ART. VIII.—*On Molecular Physics;* by Prof. W. A. NORTON,

[Continued from vol. xxxix, p. 254.]

*Thermo-Electricity.*—The key to thermo-electric phenomena should be found in the effect produced by heat on the electric condition of molecules. Now when heat is applied to a surface, the molecules at the surface first receive the ethereal pulses of which the force of heat consists. These pulses passing on to the central atom of each molecule, or the condensed universal ether at the center of the molecule, are there partially expended in expanding its electric atmosphere on the outer side, and are partially propagated on. Upon reaching the inner side of the atom they will again be partially consumed in expanding the atmosphere on that side, while a certain portion will be transmitted to the next atom. It is easy to see that this second expansion should be less than the first. Under these circumstances two important electrical effects will be produced. (1.) By reason of the greater expansion of the atmosphere on the outer than on the inner side, its density will be diminished on the outer side, and hence electric ether will flow around to that side. *The molecular atmosphere will therefore become polarized positively on the outer side.* (2.) As a consequence of this polarization the molecular atmosphere *will urge away from it a portion of the electric ether posited near its surface, and tend to develop a negative polarization in the particles of contiguous surfaces.* The surface receiving the heat will then become positively polarized, and there will be at the same time an electric movement outward from the surface. Cold, or the abstraction of heat, will have precisely the opposite tendency; that is, a surface in the act of cooling will become negatively polarized, and this change will be attended with a flow of electricity toward the surface. Such movements of the electric ether will be in waves of translation, or in currents of free electricity, or both combined, according to the conducting power of the medium exterior to the surface (p. 252). Substances may differ in the effects thus produced, under similar circumstances, from two causes; a difference in their conducting power for heat, and a difference in the degree of expansion, or in the effect of the expansion produced by the same amount of heat.

Now let a plate of bismuth be placed in contact with a plate of antimony, and let the junction be heated and the other ends be brought into good conducting communication. If the above mentioned effects of heat be different for these two metals, a current should set, at the junction, from the one which experiences the greatest effect to that which experiences the least, and pass through the circuit. Bismuth is a poorer conductor of heat than antimony, and in fact than most other metals, and hence its surface molecules should imbibe and retain more heat than those of the antimony. The diamagnetic properties of bismuth also indicate, as will be seen hereafter, that its molecular atmospheres are remarkably expansible. If these peculiarities of bismuth be admitted, we have an explanation of the fact that bismuth is positive[1] to other metals in its thermo-electric relations. The bismuth and antimony in the thermo-electric pair, it will be observed, hold the same relation to each other as the zinc and copper in the galvanic pair, and the heat does the same electrical duty in the one, that the oxygen does in the other.

If the other ends of the two metals be brought together and cooled, the current will be reënforced, since the molecular atmospheres of the bismuth will contract more than those of the antimony. (See effect of cold, p. 61.)

It has been ascertained as the result of numerous experiments, that "increasing the temperature of the negative metal generally increases the amount of deflection of the galvanometer needle produced by heating the junction; while if the higher heat is applied to the metal which is positive at moderate temperatures, a current in the opposite direction is established." To get at the explanation of these curious effects we must observe that the "higher heat" spoken of is applied at a certain distance from the junction, and hence it is the inner sides of the surface molecules which first receive the heat from this second source, and become positively polarized. Accordingly, the current should be strengthened in the first case, above mentioned, and weakened in the second. It has also been observed that a current may be excited with two wires of the same metal, by heating the end of one and bringing it in contact with the other; and that the direction of the current at the junction is from the cold to the hot wire." In this case it is to be remarked that the hot wire is in the act of cooling, and hence there should be an electric movement toward its surface (p. 61), or from the cold to the hot wire, through the junction.

*Pyro-electric Crystals.*—Tourmaline is the most conspicuous crystal belonging to this class. "A prism of tourmaline has different secondary planes at its two extremities, or, as it is expressed, is hemihedrally modified." This peculiarity of crystallization, which also obtains in the other pyro-electric crystals, indicates that in the direction of the axis, the molecules of the crystal have different mechanical properties on opposite sides. In this condition of things we may reasonably suppose that the molecular atmospheres would expand unequally on opposite

[1] By the positive metal is here meant that which imparts, at the heated junction, positive electricity to the other metal. This is often termed the negative metal. Its polarization is positive, but its electrical state is negative (p. 245).

sides, under the influence of the same amount of heat. If this be admitted we have a complete explanation of the electric phenomena exhibited by the tourmaline when heated, in accordance with the principles already laid down. Thus, let a tourmaline be heated regularly, that is, so that all points of its surface shall receive equal increments of heat; at all points of the surface the unequal expansive action of the heat upon the two sides of the molecular atmospheres in the axial direction, will determine their polarization, and an attendant electric movement from the positively polarized side of one molecule to the negatively polarized side of the next. There should accordingly be opposite electrical states manifested at the ends of the crystal. This state of things should continue so long as the temperature is rising. But it is to be observed that the effective polarization determined in each molecule by the heat is weakened by the discharge that takes place from one molecule to the next, and that from this cause the signs of electrical excitement at the ends of the crystal will be much feebler when the temperature becomes uniform than they would otherwise be. Now if the heated tourmaline be cooled regularly, the process that attended upon the heating will be reversed, and the electrical states, or effective poles, will be reversed. This reversal of the poles may occur soon after the temperature begins to fall, because of the above mentioned weakening of the effective polarization; since this remaining polarization, when the temperature becomes uniform, which is really *effective* upon bodies placed near the ends of the tourmaline, may be no greater than the opposite *transient* polarization that may arise from a small loss of temperature.

*Mutual Attractions and Repulsions of Electric Currents.*—We have seen that in an electric current there is a flow, or onward movement of electric ether throughout the entire route of the current. Now the rapidly moving molecules of electric ether must act impulsively against the universal ether in their path; and every such impulse must be propagated indefinitely outward through this ether. The innumerable impulses thus originating in a current are parallel to the direction of the current, and must take effect upon all surrounding molecules in this direction. They constitute what may be called the *external impulsive force of the current.* The well known phenomena under immediate consideration, as well as all the other phenomena of the external action of currents to be discussed, are to be ascribed to the operation of this external impulsive force. Let us first take the case of two parallel wires conveying currents in the same direction. The impulses propagated from these wires will tend to weaken the tension of the universal ether lying between the wires. A similar effect, but less in amount, will be produced upon the ether lying on the outer sides of the wires. The ethereal tension should therefore be in excess upon the outer sides of the wires, and hence they should be urged toward each other, or there should be an apparent attraction between the wires conveying the currents. The excess of ethereal tension here alluded to is attributable to the fact that the impulses proceeding from the one wire, in being propagated through the other, are materially reduced in intensity. This effect results mainly from the dispersion produced by the interstitial ether, which is brought into a very disturbed state of density by the swiftly moving atoms of the electric ether in the current. When only one of the wires conveys a current, no attraction or repulsion is observed, because the dispersion just mentioned is wanting.

If the currents be supposed to traverse the wires in opposite directions, then the same operative cause, the external impulsive forces of the currents, will compress the ether between the wires to a greater degree than beyond them, and thus there will be an effective force urging them farther apart.

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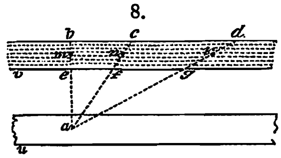

Let *a*, fig. 8, be a point of one of the currents, from which an impulse is propagated, and *ab*, *ac*, *ad*, lines radiating from it and crossing the second wire, *v*, under different degrees of obliquity. The dotted lines drawn between *bd* and *eg* represent the lines of moving electrical atoms. Each of the lines *ab*, *ac*, *ad*, will cross the same number of such lines, and therefore impulses propagated along them will encounter the same number of moving atoms, and experience the same proportional diminution. This diminution should be a certain constant fractional part of the impulse that reaches any point of the nearer side, *eg*, of the wire. The diminution of the propagated impulse, in traversing the wire, simply by reason of the increased length of the passage, as the line is more oblique, should also be a constant fractional part of the impulse; since *fc* is the same proportional part of *af*, or *an* for each point of the wire. Hence the action of any point *a* of the first wire, upon any point *f* of the second, should be inversely proportional to the square of the distance; and the entire force of action of one indefinite wire upon another should be inversely proportional to the distance between the two. (See Lamé, Cours de Physique, vol. iii, p. 236.)

If the currents cross each other under a certain angle instead of being parallel, it may be seen by attending to the mutual actions of the separate points of the two currents, that there will be attractions or repulsions according to the relative directions of the currents at the points; and that the entire action will tend to bring the two currents into the same direction, in which the attraction will be a maximum.

*External Action of an Electric Current upon bodies in their natural state.*—In undertaking to deduce from our fundamental principles the varied phenomena of the action of a current upon bodies in its vicinity, we have to consider that there are *two modes* in which the external impulsive force of a current may act upon such bodies and develop currents; the one *direct*, and the other *indirect*. (1.) The propagated impulses may take effect directly upon the atoms of the electric atmospheres of the molecules, impelling them in the same direction that the primary current is moving, and so tend to generate a current similar to the primary. (2.) Or these same ethereal impulses may fall upon the central atoms of the molecules, force up the atmospheres on the side of the atoms upon which they fall, and so develop a current opposite to the original one. We have to consider, also, that the external current-force may operate, theoretically, in both these ways, either upon the *simple molecules* which are grouped together into compound molecules, or upon *compound molecules* as a whole. The action upon the constituents of the compound molecules, tends to develop currents within the mass of these molecules. Among the variety of especial currents which may thus be excited, we have particularly to note those which may be developed in the surface of each group, and circulate around it, from particle to particle. If the direct mode of operation of the primary current predominates, such circular currents are *magnetic;* if the indirect prevail, they are *diamagnetic.* If the two tendencies countervail each other, the substance is in a *neutral* magnetic condition. The neutral magnetic state may also result from the absence of groups of particles in the substance, within which circular currents can be established.

To the action of the current upon each compound molecule, with its own proper atmosphere (p. 241), as a whole, are to be ascribed the remarkable phenomena of *Induced Currents*, especially so-called. Experiment has hitherto failed to detect the existence of any current, from one such molecule to another, or through the mass of a body, produced by the uniform action of an established current. All such induced currents result from either an increase or a decrease in the effective action of the inducing current, and are wholly due to the indirect mode of operation of this current. This fact indicates, in accordance with the views that have been advanced upon electric polarization, (p. 242), that the current develops a polarization in the compound molecules of bodies, which increases or decreases as the external impulsive action of the current increases or decreases, but remains constant so long as this action continues the same. This polarization is Faraday's "Electro-tonic state" of bodies.

*Magnetism.*—The general nature of the magnetic currents, as distinguished from other electric currents, has just been indicated. The existence of such currents in the surface of a compound molecule seems to imply that there is a virtual chain of particles extending circularly around it, which there would be if the number of particles in each group be large. Ampére's researches have completely established that the idea of circular molecular currents is the key to all magnetic phenomena. It suffices, therefore, for our present purpose, to show, as has been done, that such currents are legitimately deducible from the fundamental conceptions laid down at the outset; and that the mutually attractive and repulsive actions of currents may also be derived from the same mechanical ideas, (p. 63). We adopt, then, definitively, Ampére's theory of the constitution of a magnet.

The immediate cause of the development of magnetic currents is the direct impulsive action of an established current, taking effect upon the particles in the surface of compound molecules.

In respect to magnetic properties, we have specially to distinguish soft iron and steel. The cause of their difference of property seems to lie simply in a difference in the conducting power of the groups of particles into which they are aggregated. If in soft iron these groups are good conductors, the electric ether set in motion should pass freely around them, unattended with any material polarization of the particles, and unresisted by the force that results from such polarization, (p. 245). When the exciting cause ceases to operate, there is no force remaining to counteract the resistance of the universal ether to the flow of the electricity, and the retarding operation of contiguous opposing currents. But if we suppose that, in the case of steel, the molecular groups are imperfect conductors, the magnetizing force will develop a polarization of the separate molecules; and, as a consequence, the currents may pass chiefly through their atmospheres, as in the case of electric induction, (p. 243). In this state of things, when the force is withdrawn, it does not follow that the magnetic currents will entirely pass off; for there would apparently be a force in operation which would tend to retain currents of a certain intensity in circulation. This is the mutual action of the contiguous positive and negative sides of two molecules, throughout the chain. It would seem that such a circular chain of particles would not, of necessity, attain to a condition of statical polarization, but might reach a dynamical equilibrium; in which the impulsive force, from each discharge brought about by the action of contiguous molecules, should restore the polarization lost by the discharge to the next preceding molecule.[2]

[2] It is worthy of consideration, whether certain phenomena of luminosity, as phosphorescence, heat lightning, &c., may not have a similar origin, viz: in recurring discharges resulting from a previous molecular polarization, established by an electric discharge through the mass; or from a similar effect produced in a feebler degree by heat or light.

According to this view, permanent magnetization consists in polarizing the molecules, and it is this induced state which determines and maintains, in opposition to all resistances, currents of a certain intensity. A certain amount of force ("coercive force"), and a certain interval of time, are expended in developing this polarization. At the same time it is only when this force is exerted with this result that permanent magnetism can exist. Heat, or a blow, or an electric discharge, by destroying the molecular polarization, may demagnetize the bar. It is also to be observed that intense heat may demagnetize a bar, and destroy the susceptibility to magnetism in iron or steel, by breaking up the groups of particles into which the mass is aggregated.

*Diamagnetism.*—It has already been intimated that the diamagnetic state into which certain substances, as bismuth, phosphorus, antimony, &c., are brought by the action of a powerful magnet, probably consists in the circulation of currents around the compound molecules of the mass, in the opposite direction to the inducing current; and that these currents result from the second mode of operation of the external force of the primary current, (p. 65). Accordingly, the susceptibility to diamagnetism must arise from a special liability to expansion on the part of the electric atmospheres of the simple molecules, when urged upward by the ethereal pulses that fall upon their central atoms.

*Electro-Magnetism.*—The essential theory of the developement of magnetism by electric currents, and of electro-magnetic phenomena generally, is embraced in what has already been stated, (pp. 63–4–5).

*Magneto-Electricity.*—The excitation of electric currents by magnetic action is a phenomenon of pure induction, and will be included under the next head.

*Induction of Electric Currents.*—The term induction, as ordinarily used in Dynamical Electricity, has reference only to the development of currents, through wires, or upon the surfaces, or within the mass of bodies. It will suffice to confine our attention to the origination of currents in wires forming a closed circuit. The general idea of the process, as contemplated from our theoretical point of view, has already been indicated. The fundamental principle which covers the whole ground is, that whenever the action of the impulsive force of any current begins, or is on the increase, the induced current sets in the opposite direction to the inducing current; and when the same action terminates, or is on the decrease, the induced flows in the same direction as the inducing current. The rationale is, that the ethereal pulses of the originating force fall upon the condensed ether at the central portion of each group of molecules, and urge outward the interstitial electric ether on that side of the group.

This determines a flow of a certain portion of the electric ether around to that side; and a consequent positive polarization on that side of the group, or compound molecule. While this process of polarization is going on, there must then be a flow of electricity from one compound molecule to the next, in the same direction in which the transfer of ether occurs within the molecules themselves, as an inevitable attendant upon the increasing polarization (p. 242). When the primary action becomes constant, there simply abides a state of static polarization,—an "electro-tonic state,"—in which an equilibrium prevails throughout the circuit. But when this action falls off, the polarization maintained by it must decline, and a current arise setting in the opposite direction to the former one (p. 67). The inducing current may be either electric, or magnetic, so-called. The increase of its action upon the adjacent wire may result either from the closing of the circuit in the case of a galvanic current, or the magnetization of the iron when a magnet is employed; or from the approach of the current to the wire; or from a change in the position of the wire in the magnetic field, attended with an augmentation in the action of the external impulsive force exerted by all the circular currents of the magnet. A decrease in the polarizing effect of the inducing current may result from an interruption of the circuit, or a diminution in the force of the magnet, or a recess of the wire from the current, or a movement of the wire in the magnetic field attended with a diminished action of the entire impulsive force of the magnet.

The oppositely directed currents induced by alternately closing and breaking the galvanic circuit, when the two contiguous wires are formed into a hollow coil, are greatly augmented by inserting rods, or bundles of iron wire within the coil. The explanation of this is, doubtless, that the direct action of the galvanic current is reënforced by the magnetic currents which it develops in the iron. The other cases of induction above referred to need not be dwelt upon, with the exception of that resulting from the movement of a wire to different points of the magnetic field.

This case has been subjected to a rigorous experimental analysis by Faraday, who has deduced from his researches the following general results. If a wire, forming part of a closed circuit, be held in a direction transverse to a magnet, and moved in the magnetic field, across the "lines of force," or magnetic curves, a current will be induced in the wire. If the wire be moved in one direction across these lines of force, a current in a certain direction will arise, and if it be moved across them in the other direction, a current in the opposite direction will be induced. The quantity of electricity set in motion will depend upon the number of lines of force crossed by the moving wire, and not upon the obliquity of the direction of the motion to these lines. Thus, if the wire be placed over the middle of the magnet, (*m*, fig. 9), and moved in any direction from this position, across the lines of force as shown in the figure, a current will be induced in it, running in the same direction as the circular currents on the upper side of the magnet; and if the wire be moved across these lines toward the middle of the magnet, a current will traverse the wire in the opposite direction. In each case the comparative quantity of electricity set in motion, will depend solely upon the comparative number of magnetic curves crossed, and not upon the line, *mr*, *ms*, or *mt*, along which the movement takes place.

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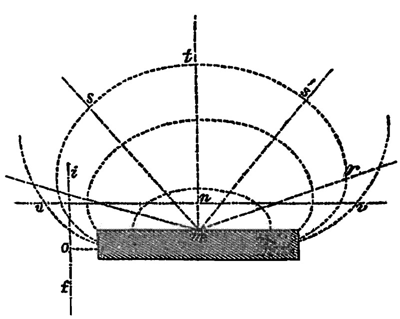

These facts are in entire accordance with the fundamental principle of induction, stated on page 67. For, (1.) the impulsive force of the magnet, at any point of the field, is the resultant of the special impulsive forces due to all the circular currents of the magnet, and has the same direction as these currents in the upper face of the magnet. (2.) This resultant will have the greatest value at the middle of the magnet, *m*, and decrease in all directions from this point. (3.) The curves of equal impulsive force correspond very closely to Faraday's "lines of force." For it will be seen on a little reflection, that the force will, beyond a certain distance from the middle, if not from the very middle, decrease most rapidly parallel to the surface of the magnet; and that the curves of equal impulsive force, proceeding from points on the ends of the magnet, will recede, over the middle of the magnet, to a greater distance from it than half its length. This is strikingly true of the curves that originate from near the center of each end; for at the very center, the force in question vanishes entirely, and therefore the curves for that point would be thrown to an infinite distance from the middle of the magnet.

In making a comparative estimate of the impulsive force of the magnet in different parts of the field, it should be observed that in receding from the magnet the force that results from any one molecular current is the resultant of the opposing impulses propagated from the oppositely directed currents on the nearer and farther sides of the molecule, and that this not only depends upon the distance of the point from the molecule, but also upon the obliquity of the line connecting the two, to the plane of the circular current. For the same distance the resultant will be greatest when the point lies in this plane, and zero when the point is opposite the center of the current. Bearing this in mind, it may readily be seen that if a line, *uv*, be drawn parallel to the axis of the magnet, at any distance from it, the impulsive force of the magnet, along this line, will decrease from the point *n*, opposite the middle of the magnet, indefinitely in both directions. Also that the force will decrease along a line, as *if*, parallel to the end, and vanish at *o* in the prolongation of the axis.

To obtain a general expression for the intensity of the external impulsive force of the magnet, let *abcd*, fig. 10, be a magnet, and let us regard its effective action upon any molecule, at *f*, as the result of the joint action of two sets of opposing currents, the one lying in the upper face *ab*, and the other in the lower face *cd*. Let $nf=y$, $nr=z$, $nr'=z'$, $nb=u$, $na=v$, $ac=d$, and $m$=coefficient of the impulsive force of an individual current. Then for the action of $r$ upon $f$ we have $\frac{mdz}{y^2+z^2}$; and for the action of $nr$, $\int\frac{mdz}{y^2+z^2}=\frac{m}{y}\,\text{tang}^{-1}\frac{z}{y}+C$. For the entire action of $nb$, we have the definite integral $\frac{m}{y}\,\text{tang}^{-1}\frac{u}{y}$. In a similar manner we obtain, for the opposing action of $od$, $\frac{m}{y+d}\,\text{tang}^{-1}\frac{u}{y+d}$. The effective impulsive action of the portion *nodb* of the magnet, will then be

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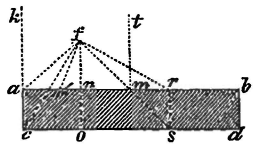


$$\frac{m}{y}\,\text{tang}^{-1}\frac{u}{y}-\frac{m}{y+d}\,\text{tang}^{-1}\frac{u}{y+d}.$$

The effective action of the other portion, *naoc*, of the magnet, will be

$$\frac{m}{y}\,\text{tang}^{-1}\frac{v}{y}-\frac{m}{y+d}\,\text{tang}^{-1}\frac{v}{y+d}.$$

We therefore have, for the entire action of the magnet,

$$w=\frac{m}{y}\left(\text{tang}^{-1}\frac{u}{y}+\text{tang}^{-1}\frac{v}{y}\right)-\frac{m}{y+d}\left(\text{tang}^{-1}\frac{u}{y+d}+\text{tang}^{-1}\frac{v}{y+d}\right),$$

$$\text{or, } w=\frac{m}{y}\left(\text{arc } afb\right)-\frac{m}{y+d}\left(\text{arc } cfd\right)\quad\ldots\ldots\ldots\quad\text{(a.)}$$

When $y$ is large as compared with $d$, we have approximately

$$w=\frac{m}{y}(\text{arc } afc+\text{arc } bfd)\quad\ldots\ldots\ldots\quad\text{(b.)}$$

To obtain the equation of the curve of equal impulsive force, let $mn=x$, and $rm=t$. Then $nr=z=x+t$, and $nb=u=x+$ $+mb=x+a$. Also $na=v=a-x$. Hence,

$$\frac{m}{y}\left(\text{tang}^{-1}\frac{x+a}{y}+\text{tang}^{-1}\frac{a-x}{y}\right)-\frac{m}{y+d}\left(\text{tang}^{-1}\frac{x+a}{y+d}+\text{tang}^{-1}\frac{a-x}{y+d}\right)=C\ldots\ldots\text{(c.)}$$

C here represents the constant intensity of the impulsive force of the magnet, for one curve. The value of C decreases as the distance of the curve from *m*, fig. 9, increases. The equation (b) shows that for the larger curves, except near the magnet, $afc+bfd$, must vary in nearly the same ratio with the ordinate $y$, from one point to another of the curve. To the left of the line *ak* the arc *afc* becomes negative in equation (b). Equations (a) and (c) fail for $y=0$.

The investigation here made proceeds upon the supposition that the breadth of the magnet is indefinitely small. If we suppose it to be indefinitely great, the action of each individual transverse current upon any point, *f*, fig. 10, would be inversely proportional to the distance of the current from this point,[3] and it will be readily seen that the amount of force propagated to *f*, within any angle, as $mfr'$, will be the same whatever may be the value of *fn*.

The equation for the value of the effective impulsive force will be approximately of the form

$$w=k\left(\frac{l}{n}+\frac{l'}{n'}\right);$$

$k$ being a constant coefficient dependent upon the strength of the magnet,—$l$ and $l'$ the parts of the length, *ab*, of the magnet, comprised between the angles *afc* and *bfd* subtended by the two ends,—and $n$, $n'$ the mean distances of these parts from *f*. We approximate to this state of things in proportion as the magnet is supposed to be broader, and shorter and thinner; or in proportion as, with a magnet of given dimensions, the point *f* is taken nearer to the magnet.

Let us now replace Faraday's lines of force by the curves of equal impulsive force of the magnet, and consider what should be the effect of moving a wire across them, along any line *mr*, *ms*, *mt*, &c., (fig. 9).

It is obvious that if the movement be outward, the impulsive force taking effect upon the wire will decrease; and that if it be inward, the force will increase. Hence, agreeably to the fundamental principle before alluded to, (p. 67,) in the first case there should be an induced current having the same direction as the currents of the upper face of the magnet; and in the second case a current pursuing the opposite direction. Again, the amount of change of force which results from the displacement of the wire, and therefore the quantity of electricity which this charge sets in motion, should depend solely upon the number of curves traversed. We may add that in whatever part of the magnetic field, and in whatever direction the wire be

[3] **The individual molecular currents lying in a transverse section of the magnet, are here supposed to be replaced by two linear currents transverse to the magnet, one in the upper and the other in the lower surface.**

supposed to move, the theoretical result is in perfect accordance with the facts as experimentally established by Faraday.

In the foregoing we have supposed the wire, transverse to the magnet, to be moved parallel to itself to various points of the magnetic field; but Faraday has shown that a current may also be induced in the wire, by bending it into a curve and causing it to revolve around the magnet, after one end has been brought into contact with the equatorial part of the magnet, and the other with a wire or rod leading out from the pole, as shown in fig. 11. "A copper ring was fixed round and in contact with the equatorial part, and the wire, $e$, made to bear by spring pressure against this ring, and also against a ring on the axis." The direction of the current changed with the direction of revolution. Corresponding currents were also obtained by rotating the magnet in the opposite directions, the wire remaining fixed. To explain these currents upon the principles now developed, we must first observe that the impulsive force of the magnet will impart a transverse polarization to the molecules of the wire. Now let a motion of revolution be imparted to the wire, in a direction opposite to that of the circulation of the magnetic currents, and the relative velocity with which the ethereal impulses will fall upon the molecules will be the sum of the velocity due to the impulse, and that of the molecules themselves in the opposite direction. The molecules at the end, $e$, of the wire, will therefore take on a higher polarization than is induced in the copper ring by the magnet simply. This polarization should be attended with a disturbance of the electric condition of the molecules in the direction of the length of the wire. There should, then, be an inequality in this disturbance at the point of contact, $e$. This inequality should originate a current that would pass around the circuit. Let $v$ denote the velocity answering to the magnetic impulse, and $v'$ the velocity of revolution of the molecule at $e$. Then the effect due to the polarizing force at the end, $e$, of the wire, may be represented by $m\ (v+v')^2$, and that induced in the contiguous particles of the copper ring by $mv^2$. The difference is $mv'(2v+v')$, which represents the electro-motive force of the current. If the wire were made to revolve around an unmagnetized bar, the originating force of the current would be $mv'^2$. The electro-motive force just mentioned would exceed this nearly in the ratio of $2v$ to $v'$. A very high velocity of revolution of the wire would therefore be required to develop a sensible current, if the bar were unmagnetized. The above expression for the electro-motive force, viz, $mv'(2v+v')$, which is nearly equal to $2mvv'$, shows that this force is proportional to the velocity, $v'$,

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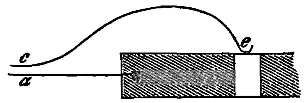

of revolution of the wire. The entire force developed in ten revolutions of the wire should then remain the same, if the velocity of revolution should be changed, (as determined by Faraday). If the magnet rotates in the opposite direction its impulses against the ether will be correspondingly increased, and the result will be the same.

Faraday, in certain papers originally published in the Philosophical Magazine, and the Philosophical Transactions, has indulged in ingenious speculations upon the probable physical character of the lines of magnetic force, and distinctly intimates that he inclines to the opinion that they have in reality a physical existence, correspondent to their analogues the electric lines," instead of being simply "representants of magnetic power," or lines of resultant magnetic action. In speculating upon the question in what this physical existence may consist, he remarks that "it may be a vibration of the hypothetical æther," (along the lines), or a state or tension of that æther equivalent to either a dynamic or a static condition, or it may be some other state." The results arrived at, in the present paper, are opposed to these speculative ideas of the great English physicist, for our conclusions are that the lines upon which the phenomena of induction by a magnet depend are merely lines of equal magnetic action; but the action is that of a force whose existence has not heretofore been recognized, viz, the so-called impulsive force of the magnet.

(To be concluded.)