



XLVIII. Researches on unipolar induction, atmospheric electricity, and the aurora borealis

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To cite this article: E. Edlund (1878) XLVIII. Researches on unipolar induction, atmospheric electricity, and the aurora borealis , Philosophical Magazine Series 5, 6:38, 360-371, DOI: [10.1080/14786447808639526](https://doi.org/10.1080/14786447808639526)

To link to this article: <http://dx.doi.org/10.1080/14786447808639526>



Published online: 13 May 2009.



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XLVIII. *Researches on Unipolar Induction, Atmospheric Electricity, and the Aurora Borealis.* By E. EDLUND, Professor of Physics at the Swedish Royal Academy of Sciences.

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§ 2. *Atmospheric Electricity and the Aurora Borealis.*

IT is known that the earth may be regarded as a relatively good conductor of electricity; while, on the other hand, the atmospheric air, in the dry state and under the pressure to which it is subject at the surface of the earth, is a very bad conductor. Its conductivity, which depends almost exclusively upon the relative quantity of humidity which it contains, is consequently subject to incessant variations from the double point of view of time and space. When the density of the air diminishes, its conductivity increases; consequently there must exist at a considerable altitude above the terrestrial surface a stratum of air the conducting-power of which is better, yet without being particularly good. The terrestrial surface, both solid and liquid, is therefore immediately surrounded by a stratum of air endowed with feeble conductivity and subject to incessant variations. To this stratum succeeds another, the conductivity of which is greater and, as far as we know, sensibly invariable. The upper limit of the atmosphere has been fixed by astronomic methods at an altitude of between 70 and 80 kilometres. Truly speaking, these determinations signify only that the atmosphere up to that limit possesses sufficient density for its presence to be indicated by the ordinary methods of determination. That the atmosphere, though excessively rarefied, extends to a still greater elevation is most evidently proved by the fact that shooting stars have been observed at nearly 900 kilometres above the surface of the earth. These small bodies evidently can only become bright in consequence of a portion of their *vis viva*, transformed into heat by the friction of the air, augmenting their temperature to such a degree that they begin to shine. Now we can only perceive the falling body from the moment when it becomes luminous; and it is clear that at that moment it will have already traversed a certain length of path in the rarefied atmosphere before attaining so high a temperature. Therefore the upper boundary of the atmosphere must be situated at a much greater distance from the earth than has hitherto been admitted.

The magnetic action of the earth cannot be explained entirely and in detail by the assumption that its magnetic force is due to a magnet of iron or steel situated in the earth, and

making a certain angle with the axis of rotation. The said action is too irregular for such an explanation to be admissible. Nevertheless the total intensity of the magnetic force is ascertained to increase in a sufficiently regular manner as we recede from the magnetic equator towards the magnetic poles. If we join the points of the terrestrial surface where the magnetic dip has the same value, we obtain curves which, though not forming true circles encompassing the earth and parallel to one another, may yet be regarded as parallel circles drawn at the surface of the earth, and having their centres on the right line which joins the earth's magnetic poles. If from the equator we proceed continually in the direction indicated by the declination-needle (not in such a direction that the angle of declination remains constantly the same), we obtain magnetic meridians converging towards the magnetic poles; these meridians are not great circles, but yet bear a certain resemblance to them*. In general, and on a large scale, it is therefore permissible to regard the earth as a magnet the axis of which makes a certain angle with the terrestrial axis of rotation. There is no need of a more exact idea of the magnetic condition of the earth for the exposition which follows.

Let $abcd$ (fig. 9) be a section passing through the axis of rotation of the earth (which we will suppose to constitute a perfect sphere); ac is its rotation-axis, bd its equator, and o its centre. To simplify the question, we will at first suppose that the two magnetic poles are on the rotation-axis, the south pole in s , and the north pole in n . $abod$ will consequently represent the northern hemisphere; and we will designate by $a'b'c'd'$ the upper limit of the atmosphere. While the earth is turning from west to east about its axis, an electric molecule situated in m describes in the same direction a circle parallel to the equator, and therefore forms a current which is acted upon by the two poles of the magnet. If now we pass planes through the circuit-element situated in m and through the two poles of the magnet, these planes will cut the figure along the right lines sm and nm ; and if in the same planes we draw the right lines mp and mq respectively perpendicular to ms and mn , we shall get the directions in which the magnetic poles tend to direct the positive electric molecule (the æther).

Let r denote the distance from the centre of the earth to m , ρ the distance from each of the poles of the magnet to the same centre, and l the latitude of the point m . We remark at starting that the magnetic phenomena presented by the earth indicate that at least ρ cannot exceed in length the half of the earth's radius; and, in consequence, we assume that ρ

* Becquerel, *Traité complet du Magnétisme* (Paris, 1846), p. 428.

is at most equal to the half of that radius. The squares of the distances of the two poles from the point m will therefore be respectively

$$r^2 + \rho^2 - 2r\rho \sin l \text{ and } r^2 + \rho^2 + 2r\rho \sin l.$$

The intensity of the current is proportional to the velocity with which the molecule m moves in its parallel circle; and that velocity is, in its turn, proportional to the distance from the rotation-axis, consequently to $r \cos l$. Designating the intensity of the magnetic poles by M , and by k a constant, we shall have, for the force with which the south pole tends to direct the molecule along mp , the expression

$$\frac{kMr \cos l}{r^2 + \rho^2 - 2r\rho \sin l'}$$

and, for the action of the north pole upon the same molecule along the line mq ,

$$\frac{kMr \cos l}{r^2 + \rho^2 + 2r\rho \sin l'}$$

Taking the sum of the components of these forces along the earth's radius drawn through the point m , we get

$$\frac{kMr\rho \cos^2 l}{(r^2 + \rho^2 - 2r\rho \sin l)^{\frac{3}{2}}} + \frac{kMr\rho \cos^2 l}{(r^2 + \rho^2 + 2r\rho \sin l)^{\frac{3}{2}}}. \quad (A)$$

This sum, which we will name the vertical component, denotes the force with which the magnet tends to direct the æther (the electropositive fluid) upward in a vertical direction. (If we assume also an electronegative fluid, this will be urged by the same force in the opposite direction.)

If now we consider an electric molecule which is situated in the atmosphere or at the surface of the earth, for which, therefore, r is $\geq 2\rho$, we see that formula (A) will be equal to zero at the polar point, and will possess a relatively minimal value in the vicinity of that point. Consequently the force tending to carry the electric molecule vertically upwards is *nil* at the pole, and a minimum in the polar region. It follows of course, and is besides proved by the formula, that the sum is equal for the same latitudes in both hemispheres.

Taking the component of these forces in a direction making a right angle with the earth's radius (the tangential component), we obtain the force with which the electric molecules are urged along the tangent of the circle the radius of which is r . We have thus:—

$$\frac{kMr(r - \rho \sin l) \cos l}{(r^2 + \rho^2 - 2r\rho \sin l)^{\frac{3}{2}}} - \frac{kMr(r + \rho \sin l) \cos l}{(r^2 + \rho^2 + 2r\rho \sin l)^{\frac{3}{2}}}. \quad (B)$$

In the equatorial plane this force becomes $=0$. The electric molecules situated in that plane move therefore vertically upward, seeing that the component of the force A is the only one which acts upon them. At the terrestrial poles ($l=90$) B and A are alike equal to *nil*; therefore the molecules situated in the parts themselves undergo no action from the magnet. For all the other molecules, the distance r of which from the centre of the earth is above or equal to 2ρ , the first term of the expression (B) will be always positive. For the molecules of the northern hemisphere (that is to say, for the positive values of the latitude) the first term will be numerically higher than the second, and consequently the total expression will be positive; for the southern hemisphere (that is, for the negative values of l) the first term will be numerically lower than the second, and consequently the entire expression will be negative. For the same value of r , and at an equal latitude, the expression (B) will have the same numerical value in both hemispheres; but this value will be positive in the northern, negative in the southern hemisphere. It appears, then, from the expression (B) of the tangential component of the force, that the electric molecules situated in the terrestrial atmosphere or at the surface of the earth endeavour, in the northern hemisphere, to approach the north pole, and those situated in the southern hemisphere the south pole. The vertical component (A) tends in the same way in both hemispheres to move the molecules always further from the centre of the earth in their course toward the terrestrial poles.

We will now see what is the influence which these forces are capable of exerting upon the electric state of the earth and the atmosphere. The lower stratum of the air is a relatively bad conductor; and we assume at first the ideal case that its conductivity is everywhere equal. The vertical component of the magnetic force in question then tends to direct the æther (positive electricity) from the earth to the air, the lower strata of which consequently become charged with that fluid, while the earth itself, which is a good conductor, incurs a deficit of æther (that is, becomes electronegative). The magnetic force being always in equally intense activity, and the earth rotating with a constant velocity, a portion of the electric fluid is soon conducted into the upper regions of the atmosphere, where the conductivity is better. Arrived there, the electric fluid is impelled towards the poles by the tangential component of the magnetic force. The æther (positive electricity) in this way accumulates in the atmosphere, while the earth itself suffers a deficit of electricity (becomes electronegative). This continues until the electric tension of the atmosphere is suffi-

ciently great to induce a discharge towards the earth. This, as is the case in the ordinary experiments of the laboratory, may take place in two ways—that is, either by an instantaneous discharge, or by a more or less continuous current. This difference of discharge depends on the following circumstances:—

The action of a magnetic pole p upon another magnetic pole q takes effect along the right line which joins p and q ; but the action of the magnetic pole p upon a current-element situated at the same point as q , on the contrary, operates in a plane normal to the said right line. The component along this right line of the action of the pole p upon a current-element is consequently equal to *nil*. What has just been said may be applied also to the case of two magnets acting upon each other. If, for instance, a magnet sn (fig. 10) acts upon another magnet $s'n'$, and the latter is movable so as to be able to take any position whatever in relation to sn , the magnet $s'n'$ will place itself in the direction of the resultant of the action exerted upon it by the magnet sn . The action of sn upon a current-element situated at the point m , or in the same place as $s'n'$, on the contrary, will take place in a plane normal to the same resultant; the component, then, along this resultant of the action of sn upon the current-element is equal to *nil*. If the circle $abcd$ represents a section of the earth, the magnet $s'n'$ shows the direction of the dipping needle at the point m , since we suppose $s'n'$ to be in the direction of the resultant of the action exerted upon it by the earth's magnetism. Therefore *the action of terrestrial magnetism upon a current-element situated in the atmosphere has zero for its component in the direction of the dipping needle.*

At the equator the dipping needle takes a horizontal position. The action of the earth's magnetism takes effect here, as the above formulæ show, in a vertical direction upward. If then, the electric fluid of the atmosphere can precipitate itself vertically into the earth, the force which produces this effect must be sufficiently great to overcome not only the electric resistance of the subjacent strata of air, but also the action of the earth's magnetism upon the electric fluid of the atmosphere; or, in other words, the force must exceed the sum of the two obstacles to the motion of the electric fluid. We must further observe that the action of the earth's magnetism in the vertical direction upon a current-element situated in the atmosphere is, according to formula (A), greater at the equator than to the south or north of that circle.

At higher latitudes the dipping needle has not a horizontal position, but makes a greater or less angle with the plane of

the horizon. Here, then, it is possible for the electric fluid of the atmosphere to descend into the earth without the terrestrial magnetism opposing to it an obstacle *directly*, provided it follows the direction of the dipping needle; but in following that direction the electricity has a longer path to travel to reach the surface of the earth, and consequently suffers a greater resistance than if it could descend vertically. At the magnetic pole the dipping needle takes a vertical position, in consequence of which the resistance opposed by terrestrial magnetism to the propagation of the electricity in the vertical direction is here equal to *nil*. From all this it follows that, *all other circumstances being equal, the resistance to the flow of the electric fluid from the atmosphere to the surface of the earth is greater at the equator and in the equatorial regions than at a certain distance from that circle, and that the resistance diminishes as the dip of the magnetic needle to the earth increases.*

It is here that, in my opinion, we must seek the chief cause of the fact that in the equatorial regions the electric fluid of the atmosphere descends to the earth by strong disruptive discharges, and in high latitudes chiefly by slow and feeble flowings, forming more or less continuous electric currents. If we continue to charge with opposite electricities two insulated bodies at a suitable distance from each other, the electricity at last traverses the intervening space, producing sparks, and the two bodies are discharged. That the discharge thus effected may be powerful and instantaneous, it is necessary that the bodies be good conductors, and the resistance of the intervening space great. If the resistance is slight, the discharge commences while the charge is yet feeble. In proportion as the resistance grows weaker, the discharge takes on more and more the form of a continuous current. In the equatorial regions, or in general in lower latitudes, the force of terrestrial magnetic induction acts with very great intensity in rendering the atmosphere electropositive, and, according to what has just been said, the resistance to a discharge is also very great. When the aqueous vapour of the air condenses so as to form cloud, this becomes charged with the electric fluid accumulated in the air in the locality. The cloud, which is a good conductor, therefore takes an electropositive charge. It is unnecessary to say that negative clouds may also in turn be formed under the inductive influence of positive clouds produced in this way. If now the clouds have become sufficiently electric, the electric fluid may escape to the earth by means of an instantaneous discharge. These discharges, or thunder-claps, then, take place when clouds are formed and when the electric resistance between them and the

earth is as great as is required. Outside of the equatorial regions this resistance is less, as has been said, and violent tempests are more rare. Finally, at a still higher latitude the resistance is so slight that the discharges are transformed into slow and continuous currents, giving rise to the phenomenon called the *aurora borealis*.

That portion of the electric fluid which does not descend into the earth by disruptive discharges in the equatorial regions is carried by the tangential component of the force of induction towards higher latitudes, while its distance from the terrestrial surface is augmented by the vertical component of that force. These currents of electric fluid receive accessions everywhere during their journey towards the poles through the inductive force of the earth's magnetism incessantly impelling into the atmosphere fresh quantities of that fluid from the subjacent terrestrial surface. In proportion as the distance to the poles diminishes, the vertical component of the induction-force also diminishes, and the dipping needle continually approaches nearer to the vertical; and in consequence the resistance opposed by the force of magnetic induction of the earth to the flow of the electropositive fluid to the earth grows less with the diminution of the distance to the poles. When the difference of electric tension between the atmosphere and the earth has become sufficiently great to overcome the resistance opposed by the induction-force of the earth and the subjacent strata of air, the electric fluid flows from the atmosphere to the earth. The places where this phenomenon takes place evidently form a circle around the pole. This circle is characterized by the circumstance that in every point of its circumference the vertical component of the force of terrestrial induction must have nearly the same value. In the vicinity of the poles the atmosphere receives only a feeble charge of electricity, the vertical component of the induction-force being there but very small (as indicated by formula A), and the tangential component directing towards those regions only an insignificant quantity of the electric fluid which enters the atmosphere in lower latitudes.

The electric fluid impelled into the atmosphere by the terrestrial force of magnetic induction descends again therefore in two ways to the earth—either by powerful disruptive discharges, or by more or less continuous feeble currents. The former mode of discharge takes place chiefly in the equatorial regions, the latter especially in high latitudes. The fluid which is not discharged disruptively in the equatorial regions is conducted by the induction-force towards higher latitudes, where the discharge takes place by means of continuous cur-

rents. From this it follows that, the less complete the disruptive discharge in the first-mentioned regions, the more numerous and intense will be the currents in the second.

We assumed above that the terrestrial magnet coincided with the rotation-axis of the earth, and that the earth was everywhere homogeneous and endowed with the same electric conductivity. Now the magnetic poles of the earth are not situated on the axis of rotation; or, in other words, the right line connecting the magnetic poles does not coincide with that axis, but makes with it an angle determined by observations to be about 17° . Moreover the conductivity of the air varies with the time and place. Yet these circumstances necessitate only nonessential modifications in what has been said. The circle *abcd* (fig. 11) represents a section passing through the rotation-axis of the earth and through the right line which joins the magnetic poles. This line makes with the axis the angle α ($=$ about 17°). The distance of the magnetic poles from the axis will therefore be $\rho \sin \alpha$ —an expression in which, as already said, ρ cannot exceed the half of the earth's radius.

We will now suppose another plane passing through the axis, and forming the angle v with the preceding plane; and we will consider the action of the magnetic poles upon an electric molecule m situated in this plane. During the rotation of the earth the magnetic poles describe circles the radius of which is $\rho \sin \alpha$. The radius of the circle described in the same time by the molecule m will be $r \cos l$, r denoting the distance of the molecule from the centre of the earth, and l its latitude. The relative velocity of the molecule m with respect to the magnetic pole s will be obtained, according to what precedes, by giving the same velocity to m and to s , but in the opposite direction to that of the already existing velocity of the magnetic pole. If the time of rotation of the earth be taken as unit, that velocity will be denoted by $2\pi\rho \sin \alpha$. The magnetic pole will in this way be brought to rest, and the molecule m will move with the velocity

$$2\pi\sqrt{r^2\cos^2 l + \rho^2\sin^2 \alpha - 2r\rho\cos l\sin \alpha\cos v}.$$

The relative velocity of the molecule with respect to the other magnetic pole will be

$$2\pi\sqrt{r^2\cos^2 l + \rho^2\sin^2 \alpha + 2r\rho\cos l\sin \alpha\cos v}.$$

Now it is obvious that these square roots denote the distance of the molecule m from the right line drawn through each pole parallel to the earth's rotation-axis. Hence it follows that the magnetic pole acts upon an electric molecule in the same way as if the pole were at rest and the molecule in rotation about

the right line drawn through the magnetic pole parallel to the earth's axis. The squares of the distances between the molecule m and the magnetic poles will be respectively

$$r^2 + \rho^2 - 2r\rho (\cos l \sin \alpha \cos v + \sin l \cos \alpha)$$

and

$$r^2 + \rho^2 + 2r\rho (\cos l \sin \alpha \cos v + \sin l \cos \alpha).$$

The forces with which the magnetic poles s and n act upon the molecule are therefore expressed by

$$\frac{kM \sqrt{r^2 \cos^2 l + \rho^2 \sin^2 \alpha - 2r\rho \cos l \sin \alpha \cos v}}{r^2 + \rho^2 - 2r\rho (\cos l \sin \alpha \cos v + \sin l \cos \alpha)}$$

and

$$\frac{kM \sqrt{r^2 \cos^2 l + \rho^2 \sin^2 \alpha + 2r\rho \cos l \sin \alpha \cos v}}{r^2 + \rho^2 + 2r\rho (\cos l \sin \alpha \cos v + \sin l \cos \alpha)}.$$

The former of these forces acts in the plane which passes through the molecule m and the right line drawn through the magnetic pole s parallel to the axis of the earth, and the latter in the plane passing through m and the right line drawn, parallel to the same axis, through the magnetic pole n . It will suffice for our purpose to seek the expression of the components of these forces in the cases in which v is equal to 90° and to 0° . This calculation will show that the electric molecule is moved further from the centre of the earth and carried from lower to higher latitudes, that it is situated in the plane represented by fig. 11 or in a plane making a right angle with it. As this must evidently take place whatever the plane in which the electric molecule is situated, the result obtained is that the electric molecules are driven vertically upward and at the same time from lower to higher latitudes. For the highest latitudes, where $\cos l$ is a minimum, both forces, as also their horizontal and vertical components, become very small; the electric density of the polar atmosphere cannot, therefore, be great. Thus, although the position of the magnetic poles is eccentric, the upper regions of the atmosphere from which the electric fluid is precipitated upon the earth in continuous currents must describe a closed annular zone about the pole. But, as we shall demonstrate, this zone is not closed around the astronomic pole as its centre.

We suppose the molecule m situated in the plane passing through the terrestrial axis and through the line joining the poles of the magnet. By making $v=0$ in the preceding formulæ we get the following expressions for the two forces:—

$$\frac{kM(r \cos l - \rho \sin \alpha)}{r^2 + \rho^2 - 2r\rho \sin(l + \alpha)}$$

and

$$\frac{kM(r \cos l + \rho \sin \alpha)}{r^2 + \rho^2 + 2r\rho \sin(l + \alpha)}.$$

Both these forces act in the plane in question—the one along mp , and the other along mq (fig. 11). The cosines of the angles formed by them with the terrestrial radius will be

$$\frac{\rho \cos(l + \alpha)}{\sqrt{r^2 + \rho^2 - 2r\rho \sin(l + \alpha)}}$$

and

$$\frac{\rho \cos(l + \alpha)}{\sqrt{r^2 + \rho^2 + 2r\rho \sin(l + \alpha)}}.$$

Therefore the sum of the vertical forces will be

$$\begin{aligned} & \frac{kM(r \cos l - \rho \sin \alpha) \rho \cos(l + \alpha)}{[r^2 + \rho^2 - 2r\rho \sin(l + \alpha)]^{\frac{3}{2}}} \\ & + \frac{kM(r \cos l + \rho \sin \alpha) \rho \cos(l + \alpha)}{[r^2 + \rho^2 + 2r\rho \sin(l + \alpha)]^{\frac{3}{2}}}. \quad (C) \end{aligned}$$

On the other hand, the sum of the tangential forces will be

$$\begin{aligned} & \frac{kM(r \cos l - \rho \sin \alpha)[r - \rho \sin(l + \alpha)]}{[r^2 + \rho^2 - 2r\rho \sin(l + \alpha)]^{\frac{3}{2}}} \\ & - \frac{kM(r \cos l + \rho \sin \alpha)[r + \rho \sin(l + \alpha)]}{[r^2 + \rho^2 + 2r\rho \sin(l + \alpha)]^{\frac{3}{2}}}. \quad (D) \end{aligned}$$

If $l = 90^\circ - \alpha$ (or the latitude of the magnetic pole) be introduced into formula (C), the sum of the vertical forces will be $= 0$. Therefore the electric molecules in the atmosphere vertically over the magnetic poles are not raised in the vertical direction by the terrestrial magnet.

In the vicinity of the magnetic pole the vertical and tangential components of the induction-force are very small; and consequently *there the electricity of the air must be inconsiderable, just as it was around the astronomic pole when we supposed the coincidence of the two axes.* If into formula (D) the same value of l be introduced, this formula takes a positive value; or, in other terms, the tangential component tends to bring the electric molecules thither from the axis of rotation of the earth. On the contrary, the same formula, when $l = 90^\circ$ is introduced into it, acquires a negative value—which signifies that the tangential force-component drives toward the magnetic pole the electric molecules which are in the atmosphere over the astronomic pole. It is therefore between these two points that the point must be situated at which the tangential

force is $=0$. While the vertical component of the earth's induction-force diminishes in general as the latitude increases, the electric tension of the upper strata of the atmosphere, on the contrary, is augmented with the increase of latitude until the tension becomes strong enough to occasion the downflow of the electric fluid into the earth. The annular space of the atmosphere where the electric fluid descends to the earth is evidently closed around the magnetic pole; it is characterized by the circumstance that in it the vertical component of the earth's induction-force has everywhere the same magnitude. Formula (C) gives an idea of its situation.

As we have seen above, the electric fluid flows from the said space to the earth in the direction of the dipping needle (of the inclination or dip of terrestrial magnetism). These electric currents in the rarefied air produce the aurora borealis. It is evident that this phenomenon ought chiefly to be seen in the vicinity of the annular space in question. According to the researches of Mr. Loomis, most of the auroræ boreales appear, in North America, between the latitudes of 50° and 62° , their frequency becoming less at still higher latitudes. The central line of the space in question lies consequently at 56° latitude—that is, at 34° from the astronomic and at 17° from the magnetic pole. This central line is denoted by the point t in fig. 11. We have now to ascertain under what degree of latitude the annular space must be situated at 180° of longitude from there, or, in other terms, between what degrees of latitude auroræ boreales will be most frequent in Europe and Asia.

If in formula (C) we make $l=90^\circ-34^\circ=56^\circ$, we shall have

$$\frac{kM(r \sin 34 - \rho \sin 17) \rho \sin 17}{(r^2 + \rho^2 - 2r\rho \cos 17)^{\frac{3}{2}}} + \frac{kM(r \sin 34 + \rho \sin 17) \rho \sin 17}{(r^2 + \rho^2 + 2r\rho \cos 17)^{\frac{3}{2}}}, \quad (E)$$

This expression designates the intensity of the vertical component of the induction-force in North America at 56° latitude.

If in formula (C) we make $l=90^\circ$, we shall have the expression of the same component at the astronomic pole, viz.

$$+ \frac{kM\rho^2 \sin^2 17}{(r^2 + \rho^2 - 2r\rho \cos 17)^{\frac{3}{2}}} - \frac{kM\rho^2 \sin^2 17}{(r^2 + \rho^2 + 2r\rho \cos 17)^{\frac{3}{2}}}. \quad (F)$$

By r is meant the distance from the centre of the earth to the electric molecule under consideration, situated in the atmosphere; ρ , being (as already observed) less than the earth's semiradius, is consequently also less than $\frac{1}{2}r$. Regard being

had to this circumstance, formula (E) obtains a higher numerical value than (F). From this it follows that the vertical component of the induction-force at the astronomic pole is less than at the point for which formula (E) holds good. If in formula (C) we make $l=90+34$, we obtain the sought force for a point t' situated at 56° latitude counted from d . Formula (C) is in this way transformed into the following:—

$$\frac{kM(r \sin 34^\circ + \rho \sin 17^\circ) \rho \sin 51^\circ}{(r^2 + \rho^2 - 2r\rho \cos 51^\circ)^{\frac{3}{2}}} + \frac{kM(r \sin 34^\circ - \rho \sin 17^\circ) \rho \sin 51^\circ}{(r^2 + \rho^2 + 2r\rho \cos 51^\circ)^{\frac{3}{2}}}. \quad \dots (G)$$

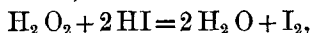
Formula (G) having a higher numerical value than (E), the point at which the vertical component of the induction-force will be the same as at the point t must be at a higher latitude than t' . From this it follows that the aforesaid annular zone will cut the plane in question at a point t'' situated between the astronomic pole and t' . Thus the zone presenting the greatest frequency of auroræ boreales must be at a higher latitude in Europe and Asia than in North America.

[To be continued.]

XLIX. On the Laws of Chemical Change.—Part I.

By JOHN J. HOOD, Esq.*

WHILE studying chemistry under Prof. Mills, I was much struck by the want of knowledge concerning the laws regulating the amount of change which chemically active bodies undergo in a given time, and in what manner the rate of change is influenced by heat, electricity, &c. Many cases of change have been investigated and represented graphically; but, as far as I am aware, no theory has been given confirmed by experiment whereby, the temperature and amount of active bodies undergoing change being known, the amount of remaining energy at any time can be calculated. The nearest approach to such a theory was given by Messrs. Harcourt and Esson in the 'Phil. Trans.' for 1867, where they showed that for the case of hydric peroxide reacting on hydric iodide,



the amount of change was proportional to the amount of acting substance, considering hydric peroxide as the active body.

* Communicated by the Author.