, that they will, after some revolutions, gradually collect together at a distance from the nucleus, and at length separate and become a distinct comet. Such a case having actually occurred under our own eyes, four years ago, with BIELA’S comet, when it was not at the time under the immediate influence of any planet in particular, nor in any trying part of its orbit round the sun, adds much additional weight to this view of the constitution of such bodies.

This brings us to the second portion of the subject, viz., the corrections which should be applied to apparent observations to deduce the real phenomena.

A comet being an elongated, gaseous, elastic, and semitransparent body, varying in size and density with its distance from the sun, evidently requires many different corrections, according to the point of view and the distance from which it is seen, to give an idea of its real nature at the instant of observation; and needs other corrections, to reduce it from that instant to some other in which it is in a normal condition. This normal condition is plainly in perihelio (though a better general comparison of the volumes of different comets would be obtained by reducing each to its *mean distance*, as they would then be all of much more nearly equal density), and viewed at right angles to the line of its larger axis. This is a position which seems generally to have been taken for granted, though it never occurs even approximately. If we could see a comet at the instant of its perihelio, the plane of its orbit being inclined 90° to that of the ecliptic, and the radius vector being infinitely small, the above view would be nearly obtained, but would gradually

be altered as the comet proceeded in its orbit. As seen from the sun, the comet should always present a circular body, and be equally illuminated on all sides, except in so far as the longer axis is inclined to the plane of the orbit: when the comet retreats towards the aphelion, the point of view from the earth becoming more nearly the same as that from the sun,—the comet should become rounder and rounder, as well as larger; and this is found actually to be the case,—the tails of HALLEY'S and those of 1843 and 1844-5, having been, at and about the perihelion passage, narrow, and intense, and becoming at the last instant in which they were seen, wide, round, and diffuse.

This, perhaps, together with the facts of phase and imperfect transparency (axioms 9 and 10), is sufficient to shew the importance of correcting the observations for both the terrestrial and the solar elements of effect on the appearance of a comet, and be able to deduce its normal condition. That there may be other changes operating is very probable, but be that as it may, these effects of geometry, mechanics, and optics, actually exist to a very sensible amount, and their corrections must be applied before we can expect to discover any of the residual causes.

I ought, doubtless, to apologize for having formed opinions different from Sir J. HERSCHEL'S last, as he is confessedly the person, above all others, entitled to paramount weight in cometary physics; and it may be that I have not properly understood, and unintentionally have not here sufficiently represented the reasons upon which his old conclusions have been altered, and on which he has thought it allowable to introduce electrical and other forces, to explain phenomena amongst the celestial bodies; and I would therefore refer inquirers to his works themselves. But while on the one side, I hope that what has been here brought forward with regard to the complete body of a comet and its symmetrical and geometrical form, when freed of the effects of phase, may remove one of the objections which he felt to allowing the all-sufficiency of gravity acting on a group of independent molecules; on the other side, I not only allow, but think it extremely probable, that some other effects besides those already mentioned, may legitimately occur; and if heat and rotation on the earth produce our trade-winds and hurricanes, much greater effects may follow the more violent alterations of temperature and velocity of motion in a comet. Further, as confirming a curious feature noticed in HALLEY'S comet, by Sir JOHN, after the perihelion passage, viz., a long thin ray posterior to the nucleus, to which it might perform the office, he suggested, of conveying back the vapour driven off in front at perihelion; I would mention, that a ray of the same sort was seen posterior to the nucleus of the great comet of 1843, of extravagant length and excessive thinness, appearing as a very fine line of light, and traceable for many degrees up the tail: in these particulars, bearing some relation, perhaps, to the excentricity of the orbit, and to the

great length and small breadth of the comet itself. The first day that I saw the comet, three days after perihelio, it was not visible; but, clearly seen on every subsequent day, it existed until the whole was lost in faintness.

The observation of these bodies is not, however, as hinted above, in a sufficiently satisfactory state for rigidly testing any calculable theory. This depends not only on the rarity of the appearance of comets (a matter beyond our control); but also on the insufficient means with which, and the untoward circumstances under which they are generally observed. The telescopes usually turned upon them, have been of so small an optical power, that they would have been considered utterly incompetent for ascertaining the nature of nebulae high up in the sky; how much more so, when employed on nebulous objects close to the horizon, as the comets usually are, flickering and faint in vapour and smoke, and almost overpowered by the strength of the twilight.

But a sufficiently powerful telescope need not any longer be a difficulty, since the publication of the inventions of the EARL of ROSSE, and Messrs LASSEL and NASMYTH; and the effect of the vapour of the horizon, and the glare of twilight, might be successfully overcome, by establishing an observatory on high land within the tropics, where the geographical position renders the twilight short even to the plains; and the rarity of mountain air would still further reduce the reflective power of the atmosphere. Micrometrical measures, with such instruments, and under such circumstances, should be combined with *photometrical determinations of the brightness of the various parts of the comet, and of the background of the sky*. The former observations are easy and straight forward enough, but the latter are difficult and new; the zero must inevitably be taken from a stellar scale, but none such exists at present; for the telescope measure has invariably failed whenever employed for the purpose, and the eye is still thought the best available mean. Hence, none but the brightest stars have had their magnitudes determined, and that but coarsely, while the great question still remains in much the same state as that in which the application of the telescope to divided instruments was in, before men had learnt how to determine the error of collimation. They knew that there were vast powers of accuracy in the optic tubes, but were afraid of great and mysterious errors, which they neither exactly understood, nor saw how to correct. Similarly in photometry, a telescope of large aperture, is confessed to have a larger scale and range than the unassisted eye, but is suspected of misleading to a greater extent.

This is hardly the place for entering into such an experimental branch of practical astronomy; for pointing out what appears to be the error of the methods adopted by others; and for shewing the correctness and efficacy, as I believe, of another plan, which might be adapted to telescopes of any size. But there can

be little doubt, from the pressing nature of the demand for advance in this department, that those who are more fortunately situated, must, before long, perfect and employ some method by which the great desideratum for inquiry into cometary physics may be obtained, viz., *drawings*, wherein every feature represented shall be accompanied by numerical statements of its dimensions and brightness, with the *probable error* of each determination. Until this shall have been done, the necessary corrections to reduce the apparent to the real phenomena cannot be undertaken, and I shall therefore hope to return to the subject if it should not be taken up in the meantime by any one better able to conduct it to a successful issue.