

PHYSICAL SECTION.

Stated Meeting, held April 23, 1902.

Electric Convection—A Historical Summary with a Bibliography.

BY J. FRANK MEYER.

If the theory of the electro-magnetic field as advanced by Maxwell in his celebrated treatise is true, the four following deductions from the theory should be true, and it should be possible to verify them experimentally:

(1) An electric charge in motion should produce a magnetic field.

(2) A varying magnetic field should produce an electric field.

(3) A magnetic pole in motion should produce an electric field.

(4) A varying electric field should produce a magnetic field.

These four points all seem to lack conclusive experimental verification, and so far only (1) and (2) have been attempted. However, a verification of any one of the four is practically proof of all the others.

It is said that as early as 1868 or 1869, the idea occurred to Professor Rowland that an electric charge in motion should produce a magnetic field. When Maxwell published his treatise in 1873 he suggests an experiment, but remarks that so far the experiment had not been tried.

If we have two parallel plane surfaces, electrified to surface densities σ and σ' , then the mutual repulsion per square centimeter is $2 \pi \sigma \sigma'$. If we now assume that a charge in motion is equivalent to a current, we may move the planes with a velocity v in their own planes, and this will cause an attraction between the planes.

If u and u' are the surface densities of current, it may be shown that the attraction is $2 \pi u u'$ per unit area, u , and u' being measured in electro-magnetic units.

If the surface density in electrostatic measure is σv and $\sigma^1 v$, and n the number of electrostatic units in one electromagnetic unit, we have :

$$u = \frac{\sigma v}{n}; \quad u^1 = \frac{\sigma^1 v}{n}$$

Therefore :

$$2 \pi \sigma \sigma^1 = 2 \pi \sigma \sigma^1 \frac{v^2}{n^2}$$

and, finally,

$$v = n.$$

In other words, the ratio of the units is a velocity, and though it is not possible to move a charged plane with a velocity $v = 3 \times 10^{10}$ centimeters per second, it is possible to move the charge rapidly enough, so that if a magnetic effect does exist it can be measured.

Rowland* attacked the problem in this way: A hard-rubber disk, 21 centimeters in diameter, was gilded on both sides and mounted on a vertical axis. The disk thus rotated in a horizontal plane. Above and below the disk was a glass plate, also gilded. Above the upper of these two condenser plates was hung an astatic needle. The gilded disk was charged by bringing within $\frac{1}{8}$ millimeter of its edge a wire point connected to a battery of Leyden jars. When the disk was rotated about sixty-one times per second, and the electrification on the disk changed, a deflection of from 6 to 8 millimeters was observed on the scale.

To guard against conduction currents in the gilding on the disk, scratches were made through it. But the same deflections were obtained. The calculated and observed deflections agreed very well, but as the needle was always unsteady, the measurements obtained were not as accurate as might have been desired. The experiment has, however, been very generally accepted, and its results have been incorporated into the text-books, while the effect is known as the "Rowland effect."

In 1884 Lecher repeated the experiment with slight modifications, but with negative results. It has been suggested that his apparatus was not sensitive enough to detect the

* *Pogg. Ann.*, clviii, p. 487.

effect. This, however, hardly seems possible, for he used an astatic needle in the axis of a vertical disk, 200 cm. in diameter, charged to 5,000 volts and rotated with a speed of 200 revolutions per second. The charge was measured by an absolute electrometer.

Röntgen in 1885 used an apparatus similar to Rowland's in an attempt to observe displacement currents. He got deflections of his needle slightly larger than those obtained by Rowland, when the ungilded ebonite disk was charged by means of a brush discharge from points. Again in 1888 Röntgen used the same apparatus in order to investigate the action of a dielectric revolving in a homogeneous electrostatic field. The dielectric was rotated around a vertical axis between oppositely charged condenser plates. Precautions were taken to prevent the rotating disk from getting a real charge, and deflections of a few millimeters were obtained when the electrification on the condenser plates was reversed.

Professor Rowland and Mr. Hutchinson again took up the question in 1889.* They used two disks facing each other, and gilded on their inner faces. Each disk ran in a guard ring, between two condenser plates, on horizontal axes. The condenser plates were charged to about 5,000 volts, while the disks were kept earthed by brushes bearing on buttons sunk into the periphery of the disks. With speeds of about 120 to 125 revolutions per second, deflections of from 5 to 8 millimeters were observed. These deflections reversed in direction as the electrification was reversed. From this experiment a value of v was calculated, giving as a mean $v = 3.19 \times 10^{10}$, the largest variations being between 3.74×10^{10} and 2.26×10^{10} .

In the same year Professor Himstedt† used a very similar apparatus. He used two ground glass plates with a strip along the edge of each made conducting by rubbing graphite on the surface. His needle system was so placed that the

* *Phil. Mag.*, **5**, xxvii, p. 445 (1889). Rowland's "Physical Papers," pp. 128, 138.

† *Wied. Ann.*, 38, p. 560 (1889).

upper and lower needles about coincided with the conducting strips. When the disks were charged, the condenser plates between which each disk ran being earthed, a deflection of the needle system was readily obtained. The deflection was in the direction to be expected, reversed in direction when the charge was reversed, and from 400 to 4,000 volts was proportional to the charge. Charges as high as 14,000 volts were used, but the proportionality did not hold beyond about 4,000 volts.

About this time Lippmann* called attention to the reciprocal of the Rowland effect, and in 1897 Crémieu† took up this reverse problem: to find the mechanical force exerted on a charged body by a rapidly changing magnetic field. This force is a very small quantity. Crémieu attempted to detect it by rotating an aluminum disk between the poles of an electromagnet. The calculated effect was about 100 millimeters, but no effect could be observed. It should be noted, however, that in 1889 Professor Lodge did observe this effect, though not as satisfactorily as he desired.

The negative results in this experiment led Crémieu to investigate the Rowland effect, and after several years of work he concluded that an electric charge in motion does not produce a magnetic field.

Crémieu's method is new and ingenious, for instead of a magnetometer needle he uses a coil of wire and a galvanometer, thus noting the current induced in the coil by the changing magnetic field, if such a field does actually exist.

A solid aluminum disk 37 centimeters in diameter was mounted on a hard-rubber hub on a horizontal axis. Concentric with and around this disk was a coil of 13,000 turns of copper wire 0.15 millimeters in diameter. The coil was entirely enclosed in a hoop of brass and in series with it was a sensitive galvanometer. The diameter of the coil was 44 centimeters.

The disk was arranged to rotate between two thick iron plates 8 millimeters apart. A brass ring on the hub was

* *Comptes Rendus*, 89, p. 151 (1889).

† *Comptes Rendus*, 130, p. 1544 (1900).

put into connection with one terminal of a battery of Leyden jars, the other terminal being earthed. In this manner the disk was charged to about 5,000 volts.

Now on the assumption that a moving charge produces a magnetic field, a current should be induced in the coil, if the charged disk is rotated and discharged and again charged in succession. A commutating device was used in order to charge and discharge the disk, and at the same time commute the current flowing through the galvanometer. No deflection whatever could be observed, though the theory predicted a deflection of about 20 millimeters.

Crémieu varied the experiment in several ways:

(1) The aluminum disk charged to 5,000 volts was rotated between iron plates. It was found, however, that sparks passed from the disk to the plates, the distance between the plates being only 8 millimeters. To prevent this, the iron plates were covered with lacquered glass plates 2 millimeters thick.

It was suggested by Pellat that even then the charge brushed across the space to the glass, leaving the disk uncharged. Crémieu tested this when the disk was at rest, and found that the charge did not pass over the gap. But it is possible that when the disk was rotating in the gap, only 1.75 millimeters wide with a speed of 110 revolutions per second, the charge did brush across. Only negative results were obtained from this experiment.

(2) A second experiment with the rotating disk covered with caoutchouc, the condenser plates being bare, also gave negative results.

(3) An ebonite disk gilded in sectors gave similar negative results.

(4) By rotating the disk in a brass drum with sides parallel to the disk, the sides being covered with mica on the inside and then gilded, no results were obtained. A needle was used to detect the effect in this form of the experiment. But when the brass ends were removed, leaving only the mica end, a slight deflection was obtained.

Mr. Wilson, of the Cavendish Laboratory, has pointed out that currents would be induced in the brass ends, with

effects exactly opposite to those due to the disk, and that the experiment therefore confirms the theory.

M. Crémieu concludes that whenever the magnetic system is protected by a good conducting screen, it is not possible to obtain a deflection of the needle due to the magnetic field produced by the moving charge, and if any deflections do occur, they are due wholly to electrostatic effects. Therefore, as a final deduction, "open circuits" must exist, and Crémieu* proceeded to show their existences in the following manner:

An ebonite disk 37 centimeters in diameter and 2.5 millimeters thick, was gilded on one side in twenty-five sectors, a space of 1 centimeter being left ungilded between the sectors. This disk was mounted so as to rotate in a horizontal plane between two ebonite plates that served as condensers.

The plate facing the side of the disk not gilded was gilded over a sector twice as wide as one of the sectors on the disk. On the other condenser plate, exactly opposite the large sector, was placed a brush that made contact with the sectors on the rotating disk, as each one passed under the large sector on the condenser plate. This brush was connected to another 60° ahead of it, through a galvanometer.

Now if the fixed sector is charged from some source of electricity when a sector on the disk comes under it, the revolving sector acquires a charge by induction. This charge is then carried forward to the second brush where it is discharged. There is then a circuit partly convection and partly conduction. To find if the electricity in the convection part of the circuit produces a magnetic effect, a needle was hung between the brushes. The sector was charged to about 100 to 130 C.G.S. units, being distant from the rotating sectors 0.5 centimeter.

When the disk was rotated, a current of from 10^{-4} to 2×10^{-4} amperes flowed through the galvanometer, while there was no effect on the needle system. But a conduction

* *Comptes Rendus*, 132, p. 1108.

current of same value deflected this needle 15 millimeters on a scale 4 meters distant.

Crémieu concludes, therefore, that the electricity carried by the sectors has no magnetic effect, that is, that an open circuit exists.

In 1901 Pender* published the results of an investigation carried out under the direction of Professor Rowland, in which Rowland's previous results were confirmed in all particulars, thus contradicting the work of Crémieu.

Pender used two micanite disks, 0.356 centimeter thick, 30 centimeters in diameter, gilded on both sides and mounted on horizontal axes. Opposite each face of each disk was a condenser plate of hard rubber, covered with tin foil. These plates were about 1 centimeter apart, and were earthed. The disks were charged by means of brushes on brass rings from a Voss machine and six Leyden jars. Between the jars and disks was a reverser so arranged that the charge could be changed twelve to twenty-five times per second. The disks were rotated from 75 to 110 times per second.

Between the two inner condenser plates was a coil of 1,295 turns of No. 21 copper wire. This coil was 30 centimeters in diameter and enclosed in a metal case, which was connected to earth. The coil was connected through a commutator on the same shaft as the reverser to a sensitive galvanometer.

It was possible to rotate the disks in the same direction with similar charges, or in opposite directions with dissimilar charges. The latter method was used most frequently.

The direction of the galvanometer deflection could be compared with that due to a current flowing in a test coil on the disk. This deflection was always in accord with Ampère's rule; the motion of a positive charge produces the same effect as that of a conduction current flowing in the direction of motion of the charge.

From 17 sets of observations, consisting of 18 determinations each, the mean value of v was found to be:

$$v = 3.05 \times 10^{10}.$$

**Physical Review*, 13, p. 203, 1901.

The greatest variations obtained were:

$$v = 2.75 \times 10^{10}$$

$$v = 3.24 \times 10^{10}.$$

These results were further confirmed by rotating the disks, when similarly charged, in opposite directions when no deflections of the galvanometer occurred. Afterwards, scratches were made through the gilding on the disks, and the mean of readings gave for v the value $v = 1.96 \times 10^{10}$.

Pender has repeated the experiment,* making greater variations in the speed of the disks and the charges were more varied, with confirmatory results.

Two other experiments have confirmed the effect. Adams† rotated copper spheres fastened to the ends of spokes of two wheels. The wheels were rotated with opposite charges of about 18,000 volts, and the effect was readily detected and measured.

Eichenwald‡ confirmed the effect by rotating a micanite disk between zinc condenser plates, using a needle system protected in a box of electrolytic copper.

The edge of the disk was covered with tin foil and the needle was placed over the edge. The calculated capacity of the condenser was 5×10^{-11} farads, and the convection current was 4.5×10^{-6} amperes. When a conduction current of 4.5×10^{-6} amperes was sent through the coil, the same deflection of the needle was obtained.

Dr. Pender has recently taken his apparatus to Paris, and it is hoped the reason for the contradiction between his work and that of Crémieu will be explained.

Supplementary Note.—Messrs. Crémieu and Pender have recently published the results of their joint work§ carried out at the Physical Laboratory of the Sorbonne and arrive at the following conclusions:

(1) A charged continuous metallic disk turning in its own plane opposite fixed condensing plates carries its charge with itself.

* Pender: *Physical Review*, 15, p. 291.

† Adams: *Phil. Mag.*, 6, 2, p. 285, 1901.

‡ Eichenwald: *Phys. Zeit.*, 2, p. 705.

§ Crémieu and Pender: *Phil. Mag.*, 6, 6, p. 442, 1903.

(2) The *entrainment* of this charge produces a magnetic field in the direction demanded by the assumption of a magnetic effect due to electric convection, and in accord with the calculated value to 10 per cent.

(3) Charged sectors moving in their own plane, without the presence of any condensing-plates, produce a magnetic effect in the direction and of the proper size demanded by this same assumption.

The authors of this joint paper say further: "It is not for us to say whether these effects are really due to electric convection in the sense in which Faraday and Maxwell understood this expression, nor to decide whether they are in accord with the fundamental hypotheses of the accepted theories."

RANDAL MORGAN LABORATORY OF PHYSICS,
UNIVERSITY OF PENNSYLVANIA.

BIBLIOGRAPHY OF ELECTRIC CONVECTION.

1. Faraday: *Experimental Researches*, vol. i, art. 1644.
2. Maxwell: *Electricity and Magnetism*, vol. ii, §770.
3. Helmholtz: *Wiss. Abhandlungen*, i, p. 791.
4. Rowland: *Am. Jour. Science*, **3**, vol. xv., p. 30, 1878.
5. " *Collected Physical Papers*, pp. 128, 138.
6. Rowland and Hutchinson: *Phil. Mag.*, **5**, vol. 27, p. 445, 1889.
7. " " " *Rowland's Physical Papers*, p. 251.
8. Röntgen: *Sitzb. der Berl. Akad.*, p. 195, 1885.
9. Lecher: *Rep. der Physik.*, vol. xx, p. 151, 1884.
10. Röntgen: *Sitzb. der Berl. Akad.*, p. 23, 1888.
11. " *Wied. Ann.*, vol. xl, p. 93, 1890.
12. Himstedt: *Wied. Ann.*, vol. xxxviii, p. 560, 1889.
13. Lodge: *Phil. Mag.*, **5**, vol. xxvii, p. 469, 1889.
14. Crémieu: *Comptes Rendus*, t. 130, p. 1544, 1900.
15. " " " t. 131, p. 578, 1900.
16. " " " t. 131, p. 797, 1900.
17. " " " t. 132, p. 327, 1900.
18. " " " t. 132, p. 1108, 1901.
19. " *Annales de Chem. et Phys.*, **7**, 24, pp. 145, 299.
20. " *Jour. de Phy.*, **3**, 10, p. 453, 1901.
21. " *Bull. Soc. Tran. de Phy.*, p. 152, 1901.
22. " *Jour de Phy.*, **4**, t. 2, p. 753, 1902.
23. " *Comptes Rendus*, t. 135, p. 27, 1902.
24. Pender: *Phy. Rev.*, **13**, pp. 203, 325, 1901.
25. " *Phil. Mag.*, **6**, 2, p. 179, 1901.
26. " *Phy. Review*, **13**, p. 291, 1902.

27. Nichols: *Phy. Review*, 13, p. 60, 1901.
28. Eichenwald: *Phy. Zeit.*, 2, p. 705, 1901.
29. " " " 3, p. 31, 1901,
30. " " " 4, p. 308, 1903.
31. Whitehead: " " 4, p. 229, 1903.
32. Adams: *Phil. Mag.*, 6, 2, p. 285, 1901.
33. Rhigi: *N. Cim.*, 3, 2, p. 233, 1901.
34. Civita: *Ann. Fac. Sci. de Toulouse*, 1901.
35. Potier: *Eclairage électrique*, t. 25, p. 352, 1901.
36. Pocklington: *Phil. Mag.*, 6, 1, p. 325, 1901.
37. Wilson: " " 6, 2, p. 144, 1901.
38. Poincaré: *Eclairage électrique*, t. 31, p. 83, 1902.
39. Crémieu: *Comptes Rendus*, t. 135, p. 153, 1902.
40. " " " t. 136, p. 27, 1902.
41. Vasilescu-Karpen: *Jour de Phy.*, 4, t. 2, p. 667, 1903.
42. Crémieu and Pender: *Jour. de Phy.*, 4, t. 2, p. 641, 1903.
43. " " " *Phil. Mag.*, 6, 6, p. 442, 1903.

BERLIN-ZOSSEN HIGH-SPEED ELECTRIC RAILWAY.

Continuing the experiments on the Berlin-Zossen military road, the German electrical engineers engaged on the work have now succeeded in pushing the speed of the car above 125 miles an hour. A cable dispatch from Berlin of October 6th, says:

"An electric car on the Marienfelde-Zossen experimental line reached a speed of 125 $\frac{1}{2}$ miles an hour to-day, or a kilometer more than the highest previous record. The machinery and roadbed were unimpaired. The engineers are determined to try for still higher speeds and venture the opinion that they will be able to attain the rate of 140 miles per hour. The current was between 13,000 and 14,000 volts, capable of driving the car at the rate of over 200 miles. This power is reduced by transformers to about 450 volts. The car used to-day had four motors, having together about 1,100 horse-power. It was the car used in the previous tests this year, and is constructed on the Siemens-Halske system. Another car of somewhat different equipment as to motors and transformers has been built for additional high-speed tests.

"The lives of all on board the experimental car were heavily insured. A large party of engineers, military men and civilians gathered at Dallwitz, where the highest points of speed are reached in these experiments. A French observer remarked that the new sensation of the power of velocity inspired by the car's flight was worth traveling from Paris to see. There were twelve to fourteen persons on board the car, all technical men. They affirm that the motion of the car was no greater than that of an ordinary express train. A curious phenomenon accompanying the car is the continuous sparking of electricity from the six trolley arms.

"While the engineers do not believe a speed of 125 miles is practicable at present on the State railroads they are prepared to recommend a speed of 93 miles an hour between Berlin and Hamburg."