



XXVII. Rain-clouds and atmospheric electricity

W.E. Ayrton & John Perry

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numbers which rigorously correspond to the deductions from the laws of Ohm, Joule, and Faraday. The cause of Favre's result being so seriously faulty lies probably, in great part, in the circumstance that, in all his calorimetric investigations, he made use of the *mercury calorimeter*, with the use of which a whole series of uncertainties are necessarily connected, and which it should be a maxim not to employ. For all galvanocalorimetric investigations in which the duration of the heat-evolution can be chosen entirely at discretion, and so the heat produced can be made as great as we please, the simple water calorimeter, managed with nicety, is by far the most reliable, and, for many reasons, even preferable to Bunsen's ice calorimeter. The numerous measurements instituted by M. Favre many years since, respecting heat-production by galvanic currents and electromotive forces, were very probably all vitiated by an error of the same order as were the values given by him for the heat developed by Daniell's and Grove's elements. Should a secure basis be obtained in this department, nothing remains but to repeat with more accurate methods all the more important of his measurements.

The unit of length employed in these investigations is the millimetre of the cathetometer of the Physical Laboratory at Zurich; the time-unit is the second of mean time; the Siemens resistance-unit is the No. 1914, which I obtained from M. W. Siemens at the commencement of the investigation, and which was most carefully compared with all the other resistances employed.

Zurich, August 1877.

XXVII. *Rain-Clouds and Atmospheric Electricity.* By W. E. AYRTON and JOHN PERRY, *Professors in the Imperial College of Engineering, Tokio, Japan.*

To the Editors of the Philosophical Magazine and Journal.

The Imperial College of Engineering,
Tokio, Japan, December 8, 1877.

GENTLEMEN,
GIVING all due weight to the theories of thermoelectric currents produced by rotation of the earth under the sun, and of currents which might be produced by moving electrified shells of air, we have always thought that these sources of electric disturbance on the earth were far too inconsiderable to give rise to the phenomena of earth-currents and of atmospheric electricity, and also totally inadequate to account for currents of sufficient intensity to produce terrestrial magnetism. We think that there cannot be any

explanation of these phenomena which does not take into account the fact that the earth and other members of the solar system are the electrified coatings of condensers, since, although the mutual coefficients of induction between the different members of the solar system may be very small compared with the capacities of long telegraph-cables, still the differences of potential between the sun and the planets may be extremely great, so that the charges in the condensers in question may be so large that a slight change in the capacities, produced by rotations or changes in the positions of the planets, may set up in the bodies themselves electric currents of considerable magnitude.

We are at present engaged in the solution of the problem to determine mathematically what is the strength of the currents produced in the earth as it rotates under the inductive action of the sun; and we may mention that the moderate conductivity of the earth, combined with the probability of the existence of an iron core, will enable us very shortly to present the results drawn from our theory in a numerical form. In the meantime, however, we desire to show how it follows from this theory that movements in the atmospheres of the earth and sun, and especially the motions of rain-clouds, or clouds of vapour, are connected with the phenomena of atmospheric electricity and earth-currents. The connexion of these latter phenomena with earthquakes, which we dwelt on in our recent paper on observations of atmospheric electricity, will more suitably be taken up again in our next paper.

When a dielectric is composed of air at different pressures, or of a mixture of gases, our experiments (recently communicated to the Asiatic Society of Japan in a paper on the Specific Inductive Capacity of Gases) showed that K , the specific inductive capacity of the medium, is different at different parts, so that (see C. Maxwell's 'Electricity') the fundamental equation connecting the potential V and ρ the charge of electricity per unit volume of the medium at different points, is

$$\frac{d}{dx}\left(K \cdot \frac{dV}{dx}\right) + \frac{d}{dy}\left(K \cdot \frac{dV}{dy}\right) + \frac{d}{dz}\left(K \cdot \frac{dV}{dz}\right) + 4\pi\rho = 0. \quad (1)$$

Consequently, if there is no real charge in the medium, we have

$$\frac{d}{dx}\left(K \cdot \frac{dV}{dx}\right) + \frac{d}{dy}\left(K \cdot \frac{dV}{dy}\right) + \frac{d}{dz}\left(K \cdot \frac{dV}{dz}\right) = 0. \quad (2)$$

Now, if we imagine the non-homogeneous dielectric to be all replaced by dry air at 760 millimetres pressure and at 0° C. temperature, and if at any point where the potential is V there

is an imaginary charge ρ' such as would produce the actual distribution of potential that we have in the real case, then

$$\frac{d^2V}{dx^2} + \frac{d^2V}{dy^2} + \frac{d^2V}{dz^2} + 4\pi\rho' = 0. \quad \dots \quad (3)$$

From equations (2) and (3) we find

$$4\pi K\rho' = \frac{dK}{dx} \cdot \frac{dV}{dx} + \frac{dK}{dy} \cdot \frac{dV}{dy} + \frac{dK}{dz} \cdot \frac{dV}{dz};$$

or if ρ is the density per unit volume of a real charge at any point of the non-homogeneous dielectric, then

$$4\pi K\rho' = 4\pi\rho + \frac{dK}{dx} \cdot \frac{dV}{dx} + \frac{dK}{dy} \cdot \frac{dV}{dy} + \frac{dK}{dz} \cdot \frac{dV}{dz}.$$

Also if at any place there is a distinct separation by a surface of one dielectric from another, ordinary air from very moist air for example, then the resultant force on one side of the surface must be greater than that on the other. Thus, if the resolved part of the resultant force in a direction at right angles to this surface be F in the first medium and F' in the second, and if K and K' are the specific inductive capacities,

$$KF = K'F'.$$

In fact it is the same as if both media were dry air as above, and an apparent charge, of density σ' , were given to the surface, such that

$$\begin{aligned} 4\pi\sigma' &= \left(1 + \frac{K'}{K}\right) F' \\ &= \left(\frac{K}{K'} - 1\right) F. \end{aligned}$$

If at the surface there is a real charge of density σ , then

$$KF = K'F' + 4\pi\sigma;$$

and the action is as if both media were air as above, and an apparent charge of density σ' were given to the surface, where

$$\begin{aligned} 4\pi\sigma' &= \frac{4\pi\sigma}{K} + \left(\frac{K'}{K} - 1\right) F' \\ &= \frac{4\pi\sigma}{K} + \left(1 - \frac{K}{K'}\right) F. \end{aligned}$$

These formulæ may be used, when we know the state of the atmosphere at every point at every time (that is, when the specific inductive capacity K is known), in order to find from any given initial distribution of potential the changes which occur when the state of the atmosphere is changed.

It is known that, from observations of atmospheric electricity and from observations of earth-currents, atmospheric

changes may be predicted (see our paper on Observations of Atmospheric Electricity, read before the Asiatic Society of Japan, April 25, 1877). And we see from the above equations why this should be the case, since changes in the state of the atmosphere, whether brought about by actual motions, or by alterations of density from cooling, or from other causes, must produce changes in the specific inductive capacity of the dielectric, and consequently alterations of the potential of the earth in the neighbourhood. Assuming dry air at 760 mil-lims. pressure and at 0° C. temperature to have a specific inductive capacity unity, then as we mix some aqueous vapour with it the specific inductive capacity increases and becomes larger than 1; and in addition, as some of the vapour condenses, we know that the globules of water, excessively small at the beginning, soon increase in size, so that, as the specific inductive capacity of water is some millions of times that of air, the mean specific inductive capacity of the space is immensely increased; and hence we see that the cooling of the atmosphere and the formation of clouds, or the approach of clouds, may occasion great changes in the distribution of atmospheric potential at any place, and consequently give rise to strong earth-currents. And if the cloud has no charge of its own, the direction of these currents will be such that positive electricity will flow from the place from which the cloud is passing to that from which it came; for since the earth is known to be negatively electrified with regard to space, the introduction of a cloud or other dielectric of greater specific inductive capacity than air must make the potential of the part of the earth's surface underneath it less negative than before—that is, must raise the potential.

Although mere changes in the density of the air will, for the reasons given above, be sufficient to produce earth-currents, still we should imagine that the changes in the atmospheric potential commonly observed are due, not so much to the direct change of the specific inductive capacity with change of density, as to the much greater changes that must be produced in the capacity by the formation of clouds resulting from the change of temperature and density; so that we should expect that observations of atmospheric electricity will be of greater use in the predicting of rain and snow than of wind-storms.

As the atmosphere does not altogether consist of non-conducting matter, portions of it, especially cloudy portions, are capable of acquiring electric charges, through changes of temperature or motions of the atmosphere; and these portions subsequently become more or less conducting through changes of

temperature : we here see an explanation of how thunder-clouds may be formed. It is probable, however, that in the ordinary phenomena of atmospheric electricity and earth-currents the real charges possessed by portions of the atmosphere may have but little effect ; but on this point we cannot at present express a decided opinion.

We beg to remain, Gentlemen,

Very truly yours,

JOHN PERRY,
W. E. AYRTON.

XXVIII. *On a new Modification of the Bichromate Battery.*
By H. C. RUSSELL*.

[Plate VIII. fig. 14.]

Sydney Observatory,
May 31, 1877.

MY DEAR SIR,

YOU were kind enough to advise me, when I was in England, about the purchase of a large Ruhmkorff coil. In using it, I have had the ordinary bichromate-of-potash cells to develop the electricity, and of course have had to suffer the inconveniences which attend the use of a cell which falls off so quickly. This has induced me to look for a more constant form of electric generator ; and I have found one that is *perfectly constant* in its action, and will remain so as long as the solution and zinc are supplied. I enclose a section-drawing (Pl. VIII. fig. 14) ; and you will see I have adopted a modification of one of Daniell's earliest ideas for obtaining a constant current. The solution used is the ordinary bichromate of potash, in the arrangement shown, which perhaps needs little explanation ; but I may say that a *drop of solution per second* keeps the cell in full and steady work. The drawing is at fault in one respect ; the only *space* in the cell for solution is between the plates, not, as shown, all round the plates : the object of this is to make all the solution pass the face of the zinc. You will observe that, supposing the waste-tap shut and the drop-tap above opened, the solution accumulates in the cell till it comes to the level of the overflow-pipe ; and then, for every drop which goes in, one goes out ; but as the overflow-pipe begins at the bottom of the solution, it is the used or waste solution which must go out. When the battery is not required, the waste-tap is opened and the other shut, and the battery-cell is left perfectly inactive and ready for the next time it is wanted. There is of course some additional first cost ; but

* Communicated by Dr. Huggins, F.R.S.