ART. XXII.—*On Dynamical Theories of Heat;* by Prof. W. A. NORTON.

QUERY. *Is heat any mode of motion of the atoms of ordinary matter; such atoms being regarded, in accordance with the common notion of an atom, as incapable of experiencing any change of form or dimensions, or in the intensities of their acting forces?* There are three conceivable modes of motion of such invariable atoms—a vibratory or oscillatory motion, either rectilinear or curvilinear; a revolution of one atom around another; or a rotation of each about an axis.

Let it be distinctly understood that *the inquiry has reference only to atoms of ordinary or gross matter.* There can be no question that heat, in its origin, and generally in its manifestations within ordinary bodies, consists in some form of periodic movement, attended with regularly recurring impulses communicated to the ether which fills all space and pervades the interstices of bodies; since waves of radiant heat cannot possibly have any other origin. But the question is, whether the constituent atoms of bodies have this movement, or those of some form of ethereal matter intimately associated with these atoms.

I. *Can heat be any mode of vibratory, or oscillatory motion, of the atoms of gross matter.* Against this notion of the origin, or nature of heat, many serious objections may be urged.

1. *It implies rates of vibration inconceivably more rapid than we have any independent reason to suppose can take place in the interior of bodies.* The most rapid molecular vibratory motion that we actually know of, occurs when a vibrating body emits a musical sound of the highest pitch that the ear is capable of detecting. This is at the rate of less than 80,000 vibrations per second, but an atom emitting the heat-rays of the red end of the

spectrum vibrates at the astonishing rate of 458 millions of million times per second. Thus in the supposed heat motion the vibration is six thousand million times more rapid than in the most acute audible musical sound. It is true the disproportion between the quantities of matter in vibration in the two cases may be very great, but it does not follow that the rate of vibration should augment in the same proportion. The case is not analogous to that of vibrating strings of diverse lengths. The comparative rapidity of movement in the two cases must depend on the comparative intensities of the accelerating forces, atomic and molecular, in operation. That the astonishing disproportion above stated, between the velocities of vibration, answering to the heat-rays and to the most acute musical sound, may exist, it is necessary that the same enormous disproportion should subsist between the accelerating forces in operation.

2. *The hypothesis under consideration implies, then, that the atomic forces in operation in the production of heat and light are inconceivably more intense than the molecular forces in action when musical sounds are originated, or propagated.* That this may be true, it is necessary, 1st, that in the case of every substance, whether in the solid, liquid, or gaseous state, the aggregation should be that of molecules made up of atoms, never that of simple atoms; since if this were not the case the forces in play in the origination of atomic heat-vibrations, would be identical with those in operation in the origination and propagation of sound. 2d, that in every instance the distance between the molecules should be vastly greater than that between their constituent atoms. Now since the mutual action of two contiguous molecules is the result of the joint action of all their atoms, and since in the case of a solid, at least, it cannot be doubted that the contiguous molecules are in a state of equilibrium under the mutual action of their own forces alone (or very nearly so), their distance apart must be that at which all the mutual attractive actions exerted by the more distant atoms of the two groups is neutralized by the repulsions which take effect between those that are nearest to each other. The distance between the surfaces of the two molecules cannot then, in general, be materially different from that between their constituent atoms. It should be less rather than greater. As to the distance between the centers of contiguous molecules, it cannot be many times greater than that between their atoms, unless the number of atoms combined together in each molecule is very great. When a substance is in the liquid form, the distance between the molecules cannot be materially different, from our present point of view, from that which obtains in the solid form; if, in fact, the aggregation of a simple substance in the liquid form be not that of atoms simply, instead of compound molecules.

In the propagation, then, of sound, or a force of percussion, through a solid or liquid, the force of repulsion developed between the contiguous atoms of two molecules should be as great as would be developed between the constituent atoms of the molecules by an equal relative displacement. The velocity imparted by this repulsion to the molecule, would of course be less than that communicated to the single atom by an equal force; but less only in the ratio of the number of atoms in the molecule to unity. Unless, then, the integrant molecules of an elastic solid, or of a liquid, contain a large number of atoms the velocity of propagation through it of sound, or a force of percussion, should not be many times less than that which should occur from atom to atom of each of its molecules, under the operation of atomic forces conceived to be of sufficient intensity to impart hundreds of thousands of millions of millions of vibrations in a second—a velocity of propagation which should be comparable with that of light itself, by the luminiferous ether. We may conclude, therefore, that the immense disproportion between the rates of movement, and accelerating forces in operation, in the origination and propagation of waves of heat and of sound, can only be reconciled with the theory of atomic heat-vibrations under consideration, by supposing that the integrant molecules of all bodies, solid or liquid, contain millions of atoms. It is hardly necessary to add that there are insuperable objections to this supposition, on both chemical and physical grounds.

3. *Certain phenomena attendant upon the development of heat by impact, are opposed to the hypothesis of atomic heat-vibrations.* It is found that a certain amount of heat is developed, as the final result of any case of impact, provided there is a residual compression of one or both of the impinging bodies at the close of the impact, not otherwise; and that the quantity of heat evolved is proportionate to the degree of condensation. Now this residual condensation implies that the impact has augmented the attractive forces exerted by each molecule upon contiguous molecules; the repulsive forces exerted by it, if experiencing any change, certainly not being proportionally increased. The constituent atoms of each molecule must then, if invariable as supposed, have taken up new positions of equilibrium, in which the attractive actions exerted by them upon the atoms of a contiguous molecule have augmented. Hence the actions of the constituent atoms of each molecule on one another must have changed. Now such a change in the intensities of the atomic forces that take effect at a given distance, cannot result from the mere fact of atomic vibrations. Again if we reflect that *the compression existing at the moment of the separation of the two colliding bodies, which serves as the meas-*

ure of the heat evolved, may have an indefinite series of values, varying by ever so small degrees with the force of impact, and with the degree of elasticity, we shall see that the molecules must be capable of taking up an endless number of new positions of equilibrium. But this is plainly impossible if the inherent atomic forces are invariable, since the mutual actions of the molecules, being the joint actions of their constituent atoms, cannot vary unless the individual atomic actions of which they are made up vary, and these cannot change, by such small degrees, unless the actions of the constituent atoms of each molecule on one another change; for it is in this way alone that these atoms can take up an indefinite series of new positions of equilibrium, and so the molecules be capable of exerting corresponding varieties of action on one another.

A similar conclusion may be arrived at, by considering the phenomena of the set of bars and beams, when relieved of strain. It has been established as the result of diverse series of experiments, under varied circumstances, that when a bar, or beam, is relieved of any strain to which it has been subjected by a weight, there is a small residual change of dimensions, form, or position, which is termed the *set;* and that this set, from being barely appreciable when the smaller weights are employed, steadily and slowly increases with the weight used. For example, according to the results of Hodgkinson's experiments on the compression of a bar of cast iron, 10 ft. long, confined in a vertical position between guides, the set remaining after a compressing weight of about 2,000 lbs. per square inch of section was removed, was only $\frac{1}{250,000}$ of the length—that is, the distance between contiguous molecules in the line of the bar was diminished by this fractional amount. The weights being gradually increased, from 2,000 lbs. to 33,000 lbs., the set remaining after their removal augmented by slow degrees from $\frac{1}{250,000}$ to $\frac{1}{2,000}$ of the length. The atoms of the individual molecules of the iron must then have taken up a corresponding number of slightly varying positions of equilibrium, giving rise to new intensities in the forces of action of one molecule on another at a given distance. Now such a series of slightly differing positions of equilibrium of the molecules, is plainly irreconcilable with any other hypothesis than that of the capability of variations, by indefinitely small degrees, in the intensities of the atomic forces exerted at given distances.

Whether, then, we consider the residual effects of a force of percussion, or of a force of pressure, we find that if we take the ground that the atomic forces vary in intensity only with the distance of action, we are involved in this dilemma; the effects observed cannot have place unless the constituent atoms of the molecules are capable of taking an indefinite number of slightly differing positions of equilibrium, and these diverse positions cannot be taken up if the forces exerted remain the same at the same distance. We are, therefore, compelled to abandon one prominent feature of the doctrine of atomic heat-vibrations, and admit that *the mutual actions of atoms are liable to change, under the influence of applied forces, by reason of some change taking place in the physical and internal mechanical condition of the atoms themselves.*

We may conclude, therefore, that when two bodies collide, the condensation that subsists at the close of the impact is, in all probability, due to some action, exerted by the force developed in the collision, upon the ultimate atoms of the bodies, which has the effect to change the physical and internal mechanical condition of each atom—a result which is conceivable only on the supposition that "the atom," so-called, *is made up of distinct parts capable of relative displacement.* We conclude also that the evolution of heat which accompanies the condensation, and is proportionate in amount to it, is probably due to the same physical change experienced by the atoms.

Let us now attempt to gain a nearer insight into the detail of the process of evolution of heat by impact It will be conceded, that in the collision of two bodies a force of mutual repulsion comes into operation between the molecules at the point of contact; which goes on increasing in intensity as the minute distance between these molecules diminishes, and then decreases to zero at the instant of the final separation of the bodies. It is this force of mutual repulsion, developed at the point of contact, that is the immediate operative cause of all the phenomena of the impact.* This force cannot be the repulsion of sensible heat, for the sensible heat-energy that pertains to any body is definite in amount, and if any portion of it is expended in the impact, it can, at most, only be given out again at the close, and hence the body could experience no increase of temperature. Now, in the impact of *perfectly inelastic bodies*, the fact that there is no recoil shows that no portion of the energy of the moving bodies, lost in the impact, is expended in effecting their final condensation; for if it were, the potential energy of the resistance that would be in operation at the moment when the bodies had a common velocity, would be expended in the production of a recoil. But this is

* The mutual repulsion between the molecules in the interior of the two bodies comes into operation, it is true; but it is only incidentally, as an antagonistic force to the condensation which the repulsion developed between the contact-molecules tends to produce, in arresting the motion of approximation of the two bodies. The amount of the condensation experienced by the bodies, and the duration of the contact, will vary with the intensity of the internal elastic resistance thus called into play, for a given displacement of the molecules: or, in other words, with their coefficient of elasticity. They should also vary with any deviations from perfect elasticity that may subsist.

equivalent to saying that the atoms and molecules take up, of themselves, by reason of variations in their mutual actions, in some way induced by the impact, a series of new virtual positions of equilibrium in the process of condensation. Again, if, as we have seen, no portion of the energy lost in the impact is expended in effecting the final condensation, then it follows that the whole of the energy lost is consumed in the production of some form and amount of movement which must be, either potentially or actually, the heat-energy developed by the impact. This movement must be associated with, and proceed *pari passu* with the changes of atomic and molecular actions above mentioned, and hence cannot be the supposed atomic heat-vibrations. But it may be conjectured that it may still be some potential change in the positions of the atoms, from which result atomic heat-vibrations. The answer to this is, that it is impossible that any such changes of position could form a series of positions of equilibrium of the molecules and atoms (which we have seen obtain, so far as the natural atomic forces are operative, in the case of inelastic impact) and at the same time result in atomic vibrations; since such vibrations imply that the mutual actions of the atoms, in the displaced positions, are either effectively attractive, or effectively repulsive, and hence these positions could not answer to states of equilibrium.

To examine the process more closely; at the instant when the distance between the molecules at the point of contact of the two bodies has reached its minimum, and, therefore, the mutual repulsion between them has augmented to its maximum value, the two bodies have been brought to a common velocity. In accomplishing this a certain amount of energy has been expended, which is measured by the mean value of the mutual repulsion between the contact-molecules during the minute interval of time that this repulsion has been in operation, multiplied by the minute distance that these molecules have approached each other during the same interval. This is the greatest amount of energy, or living force, that the bodies can possibly lose in the impact. At the instant supposed, the condition of maximum approximation of the contact-molecules is attended with a potential energy of their mutual repulsion, equal to the actual energy expended by the same repulsion in bringing the bodies to a common velocity. Now, if the bodies be supposed to be perfectly elastic, this potential energy will be expended in separating the bodies, by altering their velocities —the loss and gain effected being the same as has been experienced during the previous interval. The previous compression is now followed by an equal recoil, and the repulsions in operation between the contact molecules, and between all those which have been urged into closer proximity, pass through the same values in the inverse order, and in an equal interval of time. No heat, or other form of energy, can then be evolved.

But if the bodies be imperfectly elastic the approximation of the molecules, and also of their atoms, during the interval of condensation, will be attended with an increase in the intensities of the attractive forces exerted by the same, as compared with those of their repulsive forces. The tendency of this change is to establish a series of new positions of internal equilibrium, in which the molecules, and their atoms, are in closer proximity than before. One result of this tendency will be that the amount of the condensation, and the duration of the process, will be prolonged. But when the end of this interval is reached the two bodies will have a common velocity, and this result will have been reached by the expenditure of a certain amount of repulsive energy between the molecules at the point of contact, just as in the case of perfectly elastic bodies. But the potential repulsive energy between these molecules, now subsisting, is not, as in the former case, expended in altering the velocities and momenta of the two bodies, but *is chiefly employed in effecting some mechanical change in the internal condition of the individual atoms, conceived to be made up of distinct parts, the recoil to which is the immediate origin of the heat developed;* and these atomic changes are attended with variations in the intensities of the mutual actions of the atoms. It is to be observed that the contiguous surfaces of the colliding bodies now separate, after they have been brought to a common velocity, chiefly by a continuation of the condensation of each body on the line of impact; brought about mainly by the variations above specified as occurring in the atomic forces. A small portion of the potential repulsive energy subsisting at the point of contact, is consumed in effecting this condensation, in opposition to a decreasing resistance; but the greater portion is employed in effecting the atomic change just mentioned, which in passing off produces an equivalent amount of heat-energy. This represents the amount of energy which is lost in the impact.

Upon the conception of an atom, and of the molecular forces, adopted in my papers on Molecular Physics, published in former Nos. of this Journal, and in view of the special theory of the essential physical characteristics of imperfect elasticity presented,* the whole matter becomes intelligible. We see that the portion of the energy of the moving bodies which is lost in the impact, is expended in disturbing the dynamic equilibrium of the electric envelopes which surround the atoms, and are immersed in their ethereal atmospheres.† The reason of this result lies in the

* This Journal, June, 1872, pp. 443 and 444.
† This Journal, May, 1872, p. 336.

theoretical position taken, and sustained by various considerations,* that in the case of inelastic bodies the approximation of the atoms is attended with an increase in the attractive impulses which their contiguous envelopes exert upon each other, and therefore, with an expansion of the envelopes, and consequently a diminution in the distance between the atoms that answers to the zero of effective action. It thus happens that, as the condensation goes on, a series of instantaneous positions of equilibrium of the atoms and molecules (so far as the natural molecular actions are concerned) are passed through, by reason of the change just noticed, induced in the condition of the atoms. The potential repulsive energy subsisting at the point of contact, is thus mainly expended in disturbing the equilibrium of the atomic envelopes. *The heat-energy evolved consists in the return of these envelopes to their former undisturbed condition, with attendant vibratory movements of their different layers, and the ethereal waves resulting therefrom.* As the atomic envelopes return to their original condition, with the evolution of heat, the condensation or set, subsisting at the instant of the complete separation of the bodies, will pass off, in consequence, more or less. Any permanent set that may remain after the bodies have recovered their original temperature, being chiefly due to changes in the atomic forces, resulting from alterations of the physical condition of the atoms incidental to the act of compression, will not have been attended with the expenditure of any considerable portion of the energy, or living force, that is lost in the impact.

The theory may be succinctly stated as follows: The destruction of the motion of approximation of the two bodies, during the first stage of the impact, will introduce into the system an amount of repulsive energy equal to that expended in bringing the two bodies to a common velocity. In elastic impact this is consumed in imparting the same loss and gain of velocity already experienced; but in inelastic impact is expended in displacing the atomic envelopes from their positions of equilibrium, and their subsequent return to their former condition is the immediate origin of the heat given off. The essential ground of the distinction lies in the fact that, with elastic bodies, the atomic forces, as exerted at a given distance, do not vary in intensity; while the reverse is true of inelastic bodies. The physical reason for it is that, in the former case, the mutual attractive actions of contiguous atomic envelopes is not altered by reason of the condensation which the bodies undergo, while in the latter it is augmented.†

4. Another no less decisive objection to the doctrine of

* This Journal, June, 1872, p. 444.
† This Journal, June, 1872, p. 443 and 444.

atomic heat-vibrations, may be derived from the consideration that *the rapid subsidence of the supposed vibrations, both of heat and light, when their inciting cause is no longer in operation, implies a degree of resistance to the rapidly moving atoms, from the ether to which the living force of the vibrations is communicated, far greater than can be admitted to exist.* A short calculation will serve to make this evident. According to the experiments of MM. F. Lucas and A. Cazin,* the duration of a spark from an ordinary electrical machine does not exceed 4 millionths of a second. In this minute interval of time, then, a large fraction of the living force of atomic light-vibrations, incited by the electric discharge, is communicated to the surrounding ether. Now let us allow that the extent of the vibrations is as much as $\frac{1}{1000}$ of an inch (which is undoubtedly much above its actual value). The average number of undulations per second, in the waves of the different colors that make up white light, is about 550,000,000,000,000. In one second, then, each of the vibrating atoms will have traversed, in successive vibrations, the space of $0·001 \times 550,000,000,000,000$ in. = 8,680,555 miles. This exceeds the velocity of the earth in its orbit (18·18 miles per second) in the ratio of 477,478 to 1. Now we will suppose that in the interval of 4 millionths of a second the average velocity of the atomic vibrations is only reduced by a small fraction, say $\frac{1}{10}$, instead of being entirely taken up, and that the retarding force of the ether remains sensibly constant while this small reduction takes place. Denote this retarding force, for a single atom, by p; the initial average velocity of vibration, above given, by v; and the interval of time in which a constant retarding force, of the intensity p, would be capable of bringing the atom to rest by t: then $v=pt$. Also let $v'=v-\frac{v}{10}$, and t' the interval of time in which the same retarding force would destroy this velocity; then $v'=pt'$. Hence $v-v'=p(t-t')$, and $t-t'=\frac{v-v'}{p}=\frac{\frac{v}{10}}{p}=\frac{v}{10p}$. This is then the expression for the interval of time in which the velocity v should be reduced $\frac{1}{10}$. The retarding force of the ether, at the velocity of 8,680,555 miles, of the atom, should exceed (if we admit the law of proportionality to the squares of the velocities) that which the same atom would experience, if moving with the velocity of the earth in its orbit, in the ratio of $(477,500)^2$ to 1. Let us denote this latter retarding force by p'; and suppose $T-T'$ to be the interval of time in which this force should reduce the velocity (V), equal to that of the earth in its orbit, by $\frac{1}{10}$. Then, as before,

* Philosophical Magazine, Oct., 1872, p. 319.

$$\mathrm{V}=p'\mathrm{T},\ \mathrm{V}'=p'\mathrm{T}',\ \text{and}\ \mathrm{T}-\mathrm{T}'=\frac{\mathrm{V}-\mathrm{V}'}{p'}=\frac{\mathrm{V}}{10p'}.$$

We have, therefore, $\dfrac{\mathrm{T}-\mathrm{T}'}{t-t'}=\dfrac{\mathrm{V}}{10p'}\div\dfrac{v}{10p}=\dfrac{\mathrm{V}}{v}\cdot\dfrac{p}{p'}$;

$$\text{Or,}\quad \mathrm{T}-\mathrm{T}'=(t-t')\frac{\mathrm{V}}{v}\cdot\frac{p}{p'}=(t-t')\frac{1}{477{,}500}(477{,}500)^2.$$

Thus, $\mathrm{T}-\mathrm{T}'=(t-t')477{,}500=477{,}500\times0^{s}{\cdot}000004=1^{s}{\cdot}91$.

Accordingly, if the velocity of vibration of the atoms, produced by the electric spark, is reduced by $\frac{1}{10}$ in 4 millionths of a second, the same atoms moving with the velocity of the earth in its orbit, should lose $\frac{1}{10}$ of their velocity in two seconds.

It does not seem possible that any allowable change in the assumptions upon which the foregoing calculation proceeds, can be made that will not still reveal an enormous discrepancy between the ethereal resistance computed for the orbital velocity of the earth and any actual resistance that can be admitted. It is true this discrepancy may be much lessened, for the general mass of the earth, if we allow that the resistance of the ether takes effect upon the molecules of this mass, instead of their constituent atoms; and still more if the flow of the ether through the interstices of the mass be conceived to be wholly obstructed. But we can neither take the ground that the molecules of the earth's atmosphere contain a great number of atoms, nor that it intercepts the impulses that take effect upon the ether which pervades its interstices, by reason of the earth's motion in its orbit. Much less can such a position be taken with regard to the cometary bodies, whose substance seems at times to reach the verge of possible tenuity, and yet they traverse the sea of ether often with velocities much greater than the earth's. It is a question not yet definitely settled, whether any of these bodies are sensibly resisted in their motions by the ether of space.

It may perhaps be objected to the above calculation, that the basis of it is the exceedingly rapid subsidence of the light emitted by the electric spark, and not of heat-rays. But the origin of light is conceived to be essentially the same as that of heat—if it is atomic vibrations for the one, it is also atomic vibrations for the other, differing only, to a certain extent, in rate and amplitude. If in ordinary cases the subsidence of heat is less rapid, it must be ascribed to the fact that the loss by radiation at the surface of the heated body is supplied in a good degree by heat received by conduction from the interior of the mass. In the case of a thin gas-jet, a sudden interruption of the supply is no doubt attended with an almost instantaneous large reduction of the heat evolved.

II. *Can heat consist in a motion of revolution of the atoms of bodies?* The same objections that have been urged against the theory of atomic heat and light vibrations, will hold against the present hypothesis. The hypothesis seems, in fact, to be almost a mechanical impossibility, consistently with the ordinary permanency in the properties of substances. Whether we regard the atoms as arranged in duplex or complex systems, these systems must be within the range of powerful reciprocal action, and hence must be exposed to mutual perturbations that should apparently be destructive of all permanency in their state, and so in the mechanical and physical properties of the substance to which they belong.

III. *Can heat consist in a rotation of atoms about axes?* The same objections still hold against this hypothesis as against that of atomic vibrations. To these it may be added, that upon this idea the expansive action of heat must result from ethereal vortices originating in the motion of rotation, but if such vortices have an outward or repulsive action, in a direction perpendicular to the axis of rotation, the tendency should be the reverse of this in the direction of the axis; and hence atoms that have absorbed an additional amount of radiant heat (i. e., have taken on, under the impulses of the heat waves, a more rapid rotation) should exert an expansive action in certain directions, but a contractile action in directions at right angles to these.

Other objections, of great force, might be urged against the doctrine that heat is some mode of motion of the atoms of gross matter, drawn from both physical and chemical considerations; but those which have been presented will suffice. Unless they can be effectively answered this doctrine must be unhesitatingly abandoned.

Conclusions.—The results of the foregoing discussion seem to bring us irresistibly to the conclusion that the atoms of bodies must be made up of distinct parts bound together by certain forces; and that heat must consist in some movement of relative displacement among these constituent parts of the atoms. If now we consider that every atom is capable of exerting upon surrounding atoms an effective repulsion at the more minute distances, and an effective attraction at certain greater distances, we are led to infer that the "atom," so-called, consists of a central attractive nucleus, surrounded by an envelope, or atmosphere, composed of repulsive elements. We also readily discern the possibility that heat and light may consist in some mode of motion of this outer envelope, either in its elementary parts, or as a whole. Now we have independent evidence, afforded by the entire series of electric and magnetic phenomena, that there exists a subtile form of matter, made up of mutually repulsive elements, intimately associated with the atoms of bodies, which has received the name of the electric fluid, or electric ether. It is true that it has been vaguely conjectured that electricity may consist in some mysterious mode of motion of the atoms of ordinary matter, but such a mere conjecture, unsubstantiated by any decisive evidence in its favor, cannot throw an air of improbability over an hypothesis that is sustained by a multitude of actual phenomena.

It is, however, conceivable that the electric may be identical with the luminiferous ether which permeates all bodies, and is known to be physically linked to its atoms. We may then form two possible conceptions of an atom, with its essential accompaniments, viz: (1) that it consists of a true atom surrounded solely by an atmosphere of luminiferous ether; 2) that it has, in addition, an envelope of distinct electric ether immersed in the ethereal atmosphere. In view of the results of this discussion, we recognize the high probability that heat and light originate in some mode of motion occurring in the ethereal atmospheres, or in the electric envelopes of the atoms; or, more properly, in the force or forces by which such a movement is produced.

Against this conception of the origin and nature of heat, the objections that have been brought forward against the prevailing notion do not hold good. The source of heat is now transferred from the atom proper to its ethereal atmosphere, or electric envelope, one or both—and, therefore, to a form of matter nearly if not quite as subtile as the medium of light, and whose elastic forces are nearly or quite as intense. Hence the enormous rapidity of the recurring movements, and the amazing intensity of the accelerating forces in play in the evolution of heat and light, are in full accordance with the present hypothesis. Again, the change in the physical state of the "atom" (what is ordinarily represented by this term) and consequently in its operative forces, which we have recognized as attendant upon the evolution of heat by impact, are effects that may reasonably be expected from a disturbance of the atomic envelopes by the force of impact.* Also, upon this hypothesis the impact of the ether of space upon the earth, and other cosmical bodies, should take effect upon the ethereal atmospheres of the atoms of these bodies, and develop electric or ethereal currents, that would eventually pass off in the form of heat-energy, without finally checking the translatory motion of the atoms. It may seem improbable, from our ordinary point of view, that such a result should follow from ethereal impulsive actions; but we have already seen (p. 192) that the same potential repulsive

* What I conceive to be the actual nature of the change which the atom undergoes, and the true process of heat-evolution, has already been briefly intimated (p. 193).

energy which, in the recoil of two elastic bodies compressed by impact, imparts an additional loss and gain of velocity to the bodies, is expended, in the case of inelastic bodies, in the development of an equivalent heat-energy, without changing the velocities of the bodies as a whole. The force that is here operative is the mutual repulsion between the contact-molecules, of which we can form no other definite conception than that it consists of a perpetual stream of ethereal wave-impulses, that becomes operative, in a sensible degree, so soon as the molecules at the point of contact come within a certain degree of proximity.