ART. XXXVII.—*Dependence of Terrestrial Magnetism on Atmospheric Currents*; by PLINY EARLE CHASE, M.A., S.P.A.S.*

ON account of the mutual dependence of all the forces of nature, and the reasonableness of Prof. Faraday's conjecture, that they are often, if not always, convertible more or less into each other,¹ it seems probable that the disturbances of the magnetic needle may be as closely connected with the earth's rotation, and the continually changing position of each point relatively to the sun, as those of the barometer and thermometer. Ampère held that the earth is an electro-magnet, magnetized by an electric current from east to west, the current being excited by the action of the sun's heat successively on different parts of the earth's surface as it revolves toward the east. The friction of trade-winds and ocean currents, and the variations of light and temperature that are produced by rotation and orbital revolution, must exert an influence upon the magnetic needle, and besides these indirect effects, Arago has shown that simple rotation, in some unknown way, produces magnetism in bodies of every description. Many have supposed that this magnetism is derived from the earth by induction; but on account of the impossibility of escaping from the influence of terrestrial magnetism, it is difficult to obtain any conclusive evidence on the subject.² A similar impossibility has interfered with Prof. Faraday's endeavors to connect gravity and magnetic or electric action by experimental results. The probability of such a connection has been shown by the electricity developed in the dry pile of De Luc, and by Gen. Sabine's observation, that when the sun and moon were on the meridian, the magnetic variation reached 5°, but when they were in quadrature, it fell as low as 20'.³

The great forces of nature can be measured only by their disturbances or their deviations from uniformity. The action of gravity is so nearly uniform at all times and in all parts of the globe, that it is difficult to imagine any crucial experiment that could demonstrate its relations to magnetism. Perhaps a needle, hinged at its point of support, with the two extremities nicely balanced, might help us toward such a demonstration, if careful experiments were tried, to show the relative influence of gravity upon each extremity, both before and after magnetizing, and when subjected to artificial magnetism, so as to produce various amounts of deviation from the normal dip and declination. Or, centrifugal force, so applied as alternately to assist and oppose the effects of gravity, as in large fly-wheels revolving with va-

* From the Proceedings of the Am. Phil. Soc.

¹ Phil. Mag., [4], i, 68.

² See correspondence of M. J. Nicklès, this Journal, [2], xvii, 117, &c.

³ This Journal, [2], xix, 424.

rious degrees of rapidity, may indicate variations of magnetic influence, that can be explained only by the conversion of gravity into magnetism, or the reverse.

Prof. Faraday, in a lecture before the Royal Institution in the year 1857, endeavored to show that our usual conception of gravity is not in harmony with the principle of "conservation of force." Prof. Brücke⁴ and others have tried to remove the difficulties in which the question is involved, but I believe none of the proposed solutions have been satisfactory to the learned philosopher who first started the discussion.

It has even been questioned whether gravity can be properly called a force, or whether it is anything more than a simple "tendency." Prof. Brücke has shown conclusively, that it is subject, like heat and other recognized forces, to all the laws which regulate the interchange of *actual* and *potential* energy; and our barometrical investigations furnish a beautiful illustration of the manner in which its tension is balanced by opposing forces.

We speak, indeed, of weight, as if it could be predicated only of bodies at rest, and as if it were so entirely distinct from momentum that no comparison could be properly instituted between the two. Precisely the reverse is true. Absolute rest is apparently an impossible condition of matter, for, to whatever extent the action of opposing forces may be relatively neutralized, the inconceivable rapidity of æthereal, planetary, and stellar motions produces a constant change of place. Even if we confine our attention to the earth alone, in each instant (dt) every particle has a tangential motion ($\sin d\theta$), and a central motion of gravity ($\text{vers } d\theta$) that constitutes a *vis viva* which we call its weight, and which is in equilibrium with the elasticity of the molecular æther. The sum of all the instantaneous energies is the same, whether the particle fall freely for any given time, or remain apparently at rest. All the potential energy which is transformed in one case into the actual energy of motion,⁵ in the other is counteracted by an equivalent and opposite central energy of elasticity. Therefore, when we compare the relative effects of rotation and gravity, it is immaterial whether we use as the measure of force, the integral of the *vires vivæ*, or the re-

⁴ Phil. Mag., [4], xv, 81.

⁵ The potential energy of gravity is represented by $g = 32$ ft. per second. The earth's rotation allowing only about $\frac{1}{250}$ of this amount, or $\cdot 1107$ ft. per second, to be converted into actual energy, the remainder must be employed in overcoming molecular elasticity. The formula $a = \left(\frac{gt^2r^2}{4\pi^2}\right)^{\frac{1}{3}}$ gives 26,221 miles as the radius of the sphere of attraction that is in equilibrium with the molecular elasticity at the earth's surface. These opposing forces must produce constant oscillations, and, by the study of these oscillations, it may perhaps be possible to reconcile the several hypotheses of Newton, Faraday, Mossotti, and Challis, respecting the nature of gravitation. See Phil. Mag., [4], xiii, 231-7, and xviii, 447, sqq.

spective amounts of motion that the two forces would produce, if they were able to act freely for the same time. The difficulty of determining the repulsion of molecular elasticity precluding any satisfactory use of the former measure, I employed the other;⁶ and the precise accordance of the results, thus obtained, with the results of observation justified the correctness of the hypothesis, in the same manner as the accurate computation of planetary motions has confirmed the Newtonian theory of gravity.

Gravity, therefore, with the same propriety as heat, may be considered as a "mode of motion," whether acting merely as "dead weight," or as an accelerating or a deflecting force. If it can be shown that magnetism also originates in motion, we may be able to demonstrate the mutual convertibility that Faraday suspected.

The earliest hypothesis with regard to terrestrial magnetism looked for its cause to a powerful magnet, lying nearly in the line of the earth's axis. Subsequent discoveries led to a modification of this view by the supposition of another magnet, pointing toward the Siberian pole. Mr. Barlow's idea, that the magnetism is superficial and induced,⁷ has now been generally adopted, and if it could be shown that solar or rotary action is capable of developing magnetism in particles such as those which are known to constitute our globe, the great difficulty in the way of a satisfactory explanation would be removed.⁸ Ampère's, Barlow's, and Christie's experiments showed that simple rotation is sufficient to affect the magnetism of a compass-needle,⁹ and in the oxygen of the atmosphere, which, as Faraday discovered, has a specific magnetism, variously estimated at from $\frac{1}{812}$ * to $\frac{1}{2187}$ † of that of iron, we have a medium through which any induced magnetism may be distributed over the entire surface of the earth. Some simple experiments, that can be easily repeated, seem to confirm Ampère's views, and to indicate the manner in which the circulating electric current is excited.

There is a species of mechanical polarity, of which I have never seen any notice, that is apparently produced by motions resembling those to which the air is continually subjected. It may be exhibited in the following ways:

1. In the middle of a basin of water lay a long strip of any substance (floating it by corks or otherwise, if it is heavier than water). After the water has become still, lift the basin carefully by one hand, and hold it at arm's length. The intermittent muscular action produces longitudinal vibrations, which tend to

⁶ Proc. Am. Phil. Soc., ix, 284.

⁷ Phil. Trans., 1831.

⁸ Enc. Brit., Art. "Magnetism."

⁹ The effect of rotation on the magnetic needle may be shown in a rough way, by causing an ordinary grindstone to revolve rapidly, and bringing a compass near its edge.

* By Becquerel.

† Plücker.

bring the floating strip into a line with the outstretched arm, and the tendency may be increased by moving the basin gently up and down.

2. Hold the gimbals of a binnacle compass so that it can swing only in one direction, and cause it to move like a pendulum in that direction. The needle will tend toward the line of oscillation. Vessels may have been lost from ignorance of this fact, for it is not unusual for compass pivots to become so worn that the needle moves sluggishly, and, in order to start it, the compass-box is shaken. If one of the gimbal hinges should be rusty, the shaking would bring the needle toward a line perpendicular to the axis of the free gimbal, and the captain might easily suppose that he was sailing north, when his course was due east or west.

3. Take an ordinary pocket compass, grasp it firmly between the thumb and finger of one hand, and move it quickly up and down through a small arc. The needle, as in the last instance, will tend toward the plane of motion. This experiment may be variously modified, according to the length and directive energy of the needle, the steadiness of the operator's nerves, &c. Sometimes a simple grasp, with a powerful muscular contraction, will bring the needle into line, without any other vibration than that which arises from the irresistible nervous tremor. Sometimes the momentum acquired by each pole in its approach to the operator, carries it forward so as to bring the other pole under the wave-influence, and the needle is thus made to rotate so rapidly as to become nearly invisible.

The polarity in each of the three cases here enumerated, is easily explained upon purely mechanical principles, but there are some indications that seem to show a close connection between the mechanical vibrations and those of nervous electricity. There appears to be a great difference in the control of different individuals over the needle. Some can bring it into line at once, with scarcely any perceptible motion, while others are obliged to use considerable effort; the needle does not seem at all times equally susceptible; it often appears more easy to produce rotation in one direction, than in the other. There may, therefore, be a natural connection between these experiments and those of M. Du Bois Raymond, who attached two strips of platinum to a very delicate galvanometer, and caused them to dip into two cups of salt water. Dipping the fingers of each hand into the cups, and alternately bracing the muscles of each arm, he produced a perceptible deflection of the needle. MM. Becquerel and Despretz repeated the experiment without obtaining very satisfactory results, but M. Humboldt was more successful.¹⁰ Add to these phenomena the well-known evidences of a constant current, circulating around magnets, and if we

¹⁰ This Journal, [2], viii, 405.

suppose that electricity consists simply of vibrations, it will seem perfectly natural that the magnet should obey the strongest vibrations.

Barlow's and Leconte's laws for the distribution of the induced magnetism in masses of iron, are precisely the same as would follow from the relative centrifugal motions of different portions of the earth, provided the magnetic axis coincided with the axis of rotation. It is therefore reasonable to presume that they accurately represent the superficial motions or currents on which the magnetism depends, and to hope that a careful study will enable us to detect the cause of the oscillations that polarize the air and all other bodies that are capable of vibrating in harmony with it.

If the earth were stationary, the sun's heat would produce a constant ascending current over the whole meridian, which would be supplied by colder lateral currents from each side. The effect of these several currents would be a mechanical atmospheric polarity, precisely analogous to that which was indicated by our experiments upon the control of the magnetic needle by mechanical vibrations.

In consequence of the earth's rotation, this condition exists only at the instant of noon. At all other times, the flow of the cool air toward the equator, and of the warm air to the coldest portions of the globe, is modified by the earth's motion. The warm air rises at the equator, and flows toward the point of greatest cold, until it becomes sufficiently cooled to sink to the earth. Still flowing onward, it absorbs the heat of the earth, until it is so rarefied as to rise again. This process of alternate rise and fall, is continued until the air reaches the pole, and then returns by the same law, and in a similar manner, to the equator." These currents, which are flowing at all hours, and in all portions of the earth, produce an atmospherical directive energy toward the poles of maximum cold, which appear, according to Sir David Brewster, to coincide with the magnetic poles.

Now, if we consider that in addition to these permanent currents, there is a continual motion of silent convection, the warm air rising, and the cold air descending in parallel columns, like the particles in a vessel of boiling water," and if we remember

¹¹ Halley, in 1686 (*Phil. Trans.*, No. 183), explained the trade wind, and the necessity of a reverse upper current, but he found it "very hard to conceive why the limits of the trade wind should be fixt about the 30th degree of latitude all around the globe." The problem has been solved by Prof. Ferrel. I am not aware that any one has ever pointed out the combined effects of convection, absorption of heat from the earth, and the daily superposition of the rotation- and temperature-currents.

¹² It is very probable that this motion of convection is a more important agency than has generally been supposed. If we close the lower drafts of a common airtight stove, and open a register immediately over the fire, the cold air does not rush directly to the draft pipe; but it falls with great velocity to the surface of the fuel, as may be shown by dropping pieces of paper through the register.

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that the warm air is charged with moisture which is condensed as it ascends, parting thereby with much of its heat and electricity, we can hardly deem it necessary to adopt Dr. Dalton's hypothesis that ferruginous matter is the source of atmospheric magnetism. Still, the existence of vaporized iron in the air undoubtedly contributes an increased intensity to the magnetic currents, and it may probably be an important agent in the production of magnetic storms.

The two vibratory systems above mentioned are conjoined during the hours when the sun is above the horizon, and the laws of motion applicable to the first system correspond precisely, as I propose to show hereafter, with the laws of the solar-diurnal magnetic variation deduced from General Sabine's admirable discussions of the St. Helena observations. It is not so easy to explain in its minute details the comparatively insignificant lunar-diurnal variation, but I am convinced that the aërial currents produced by lunar attraction will sufficiently account for all the magnetic influence that is due to the moon exclusively. The changing barometric pressure, and the deposition of dew during the night, modify these currents in such a way as to disguise the simple effect of any slight disturbing cause; nevertheless, there is a manifest tendency, underneath all the disguise, to maxima and minima at the precise hours when they ought to occur in consequence of the moon's attraction.

In the influence of the violet rays upon magnets, the connection of the violet rays with the tension of brass in the polariscope, the excitement of magnetic vibrations in iron by percussion and torsion, the increase of magnetism by cold and its diminution by heat, and the general correspondence between Challis's laws of molecular action and the laws of attraction and rotation, we may find interesting evidences of the unity of force which all modern discovery tends to demonstrate, and in that unity a sufficient explanation of the observed annual and secular variations of the magnetic needle, the disturbing magnetic effects of auroras and solar spots, the changes of the wind, and storms of every kind. Some of the well-known phenomena of storms furnish a ready test of the principles I have attempted to establish.

Although I have described the general tendency of a particle of air, it is not probable that all the atmosphere, or even perhaps any considerable portion of it, follows so regular a path. In the upper regions, where the air is not so much affected by the radiation of the earth, it may oscillate, as suggested by Redfield, "from centrifugal action toward the equator, and gravitation toward the poles,"¹³ and between the points of decussation there are undoubtedly eddies which have a general movement east-

¹³ This Journal, xxv, 130.

ward or westward, in accordance with the theory of M. Dové. The disturbance of the æther, dependent upon the relative attractions of the earth and sun, probably produce tides corresponding in time with those of the barometer, which must modify the atmospheric currents.

Having thus ascertained the causes and directions of the principal normal currents, the ordinary theory of winds enables us to understand the effect of mountain peaks, deserts, forests, rivers, and ocean streams. Every point of the earth's surface that accumulates or radiates an undue amount of heat, becomes a centre of polarity with an attractive energy that disturbs the atmospheric equilibrium, tending to produce wind and rain. If the disturbance is confined to a limited area, there is a well-known cyclonic tendency, the portion of the eddy which is nearest the equator *generally* flowing eastward. Mr. Galton¹⁴ has ingeniously shown that, in descending cyclones, the direction may be reversed, and I should expect a similar reversal to be of frequent occurrence in the neighborhood of some of the powerful ocean-currents, at points where they tend to produce backward eddies. Such points are found midway between the Sandwich Islands and California, about 35° west of Chili, near the west coast of New Holland, in the Indian Ocean, northeast of Madagascar, and in other places.

The effect of ocean-currents in producing cyclones, and directing their course, is well illustrated by the repeated observations that have been made in the Gulf Stream. Prof. Lesley's interesting account of the series of storms encountered by the Canada on her one hundredth voyage,¹⁵ exhibits the natural consequences of the friction of two belts of air at different temperatures, moving in opposite directions. The warm air over the Gulf Stream, and the cold air over the Arctic currents that flow nearer to the American continent, are both borne very nearly in their normal directions, but with the approach of winter their parallelism becomes almost vertical, the cold belt becomes wider from its encroachment upon the land, and the vortices that arise from their concurrence are frequently brought down to the surface of the ocean, instead of taking place in the higher regions of the air, as they usually do during summer.

While sudden, violent tempests that are occasioned by local disturbances over a limited area, are almost necessarily cyclonic, I am inclined to adopt Espy's theory with regard to long storms, that usually "the wind will blow in toward a line rather than toward a point;" and in favor of this hypothesis, as well as of the periodicity of weather-changes, I would suggest the following explanation.

¹⁴ Phil. Mag., Sept., 1863.

¹⁵ Proc. Amer. Philos. Soc., ix, 361.

The normal currents of the atmosphere are subject, as we have seen, to a daily disturbance by the sun's action. This disturbance, like the moon's tidal action, is cumulative, and has a constantly increasing tendency to overcome the aërial polarity. The gathering wave follows the sun until it is saturated with vapor, and as soon as it becomes powerful enough to influence the normal current, it must produce a shifting of the wind and a deposition of moisture. The equilibrium of temperature is then restored, to be subjected anew to the same constant disturbance and the same stormy culmination.

[My attention has been called by the *Journal of the Franklin Institute*, to some extracts from the *London Athenæum* for January, announcing a paper on Magnetic Storms, which was read by Mr. Airy before the Royal Society, in which the Astronomer Royal appears, in some measure, to have anticipated my views upon the sources of terrestrial magnetism.

As I have not yet seen the paper in question, I do not know how far the priority may extend; whatever may be its limits, it will give me pleasure to yield my claims to so distinguished and cautious an investigator, and to find that my own independent conclusions have been so ably corroborated. And I believe I have good grounds for hoping that in the specific solar action which I have pointed out, Mr. Airy will find the precise "occasional currents produced by some action or cessation of action of the sun," for which he is looking.]