ART. LVII.—*On the Physical Constitution of the Sun;* by Professor W. A. NORTON.

AMONG the recent theories of the Physical Constitution of the Sun, based on the later discoveries, astronomical and spectroscopic, that propounded a few years since by M. Faye* has been most favorably received. It is an essential feature of this theory that the sun's mass consists wholly, or in a great degree of gases or vapors; and that a process of interchange of solar matter between the interior and the photosphere is in incessant operation, in ascending and descending currents, by which the

* Comptes Rendus, vol. lx, pp. 89 and 138.

solar radiation is maintained. In a paper by J. Homer Lane, on the Theoretical Temperature of the Sun, &c., published in this Journal, July, 1869, it is elaborately argued, and appears to be successfully maintained, that the great rapidity of circulation required by this theory cannot subsist consistently with the received laws of gaseous circulation. Quite recently another theory of the sun's physical constitution has been propounded by Professor F. Zöllner of Leipzig; based mainly on the well established fact that the solar protuberances, conspicuously visible in total eclipses, and observable at all times with the aid of a spectroscope, are most of them due to violent eruptions of masses of incandescent hydrogen.* He remarks that "it is impossible, without passing beyond the well known analogies necessary for the explanation of cosmical phenomena, to assign any other cause to these eruptions than the difference of pressure of the gases emanating from the interior and from the surface of the sun. To make such a difference of pressure possible it is necessary to admit the existence of a separating stratum between the inner and outer strata of hydrogen—the latter of which, as is well known, forms an important portion of the solar atmosphere. In reference to the physical constitution of this stratum, we must furthermore assume that it cannot be gaseous, and must therefore be either solid or liquid." He remarks further, that "with regard to the inner masses of hydrogen bounded by that stratum, two suppositions are possible, viz: 1. The whole interior of the sun is filled with incandescent hydrogen gas, which would make the sun an immense bubble of hydrogen surrounded by a liquid glowing envelope. 2. The masses of hydrogen, bursting out into protuberances, are local collections in bubble-like caverns, which form in the superficial layers of a liquid glowing mass, and burst through when the pressure of the confined gas increases." Prof. Zöllner adopts the latter supposition as the more probable of the two.

This theory may furnish an adequate supposable cause for the observed eruption of incandescent masses of hydrogen, but its fundamental hypotheses have no secure ground to rest upon. The notion, that the sun's photosphere is in the liquid state, is irreconcilable with the astonishing rapidity with which changes often occur on the sun's surface, and also with the fact that the vast elevated masses, seen as the faculæ, occasionally retain the same position for several days; and though suggested long since, has not, to my knowledge, been adopted by any astronomical observer. No hypothesis of the possible origin of the sun's spots, upon this idea, has been framed that affords a satisfactory explanation of even their more conspicuous features and phe-

*Journal of the Franklin Institute, Nov., 1870; also Philosophical Magazine, Nov., 1870.

nomena. To this remark the theory advanced by Prof. Zöllner, viz: that "the nucleus of the solar spots is a scoriaceous product of local cooling on a liquid surface, and the penumbræ clouds of condensation, which surround at a certain height the coasts of these islands of slag, offers no exception." It is not new, and has been already overthrown by the investigations of M. Faye.* The other fundamental hypothesis of Professor Zöllner's theory of the physical constitution of the sun, viz: that the masses, which burst out into protuberances, are local collections in bubble-like caverns, which form in the superficial layers of a liquid glowing mass, does not derive any support from analogical facts. It must be regarded as a pure hypothesis, unsustained by any inherent probability, or by any known fact, other than that which it is framed to explain. Besides, an hypothesis which brings the hydrogen in eruptive, or streaming masses, to the sun's surface, does not suffice. Another arbitrary hypothesis is required to dispose of the hydrogen which has thus been accumulating above the sun's photosphere for an indefinite period of time.

Such being the state of the case with regard to the recent attempts to discover the secret of the sun's physical constitution, in the light of the late remarkable discoveries, we seem to be in this dilemma; whatever conception is formed of the condition of the sun's photosphere—whether liquid or gaseous—it appears to be contradicted by received principles, or controverted by established facts. We are thus naturally led to suspect that either some physical cause has been hitherto left out of account, which plays an important part in solar phenomena, or else the conception adopted of the mechanical condition of the solar vapors is radically at fault. It appears to me that good and sufficient reasons may be urged that will justify both these grounds of suspicion; and that a new point of view may be gained from which we may obtain a deeper insight into the physical processes in operation on the sun.

It is a little remarkable that it should have been hitherto assumed that the facts and laws of Terrestrial Physics can alone furnish a true philosophical ground for a theory of Solar Physics; and that no serious attempt should have been made to obtain additional light from known processes in operation on a cosmical scale in the regions of space. There is a class of bodies, some of which in their periodical excursions through the fields of space approach quite near the sun, and which are in general conspicuously subject to influences of a powerful nature exerted by the sun, besides the force of gravitation. It cer-

* Comptes Rendus, vol. lxi, p. 1089.

tainly seems natural to expect that these cosmical bodies might give us some insight into the nature of the forces in operation at the sun's surface. It is assuredly too late to urge that the transformations which they undergo under the sun's influence are wholly involved in mystery; for it has certainly been satisfactorily established that a portion of the cometary matter becomes subject to a *solar repulsion*, and is urged away by this force with a high velocity, and to great distances from the sun, and that this repulsion augments in intensity as the comet approaches the sun.* Now if such an energetic force of repulsion emanates from the sun, and operates on cometic matter at all distances, both small and great, according to the law of inverse squares, there is assuredly a high probability that it may play an important part on that vast arena, where solar forces are obviously engaged in fierce contention. It may be conjectured that the solar vapors are entirely different substances from, and wholly unlike, in their physical state, the cometary vapors that appear to be so exceedingly subtil. But it is certainly more philosophical to suppose that the same substances, or substances possessed of the same general properties, are present in all cosmical bodies, and the earth. Besides we are not without direct evidence on this point. Huggins, by examining the spectrum furnished by the light emitted from the Comet II, 1868, detected the presence of the vapor of carbon in the brighter portions of the comet. "He has been able to discriminate between the light of the nucleus of a comet and that of its tail. The nucleus is self-luminous, and its substance is in the form of ignited gas. The coma shines by reflected light as clouds do."

If, as is now conceded by astronomers, the tail of a comet is made up of matter detached from the general mass of the comet, by reason of a repulsive action exerted by the sun, it must also be admitted that the matter expelled is not all urged away by the same intensity of force, and with the same velocity; for we find that it is much more widely dispersed in the plane of the cometary orbit than is consistent with this supposition. For example, I have shown, in my theoretical discussion of Donati's Comet,† that if we conceive particles of matter to have been expelled from this comet, with a certain small lateral velocity, and urged away during a certain interval of time by a solar repulsion bearing to the force of gravitation the ratio of

* This is generally, if not universally, admitted by astronomers. The author has undertaken in former numbers of this Journal, to establish by rigorous calculation that the luminous train of Donati's comet was developed by a force of solar repulsion coöperating with the attraction of gravitation—both varying according to the law of the inverse squares. (See this Journal, vol. xxxii.)

† This Journal, II, vol. xxxii, pp. 54–66.

1·213 to 1, they would, at the end of the interval, have been found distributed over a narrow band coincident, at its forward line, with the curved preceding side of the tail of the comet; and that the other portions of the tail must have been composed of matter subject to various degrees of solar repulsion less than this. In fact the definite conclusion was in this way reached that the preceding half of the tail consisted of matter repelled from the sun with a force varying between the limits 1·213 and 0, and that the following half was for the most part composed of matter detached from the comet simply by reason of a weakened gravitation toward the sun,—the intensity of the force of gravitation along the following side of the tail being 0·455. There would seem then to be no alternative but to admit that the tail of Donati's comet was composed of different substances, (or else of one substance in different physical states) subject to a repulsive action from the sun of various degrees of intensity; and either prevailing over the sun's attraction of gravitation, or partially counteracting it, and so giving rise to an effective repulsion for certain of these substances, and to a diminished gravitation for others. The simplest theoretical explanation that can be given of this state of things is to suppose that the *solar repulsion consists of a series of impulses propagated in waves through the ether of space, and taking effect upon atoms of different sizes with varying intensity.* It is obvious that if this be true, the smaller the atom the more effective should be the repulsion as compared with the gravitating force soliciting the atom; since the ratio of the two forces should be proportional to the surface divided by the volume of the atom,—assuming that the mass is proportional to the volume, or that all atoms have the same density. We are thus incidentally led to infer that the larger comets consist of a variety of substances, like the earth.

The question now arises what can be the origin of the force of solar repulsion. There is another side of the diversified picture presented by cometary transformations under the sun's influence, which gives some intimations on this point. Not only is a certain portion of the cometary matter repelled by the sun, but it is also repelled by the nucleus of the comet. We see in large comets, a series of envelopes rise at intervals from the nucleus, on the side turned toward the sun, and recede at a nearly uniform rate until they become dissipated by the sun's repulsion. Luminous jets also stream out at times from the same side of the nucleus. These phenomena, it can hardly be doubted, are in some way the effect of the sun's heat. The simplest and most probable conclusion is that the ejecting force which is brought into play by the sun's heat is the direct repulsive energy of the heat received by the comet. We are thus led to infer that *the repulsive action exerted by the sun upon matter in the state of the cometary vapors, probably consists, either wholly or partially, in repulsive impulses propagated in the heat waves proceeding from the sun.*

Let us now see whether any confirmation of these inferences, and any additional light in the direction of our present inquiry, can be obtained on the substantial ground of Terrestrial Physics. The definite question presented for consideration, is whether the results of observation or experiment afford any indication of a direct repulsive action exerted by radiant heat on the atoms of bodies. It is universally admitted that radiant heat, when imbibed by a body, acts as a repulsive or separating agency among its molecules. It is also conceived that the conduction of heat is by radiation from atom to atom. The most natural inference from these facts is that the waves of radiant heat, which pass from atom to atom, directly urge the atoms away from each other by repulsive impulses. Instead, however, of adopting this simple idea, physicists have generally been inclined to refer the expansion of bodies from heat to some mode of motion of the atoms, originated by the heat received; though no detailed satisfactory explanation has yet been given of the manner in which such motions would directly originate an expansion. Strangely enough this notion is even entertained by physicists who regard heat as the only cause of the repulsion subsisting among the molecules of bodies. It should here be noted, that if the expansion of all bodies of matter from heat is to be ascribed to a direct impulsive, or repulsive action of heat waves proceeding from one atom and falling upon the surrounding atoms, then this force takes effect at the greatest distances by which the atoms are separated in the rarest gas under the feeblest pressure; and we would thus be led to expect that heated bodies in contact with each other might manifest signs of repulsion.

In point of fact, many evidences of a heat repulsion subsisting between particles of different bodies, in contact or in close proximity, have been adduced by different experimentalists, and writers on physics, some of which may be briefly mentioned.

1. "When pure silica, in an extreme state of division is highly heated, the slightest motion then causes the particles of the powder to slide over each other, and the surface of the powder is thrown into undulations almost like those of a liquid."

2. A rise of temperature is attended with a decrease of capillary attraction. Also the frictional resistance to the flow of water in pipes is diminished by heat.

3. "The spheroidal state of liquids is a complicated result of four distinct causes. The most influential is the repulsive force which heat exerts between objects which are closely approximated to each other."*

4. The vibrations of heated metals, as shown in "Trevilyan's Instrument," or "rocker," resting on a block of metal, are probably due to the direct repulsive force of heat, as maintained by Professor Forbes, of Edinburgh, in opposition to Faraday, who conceived that they were attributable to the sudden expansion by heat of the body on which the rocker rests. Faraday's explanation of these curious phenomena is adopted by Tyndall, who endeavors to overthrow Prof. Forbes's theory. His experiments serve to disclose the fallacy of certain features of the theory, but do not dislodge the fundamental idea that the phenomena are due to a force of heat-repulsion. This might be made apparent if we had space for a statement of the general principles on which the explanation rests, and for a detailed discussion of the results of the experiments.

Let us now consider if any sufficient evidence exists of a general force of molecular repulsion in operation at all temperatures,—beyond the sphere of sensible adhesion, or cohesion. We need, in fact, to look no farther for this than to the simple fact that in the ordinary contact of bodies the interval of distance between them, minute as it is, much exceeds the range of the attraction of cohesion, or adhesion; for in such contact the weight of the upper body is counteracted by a repulsion between the molecules about the point of contact. Dr. Robison has shown in his System of Mechanical Philosophy, that if two glasses, one slightly convex, the other flat, are placed on each other and pressed by a force of 1000 pounds to the square inch, they are still at the distance from each other of the thickness of the top of a soap bubble just before it bursts, or at least $\frac{1}{4450}$th of an inch. In effecting this contact there was no evidence of any attraction existing at distances greater than that at which the contact occurred. A similar remark may be made with regard to all cases of the apparent contact of homogeneous substances under a moderate pressure. It is only by increasing the pressure more or less, that the contiguous particles can be brought within the range of their reciprocal attraction of cohesion. When the particles are readily displaced among themselves under the direct action of a pressure, or blow, as in the case of soft or malleable substances, a permanent union may be effected without difficulty between the surfaces; that is, the outer repulsion of some of the particles may be overcome, their attraction of cohesion brought into play at the reduced distance, and an equilibrium established at the neutral

* Miller's Physics, p. 285.

point between this attraction and the inner repulsion. This occurs in the welding of iron.

Other evidences of an effective repulsion in operation between the molecules of bodies in contact, or in close proximity, are cited in treatises on Physics; although it is not always distinctly recognized that the sphere of its action lies entirely without that of the effective molecular attraction. Now what is the range of this *effective* repulsion between bodies. It obviously extends only to a small distance. Cavendish's well-known experiment has established that, when bodies are separated by considerable distances they tend toward each other by the attraction of gravitation. But are we therefore to conclude that the repulsive action, so energetic at the near approach of the molecules, has vanished altogether when they are a considerable distance apart. Is it not more probable that this force is confined to the surface molecules, and disappears at moderate distances, in comparison with the attraction of gravitation which is the result of the action of the entire masses on each other, because it decreases according to the inverse squares of the distance between the surfaces instead of the distance between the centers. I have elsewhere shown* that the force of gravitation cannot be the attraction of cohesion operating at considerable or great distances. It is a force *sui generis*, entirely distinct from the forces of molecular attraction and repulsion in operation at minute distances, and determining the constitution of bodies and their mechanical properties; and operates in conjunction with, but independently of, these molecular forces.†

In view of the concurrent testimony that we have now seen is afforded by the two departments of Cometary, and Terrestrial Physics, it will be admitted that, in attempting to gain a new insight into the physical constitution of the sun, and the pro-

* Philosophical Magazine, vol. xxxviii. p. 38.

† It ought here to be stated, that in my paper on Molecular Physics published in this Journal, vols. xxxviii, xxxix and xl, I have deduced from the fundamental conception of a primitive molecule (or chemical atom) adopted, a force of molecular repulsion operating beyond the sphere of the molecular, or cohesive attraction; and reached the conclusion that this force has its immediate origin in the physical change to which the development of heat is in every instance due, viz: an inward or contractile vibratory movement of the electric envelopes by which all atoms are conceived to be surrounded, as well as by ethereal atmospheres. It is accordingly termed the molecular heat-repulsion. The repulsive energy of heat in operation on any molecule, is the sum of all the ethereal impulses developed by such movements of the envelopes of other molecules, (whether originating in the attraction exerted by the central atoms on their envelopes, or in an external collision or pressure), and propagated to the molecule. From the principle of interception of wave-force it results that the external repulsive action exerted by a solid body is confined to the surface molecules; while a force of heat-repulsion is propagated to an indefinite distance from all the molecules of a gas.

cesses of change in operation on its surface, we are at least entitled to assume the following as probable hypotheses.

1. That the sun exercises a repulsive action upon the molecules of every gas or vapor that subsists at its surface, or is at any time in any part of the region of space exterior to the surface; that this force is the sum of all the heat impulses propagated in ethereal waves from all the gaseous molecules posited above the solid or liquid body of the sun, and from the surface molecules of this central mass, except in so far as these impulses may be intercepted in their passage; and that it is opposed to the force of gravitation, which is due to a virtual attraction of the sun's entire mass,—so that the effective force soliciting any gaseous molecule is the difference between these two forces, attractive and repulsive, by which it is urged.

2. That the force of solar repulsion, since it consists of impulses propagated in ethereal waves, is comparatively more effective in proportion as the atomic weight of the solar vapor is less; it being assumed that the quantity of matter in any atom is proportional to its volume.

3. That in a hypothetical condition of equilibrium of the sun's atmosphere the elastic force of each of its vaporous constituents, at any depth, will consist in the intensity of the effective heat impulses tending to urge its molecules outward; which will be counteracted by the weight of the superincumbent portion of the atmosphere. Now, let us assume, for the moment, that at some anterior epoch in the sun's history, all the present vaporous constituents of the sun's atmosphere were diffused throughout a space exterior to the central body of the sun and limited by the spherical surface (A), at which the molecules of the vapor of greatest atomic weight are in equilibrium, under the action of their own weight and of the heat-repulsion urging them upward. This hypothetical state of things could not continue, since the atoms of each of the other solar vapors would be urged upward by an effective force. If we conceive a small quantity of each of them to escape from all points of this surface, the rising vapors will ascend to greater heights in proportion as their atomic weights are less, and finally, when the equilibrium is attained, form a series of spherical envelopes, wholly detached from each other, and arranged in the order of atomic weights;—beginning with the heavier metallic vapors, and terminating with the lighter (potassium, sodium, &c.), and the permanent gases, with hydrogen outermost. If other small portions of each of the vapors were to rise from the surface, A, they would serve to augment the thickness of the envelopes already formed; and the same would be true for each successive discharge. The final result would be the same if the discharge were continuous during a certain interval of time, as

would naturally happen. After a certain amount of the solar vapors have escaped, contiguous envelopes might interpenetrate each other more or less. What it is especially important to observe, is, that *throughout the whole depth intercepted between each envelope, and the outer limiting surface,* A, *of the vapor of greatest atomic weight, every atom of the substance of which the envelope is composed, that may chance to be present, is urged upward by a force of repulsion.* If, as we must suppose, the rise of the solar vapors from the surface, A, continues for an indefinite time, the interpenetration of contiguous envelopes would increase, and eventually a condition of equilibrium would be attained; if the sun's temperature remained the same. But if this temperature were to increase, as it must down to a certain epoch in the process of consolidation, the process above indicated would be continually renewed. It is still more important to observe, that if there were any cause in operation withdrawing continually at short intervals a portion of one or more of these rising vapors, a statical equilibrium would not be reached; and it would be permanently true that *for every such vapor there would be a region of repulsion,* as above stated, *extending from its envelope down to the outer limit,* A, *of the vapor of greatest atomic weight.* Throughout this region the vapor would be perpetually rising, taking the place of that which is withdrawn, and so maintaining a *dynamical equilibrium.* The depth of this region would be the greatest for hydrogen, the outermost gas (unless there is some solar vapor of less atomic weight than hydrogen). Now it is easy to see that a certain physical cause tending to produce such results, must come into operation at some stage of the sun's process of consolidation. As conceived by Faye, the cooling going on at the outer surface must eventually bring the temperature there down to the point at which the vapors having the highest affinity for oxygen will undergo combustion. The products of such combustion, being compound molecules, will have a greater weight in comparison with the repulsion to which they are exposed, than the simple molecules before the combination took place, and hence they will descend, more or less rapidly, into the depths of the photosphere. To all appearance the sun is now passing through this period of its physical history, as supposed by Faye; and in the "granulations" which give to the solar disc a mottled appearance (Herschel's "subsiding chemical precipitates,") we probably discern the products of the combustion occurring in the upper photosphere and determining its outer limit, in the act of descending. The continual upward flow from the depths of the photosphere, of the hydrogen, oxygen, and the lighter metallic vapors, will bring about the necessary intermixture of oxygen with the other vapors. This must occur below the natural outer limit of the hydrogen envelope; and we know that as a matter of fact, the chromosphere, composed chiefly of hydrogen, extends above the photosphere.

If the products of the surface combustion were all to descend indefinitely into the vaporous photosphere, without undergoing decomposition, no farther visible effects would ensue. We could only follow with the mind's eye the gradual growth of the central nucleus of the sun, and recognize that we probably have before us a picture of the process by which the materials of the earth's crust were fashioned and accumulated in the earlier ages of its history. But the probability is that the descending masses would eventually arrive at a depth where the higher temperature would effect a dissociation of the combined elements (as Faye supposes). This must inevitably happen unless the tendency of the heat, that augments with the depth, is counteracted by the opposing tendency of the increasing gaseous pressure. By reason of these opposing tendencies it may well happen that there may be a certain region of dissociation of limited depth, above and below which decomposition would not occur. But it is to be observed that it does not follow that all of the products of surface combustion as they pass through such a region would be decomposed; since the reduction of temperature attending every instance of decomposition tends to prevent decomposition of other surrounding masses in the act of descending.

This sudden dissociation of large masses of combined elements, though occurring at certain depths within the photosphere, it will be seen may eventually play a conspicuous part at the surface. Unless the region of dissociation should lie below that of repulsion for the elements separated, these elements after separation will be urged upward by the effective force of repulsion, ascend rapidly, and emerge with a high velocity above their respective envelopes. The ascensional velocities attained will be greater if large masses are suddenly decomposed. The masses of hydrogen set free should attain to the greatest velocity, and rise to the greatest height. They should rise, in eruptive masses, above the hydrogen envelope, or in other words, the chromosphere. According to Lockyer, in the solar protuberances, the ascending hydrogen has in some cases, a velocity as high as 120 miles per second, and rises to a height of more than 40,000 miles.

A vertical jet of hydrogen, having a projectile velocity of 120 miles per second, should attain an altitude of 43,000 miles, if the solar gravity were constant for that altitude. Some prominences have extended to a height of 100,000 miles above the sun's photosphere. Prof. Respighi, has even noticed instances of an elevation of 160,000 miles. Such enormous heights imply either a greater initial velocity than 120 miles per second, or that the full energy of the solar attraction does not take effect on the eruptive masses of hydrogen, in the region above the photosphere. From our theoretical point of view, we perceive that the latter supposition should be true; since the solar repulsion should be in operation above the hydrogen envelope, or the chromosphere, diminishing the gravitating tendency.

The metallic vapors set free in the region of dissociation, should rise to heights varying with their atomic weights. Some of them, especially the lighter ones (sodium, magnesium, calcium, &c.), may acquire velocities sufficient to bring them above the chromosphere. In fact the spectroscope has detected besides hydrogen, magnesium, sodium, iron, and chromium, in the solar protuberances. Lockyer states that he has invariably found that in solar storms, the chromospheric layers are thrown up in the order of vapor density. He regards the chromosphere as built up of the following layers, which are in the order of vapor density in the case of known elements: a new element giving the green coronal line in the spectroscope, hydrogen, another new element, magnesium, sodium, barium, iron. He remarks that "all the heavier vapors are at or below the level of the photosphere itself."*

The green coronal line was traced in the late eclipse by Profs. Young and Winlock as far as 16′ or 425,000 miles from the sun's limb. From our present theoretical stand-point, we naturally infer, as Lockyer has already done from his observations, that the element present in the solar corona which gives this line is much lighter than hydrogen. We see also that an element several times lighter than hydrogen might be subject to a solar repulsion that would predominate over the attraction of gravitation at all distances, and urge the subtil vapor indefinitely away from the sun. Since the same line is seen in the light of terrestrial auroras, we must conclude that the same substance is present in our upper atmosphere;—either in a permanent upper layer, or derived from the sun (as I have elsewhere maintained). We must infer also that it is magnetic, which apparently cannot be the case unless it takes on the condition of compound molecules. Such compound molecules might become dispersed in the upper atmosphere of the earth, or in the photosphere of the sun, by electric discharges or sudden evolutions of heat; and then the separate atoms repelled off, forming the streamers of the corona and aurora, illuminated either by electric

* It is admitted by Angström, and Zöllner, that the absence of spectroscopic indications of oxygen and nitrogen in the sun, is no sufficient evidence that these gases are really wanting in the sun's atmosphere.

light, or in the case of the corona in part also by reflected solar light.*

The probable origin of the sun's spots, and other questions of solar physics that claim attention, must be left for future consideration. I will only remark here, that it has long been apparent that the diverse phenomena which occur at the sun's surface are traceable, more or less directly, to the action of some form of eruptive force. *The present investigation seems to have led to the discovery of the true nature and origin of this force; and at the same time to have revealed the process by which the sun's radiation is maintained.* The primary source of the solar heat being, doubtless, as now generally believed, the process of condensation maintained by the force of gravitation.

It is worthy of remark, in conclusion, that as comets directed our attention, at the outset, toward the sun, so the sun, in its turn, leads us back again to our starting point; since we see that if we transfer to cometary bodies the physical structure we have recognized in the sun's upper photosphere, viz: the existence of a succession of light vaporous envelopes, subject to the energetic action of the force of heat repulsion, the mystery in which some of the curious transformations they undergo, have hitherto been involved, seems to be in a great degree dispelled. No one doubts that comets are chiefly composed of very light vapors; though some of the larger ones may have a solid nucleus. If, as intimated, certain observed cometary phenomena indicate that these vapors, like the solar vapors, are arranged, for a certain depth at least, in envelopes, which are liable to be greatly expanded, or even wholly expelled by the increasing amount of heat received from the sun, we have in the probable physical structure of comets, another indication that these bodies were originally detached from the sun's photosphere, in addition to that furnished by certain features of the cometary motions.†

* It is also conceivable that the subtil vapor streaming off in the coronal rays, has been set free by dissociation like the hydrogen, from some other element of a compound substance, in the depths of the photosphere. However this may be, it can hardly be doubted that the ascent and descent of the solar vapors, and the combinations and decompositions going on among them, must be attended with disturbances of electric equilibrium, from which decided effects must result.

† Norton's Astronomy, revised edition, p. 276.