



XCII. On the law according to which the electro-magnetic power of the connecting wire of the voltaic pile is augmented by Schweigger's multiplier

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rantes lineares erectæ exiguæ albæ, quasi imbecilles et forte sine polline. *Stylus* albus strictus antheras 3-4 lineas superans, at coronâ humilior, *stigmat*e obsolete trilobo. *Germen* triloculare embryonibus pluribus.

Floret—Apr. medio. H. 4.

major. D. corollæ laciniis oris reflexis, filamentis plus quam 2. semiliberis, stylo coronam æquante.

Narcissus albus oblongo calice luteo serotinus major. *Park. Parad.* 73. 3.

DESCRIPTIO. Priore in omnibus triplo major at similis, scapo minus striatulo læviore. *Spatha* uniflora. *Corollæ* laciniæ speciosæ incurvo-expansæ, ad oras altissimè reflectentes, basi imbricantes, tubum cum germine æquantes, vel superantes, coronâque tertiâ parte longiores. *Corona* lutea, at pallidior quam priore, ore magis plicatim crenulato. *Filamenta* æqualia tubum longè superantia, sed humiliora quam corona; tria tubo infernè connata, at supernè plus quam semilibera; tria alia aliquantulum altiùs tubo connexa. *Antheræ* erectæ, externè parum curvatulæ, colore subaurantiaco, polline magis conspicuo quam in priore, sed non abundante. *Stylus* prioris, at major, coronæ longitudine.

Floret fine Aprilis. H. 4.

XCII. *On the Law according to which the Electro-Magnetic Power of the Connecting Wire of the Voltaic Pile is augmented by Schweigger's Multiplier.* By L. F. KAEMTZ, *Phil. Doct., of Halle.**

1. **I**MEDIATELY after Oersted's discovery had become known, the idea occurred to Professor Schweigger of increasing the electro-magnetic power of the voltaic pile by winding the connecting wire around the compass; he showed at the time, in his lectures, some experiments, with intent to examine in what degree the electro-magnetic power would be augmented by each additional convolution of the wire around the compass. The experiments, however, which were made here soon after the invention of the multiplier, were unsuccessful as to the discovery of a determinate law for this increase: (see Schrader de *Electro-magnetismo*, § 2. Schweigger's Journal, N.R. bd. i. p. 6.) I considered, therefore, that it would not be superfluous to ascertain this law by more exact experiments.

2. Before I proceed, however, to the description of the ex-

* From Schweigger and Meinecke's *Nues Journal*, band viii. p. 100.

periments themselves, I will develop a few formulæ by which the amount of the electro-magnetic power may be found from the given angles of attraction or repulsion of the magnetic needle.

M may therefore denote the power of the terrestrial magnetism;

m the magnetic power of the needle, whose length is = 1.

Now if the dipping needle is brought round an angle c out of the magnetic meridian, then the terrestrial magnetism strives to bring the needle into the meridian again, and with a power too which is equal to

$$M m. \sin. c.$$

(Compare Hansteen on Terrestrial Magnetism, part i. p. 130. Biot *Précis de Physique*, tom. ii. p. 26. edit. 2d.)

The magnetic power of the connecting wire of the electrical apparatus now acts on the needle likewise. If it be required to calculate the amount of the magnetic power of the electrical apparatus, from the angle of repulsion or attraction, where both powers (the terrestrial magnetism and the electro-magnetism) are in equilibrium, there are two cases to be distinguished: namely, the connecting wire either passes through the magnetic meridian, or forms an angle with it.

a) If the electrical stream passes through the magnetic meridian below the needle from south to north, and above it from north to south; thus does it pass in SN ; then it has on the western side a southerly, and on the eastern side a northerly polarity. The north pole of the needle (*pole austral* of the French) is driven towards the east, and the needle remains stationary in ns .

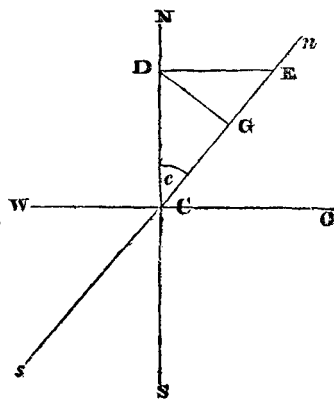
Now E may denote the magnetic power of the connecting wire: this acts in a direction perpendicular to the axis of the wire, towards DE . Therefore we may at the same time take for granted, that DE is proportional to the magnetic power. We therefore change DE into DG and GE , in which case DG is perpendicular to ns . Now the relation is,

$$DE : DG = 1 : \cos EDG, \text{ that is,}$$

$$E : DG = 1 : \cos c \text{ is consequently}$$

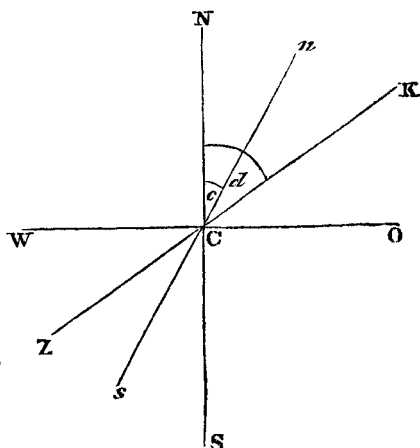
$$DG = E \cos c.$$

The needle reacts against this power with the power m ; the
electro-



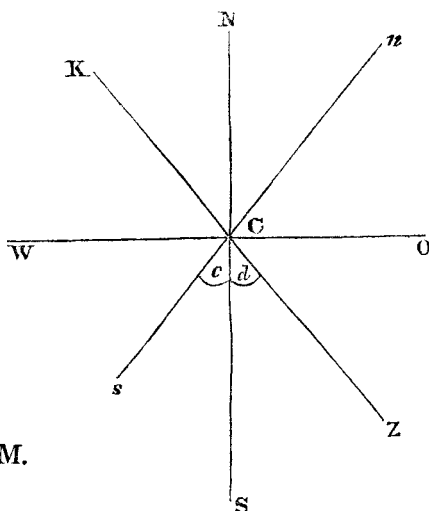
But the magnetic power of the connecting wire may likewise be of such amount only, that the needle remains stationary between it and the magnetic meridian, and therefore in *ns*. In this case we find, in a similar manner,

$$E = \sin. c. \text{tang. } (d - c) M. \quad (C)$$



β) The connecting wire intersects the magnetic meridian in such a manner that its north pole is opposite the north pole of the needle, in the direction KZ; therefore, where there is in KZ, on the right a north, and on the left a south pole. In this case the needle is impelled towards *ns*. Here we find in the same manner as above,

$$E = \sin. c. \text{tang. } (c + d) M. \quad (D)$$



3) The equations hitherto developed however are not quite exact, as it was taken for granted, that the connecting wire and the needle were lying in *one* plane. If, however, the needle be very long, and the distance of the wire from it very trifling, they may always be applied, particularly on this account, that the error which is committed by neglecting this distance, is generally committed in the comparison of electromagnetic powers, and is therefore less striking. The more exact equations however, which certainly are not so simple as the

ing the value of x . It is clear, namely, that E must be equi-persistent for the same electromotor, and for the same fluid. Now if the angle, which the connecting wire forms with the magnetic meridian, is at one time d , at another d' , in the same manner the angle of repulsion at one time c , at another c' ; then in the first case :

$$E = \frac{\sin. c}{\cos. (c-d)} \sqrt{(x^2 + \sin.^2 (c-d))} M;$$

and in the second case

$$E = \frac{\sin. c'}{\cos. (c'-d')} \sqrt{(x^2 + \sin.^2 (c'-d'))} M;$$

therefore

$$\begin{aligned} & \frac{\sin. c}{\cos. (c-d)} \sqrt{(x^2 + \sin.^2 (c-d))} \\ &= \frac{\sin. c'}{\cos. (c'-d')} \sqrt{(x^2 + \sin.^2 (c'-d'))} \\ \text{or, } & \frac{\sin.^2 c}{\cos.^2 (c-d)} (x^2 + \sin.^2 (c-d)) \\ &= \frac{\sin.^2 c'}{\cos.^2 (c'-d')} (x^2 + \sin.^2 (c'-d')). \end{aligned}$$

Whence

$$\left(\frac{\sin.^2 c}{\cos.^2 (c-d)} - \frac{\sin.^2 c'}{\cos.^2 (c'-d')} \right) x^2.$$

$$= \sin.^2 c' \text{ tang.}^2 (c'-d') - \sin.^2 c \text{ tang.}^2 (c-d);$$

and therefore

$$x^2 = \frac{\{\sin.^2 c' \text{ tang.}^2 (c'-d') - \sin.^2 c \text{ tang.}^2 (c-d)\}}{\sin.^2 c \cos.^2 (c'-d') - \sin.^2 c' \cos.^2 (c-d)}.$$

Now, in order to determine this value of x in my experiments, I gave various values to the angle d , and observed the corresponding angle c . My experiments were the following, and were made with two electromotors.

Angle d	-20°	-10°	0°	$+10^\circ$	$+20^\circ$	
Angle c	$24^\circ 55'$	$22^\circ 12'$	18°	$14^\circ 38'$	$11^\circ 33'$	A
Angle c	$32^\circ 50'$	$27^\circ 55'$	$22^\circ 43'$	$17^\circ 53'$		B

If the equations for the angles in A be calculated first, and the equation for $d = -20$ placed in a series like the others, and the same be done with the angles in B, then we obtain,

$$\left. \begin{aligned} 0.17881x^2 + 0.0013134 &= 0.14943 x^2 + 0.0066736 \\ 0.17881x^2 + 0.0013134 &= 0.10557 x^2 + 0.0100813 \\ 0.17881x^2 + 0.0013134 &= 0.077243x^2 + 0.013419 \\ 0.17881x^2 + 0.0013134 &= 0.055203x^2 + 0.015114 \end{aligned} \right\} \begin{array}{l} \text{from} \\ \text{A.} \end{array}$$

$$\left. \begin{aligned} 0.30219x^2 + 0.018769 &= 0.24214 x^2 + 0.022915 \\ 0.30219x^2 + 0.018769 &= 0.17527 x^2 + 0.026138 \\ 0.30219x^2 + 0.018769 &= 0.12070 x^2 + 0.026398 \end{aligned} \right\} \begin{array}{l} \text{from} \\ \text{B.} \end{array}$$

Adding

Adding these equations together, there results

$$1\cdot62181x^2 + 0\cdot0615606 = 0\cdot925556x^2 + 0\cdot1207389,$$

Also $0\cdot696264x^2 = 0\cdot0591783$
 $x^2 = 0\cdot084905$

5. Setting out from these principles, I made several series of experiments, in order to develop the law of the relation of the magnetic power of the connecting wire in Prof. Schweigger's multiplier to the number of convolutions it was made to take. For this purpose I made use of a magnetic needle six inches in length, made by M. Kraft an instrument-maker of this town. Glass tubes had been applied to the compass, at two opposite points, through which the wire was introduced. The limb was divided into half degrees, and I could very well estimate small fractions of a degree, by means of a lens. The compass stood upon a vertical pillar, revolving on its axis, at the foot of which was placed a graduated disk three inches in diameter. In this manner I could put the connecting wire into each azimuth, and vary the angle d as I pleased. I could also use the same needle as a dipping needle; I confined myself, however, to experiments with the variation needle.

The electromotor I employed was a simple alternation on Prof. Schweigger's construction (Gehlen's *Journal*, bd. vii. taf. 5. fig. 18: Schweigger and Meinecke's *Journal*, N. R. bd. i. p. 7); the strip of zinc being about eight inches long and four wide, and that of copper consequently double that size. The fluid conductor was a solution of muriate of ammonia in spring water, to which was added about 0.01 of concentrated sulphuric acid. For connecting wire I made use of copper harpsichord wire, covered with silk thread, and connected with the electromotor by finer wire (No. 14).

To the above I have to add the following observation: Several authors complain, that the results obtained by the electro-magnetic experiments can never be relied upon, *because this power rapidly decreases in a short time.* The remark may be true, but I maintain that this source of error may be entirely avoided. It appears to depend, principally, upon the construction of the electrical apparatus. If a voltaic pile be made use of, the diminution of power takes place pretty quickly; it is much slower with the apparatus consisting of a copper vessel in which a plate of zinc is placed; and it decreases slower still with the *couronne des tasses*. If the apparatus just described be employed, however, the diminution of power takes place very slowly; but the precaution is to be taken of first bringing the metals into contact with the conducting wire, and then immersing the electromotor in the fluid.

fluid. In this case, as I have convinced myself by experiments made for the purpose, the diminution of intensity may be neglected at the commencement. It is also convenient, that the electromotor be always immersed in the acid in an equable manner, not quicker at one time than at another.

The diminution of intensity appears to have some relation likewise to the region of the globe in which the electromotor is situated. This however is merely a supposition, to which I have been led by experiment; I will not venture to maintain that it is an absolute fact.

I have also to observe, that the wire had always an equal length in my experiments, which is in all cases important, since the length of the connecting wire greatly weakens the electro-magnetic power. The fluid was always of an equal temperature; for the greatest difference of temperature, which was observed, did not amount to more than 2° R., and I can therefore take it for granted, that the temperature had been equal.

6. In this manner I found the following angles for every convolution of the wire around the compass.

Angle <i>d.</i>	1 Convo- lution.	2 Convo- lutions.	3 Convo- lutions.	4 Convo- lutions.	5 Convo- lutions.	6 Convo- lutions.	26 Convo- lutions.
0°	$15^{\circ} 7'$	$22^{\circ} 5'$	$28^{\circ} 30'$	$30^{\circ} 55'$	$38^{\circ} 12'$	$41^{\circ} 56'$	$70^{\circ} 20'$
-20	$23 58$	$33 47$	$40 52$	$44 57$	$46 18$	$52 12$	$86 10$
-40	$7 39^{(*)}$	$13 54^{(*)}$	$55 16$	$60 6$	$63 15$	$67 30$	$109 38$
-60		$8 5^{(*)}$	$66 12$	$76 27$	$80 25$	$86 50$	$130 10$
-80			$4 20^{(*)}$	$5 6^{(*)}$	$8 48^{(*)}$	$13 30^{(*)}$	$164 11$
-90	0	0	0	0	0	0	180
$+20$	$9 33$	$14 54$	$19 12$	$21 52$	$27 15$	$30 5$	$50 16$
$+40$	$5 4$	$9 10$	$12 43$	$13 51$	$16 23$	$19 36$	$36 30$
$+60$		$5 8$	$7 5$	$7 58$	$10 2$	$11 30$	$21 12$
$+80$			$2 25$	$3 6$	$3 30$	$3 45$	7
$+90$	0	0	0	$.0$	0	0	0

This table contains, in the first vertical column, the values for the angle above denoted by d , i. e. for the angle which was made by the connecting wire with the magnetic meridian. The negative values of it indicate that in this case an attraction took place while the needle was repelled at the positive pole. The succeeding columns contain the angle c round which the needle was driven out of the meridian; the angles marked with an asterisk indicate, that the angle $d - c$, and not the angle $c - d$, is to be taken, and the equation must be applied.

All the angles are at least from ten observations, and I very seldom took that point at which the needle remained stationary; but I usually observed several arcs succeeding each other,
between

between which the needle oscillated, and took the mean of them.

7. If we now calculate the intensities of the magnetic power of the connecting wire, we find, that if the power of one single convolution is made $=1$, the power of n windings is $=n$, and that this apparatus may be more appropriately called a multiplier than a condenser. The values found are as follows :

Number of Convolutions,	Coefficient of M.	Relative Proportion to one Convolution.	
		calculated.	observed.
1	0.101749	1	1
2	0.214004	2	2.103
3	0.310509	3	3.052
4	0.408097	4	4.011
5	0.492592	5	4.841
6	0.605523	6	5.951
26	2.498289	26	24.652

That the law just now established does not exactly apply for 26 convolutions, cannot in any respect be considered as an instance of inaccuracy in it, but is probably an error in the observation of a convolution.

The law is confirmed moreover in the following manner : If the connecting wire intersect the magnetic meridian under an angle of 90° , then we know that the needle is turned back, if the electric stream passes from W. to E. After I had previously calculated the intensities for one or two convolutions, I then calculated the number of convolutions for this case. Then we have $E=M$, consequently the number of the requisite convolutions $= \frac{1}{0.101749} = 9.7$. I took therefore at first 9 convolutions, then 10; in both cases the needle remained stationary; but at 11, it immediately turned back very quickly.

It results at the same time from the above, that if the connecting wire pass through the magnetic meridian, the needle can never be repelled at 90° ; for in this case, according to the equation (A'), we shall have

$$E = \text{tang. } 90^\circ \sqrt{(x^2 + 1)} M;$$

but as $\text{tang. } 90^\circ = \infty$, then the magnetic power of the connecting wire should be infinitely great, therefore the magnetic power of the earth ought to be $=0$.