Dr. A. LEBRET. *A new method for measuring the Hall-effect, especially the variation of it with temperature.*

The preliminary numbers for the variation of the Hall-effect in bismuth with temperature, communicated in n⁰. 15 of this series, have been acquired by a method, wholly independent of any variation of the primary current. This method, which I will call the method of compensation is a null-method. It requires but a momentary observation, and therefore all disturbances fall away, which need some time before entering. Of these the principal is the "galvanomagnetic difference of temperature" [1]) discovered by VON ETTINGSHAUSEN. The error occasioned by this disturbance is not eliminated by any method employed as yet.

By means of this method, I also have studied the dissymmetry of the Hall-phenomenon in bismuth. To judge about the experiments, which explain the dissymmetry and are treated of in this Communication, it will be necessary to know the method and therefore it is described as follows.

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[1]) WIED. Ann. 31, p. 737.

Through one of the two windings of a galvanometer a branch of the primary current is sent, the Hall-current passing through the other. The branch, shunted by the small resistance L M, contains besides the winding of the galvanometer a rheostat, from which we introduce as much resistance as is necessary for the effects of the two windings of the galvanometer on the needle to neutralize each other. The magnetic field being constant, the relation of the difference of potential due to the Hall-effect to the strength of the primary current must be proportionate to $\frac{1}{W}$, W being the resistance of the resistance-box.

We give two schemes of the circuit [1]). The wires of the primary current are fastened to the plate [2]) in *A* and *B*. To *C* and *D* are joined the ends of that winding of the galvanometer, which is destined for the secondary current. In the more elaborate scheme II we also have delineated the "by-current", joining the primary circuit to the secondary current and containing the rheostat 2.

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[1]) See engraving II.

[2]) The plate of bismuth, length and breadth 2.9 cM., thickness 3.5 mM. has been obtained by founding in a case of mica, especially manufactured for the purpose. The fastening of the plate to the wires has been accomplished by screwing in.

It was placed in a vessel of hard-soldered copper, filled with some liquid. This vessel consists of three parts (see the engraving I) the middle (B) of which is flat and placed between the poles of the magnet. The uppermost (A) and the undermost (C) parts are cylindrical, the latter jutting out in an angle of 45° so that we may put a burner of Bunsen under it.

On the wholer we have placed the cooler D.

Besides one may see in this scheme the mercury cups, serving to reverse the primary and the "compensative current" [1]).

The secondary electrode, which is fastened in *D*, divides itself into two parts, mounted up symmetrically with respect to the wire fastened in *D*. These parts come together in *E*.

Method of measurement.

1. *Preparations.*

Take order that the needle of the galvanometer is unaffected when closing the magnetizing current, the primary and the secondary circuit being opened.

No deviation either may occur if we close the primary current, the compensative, secondary and magnetizing circuits being opened.

Now close the secondary circuit, the primary circuit remaining opened. Closing also the magnetizing current we do not observe a shock of induction, the plate of bismuth having been placed in the middle between the poles, and the two parts, into which the secondary electrode is divided being mounted up wholly symmetrically with respect to the wire fastenend in *C*. By bending the wires this may be obtained.

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[1]) In making preliminary or auxiliary experiments, but not for the principal measurement we want a commutator in the secondary circuit yet. In the scheme we have not marked the electromagnet, between the poles of which the plate of bismuth has been placed. For reversing the current, which excites the magnetic field, a commutator is yet required.

Now close the primary current, the secondary circuit remaining closed, the compensative and the magnetizing currents opened. We will see a deviation if the secondary electrodes do not lie in one equipotential line.

In this case, search which of the two corners of the mercury cup I, which are to be taken into consideration must be connected with the previously chosen secondary electrode in order to reduce that deviation. Then choose the resistance in such a manner that the deviation be annulled [1]).

2. *Principal measurement.*

First close the secondary circuit. A small deviation may occur in consequence of a thermo-electric current. Close the magnetizing current. After the preparations taken, but a small deviation will occur [2]).

Now close the compensative current. This does not produce any deviation, the primary current being opened.

Now close the primary circuit, the secondary and compensative currents then being produced at once. A very great deviation will not take place, the actions of both currents on the galvanometer-needle being of op-

[1]) The annulling of the deviation has not been acquired yet for a zero magnetic field, in consequence of the remanent magnetism. Therefore we will research how much resistance mus- be introduced into the by-current in order to annul the deviation for the remanent magnetism of opposite direction and we use the mean of these values for the principal measurement.

[2]) See the Chapter „Sources of Errors" A 2.

posite direction [1]). Now search which of the two currents preponderates, and vary the resistance in order to diminish the difference.

Soon we obtain that the secondary current first seems to preponderate and (after the primary current has passed some time) [2]) subsequently the compensative current seems to be stronger. In fact, the secondary current has diminished, in consequence of the occurring *galvanomagnetic difference of temperature* [3]).

We see f. i. the image of the graduated scale first deflect to the right, afterwards to the left. Now introduce somewhat less resistance in the compensative circuit, the deflection to the right will be smaller. Now still diminish the resistance somewhat (every time very little if great accuracy is desired), then we finally get to the point that the needle remains one moment at rest and afterwards wanders to the left. Then the compensation has been acquired as completely as possible, and the value read on the rheostat ought to be noted.

Now close the primary current in the opposite direction, neither touching the bridge of the mercury-cup II, nor reversing the magnetizing current, and determine the value of the resistance to be chosen in the compensative circuit.

[1]) The direction, in which the compensative circuit is to be closed, must be rightly chosen with regard to the direction of the previously chosen magnetizing current. By preliminary experiments one should learn how to make the right choice.

[2]) We close the primary circuit every time only during one moment, in order not to produce needless thermo-electric currents.

[3]) See the Chapter „Sources of Errors" A 3.

This value having been noted, the magnetizing and the compensative current (mercury-cup II) should be reversed, whilst the primary current is open.

Determine also for this direction of the magnetic force the values, which are to be chosen in the rheostat.

This yields two numbers more, which with the two already found refer to one temperature.

For each temperature these four measurements are made and so the materials have been collected for calculating the variation of the Hall-constant with temperature.

Sources of errors, which may occur in measuring.

Group A. *Thermomagnetic phenomena.*

1. Differences of potential at the secondary electrodes arising in the magnetic field in the direction of the primary current. (Transversal thermo-magnetic effect of VON ETTINGSHAUSEN and NERNST) [1]).

For this one may give the law:

$$e = E_t M (t_1 - t_2),$$

e being the difference of potential at the secondary electrodes, $t_1 - t_2$ the difference of temperature at the primary electrodes, E_t a constant, M the magnetic force.

All dieffrences of temperature, which are independent of the direction of the primary current will cause differences of potential, which increase the Hall-effect for one direction of the primary current, and diminish it

[1]) Wied. Ann. 29 p. 343. 1886.

for the opposite direction. Taking the mean of the two values for the two directions of the primary current, the error caused by this effect is eliminated.

For differences of temperature, caused by the Peltier-effect, this will not do. The difference of potential hereby arising may be put in the form

$$e = P E_t M I$$

P being a new constant, depending on the Peltier-effect, and I being the primary current. This difference of potential depends also on M and I in the same manner as the Hall-effect itself and is not separated from the Hall-effect in the methods used as yet.

The Peltier-effect however wanting some time for arising, the separation is performed by our momentary method.

2. Differences of potential at the secondary electrodes arising in the magnetic field by flows of heat in the direction of the secondary current. (Longitudinal thermomagnetic effect of VON ETTINGSHAUSEN and NERNST [1]).

For this one may give the law:

$$e = E_l M^2 (t_3 - t_4)$$

$t_3 - t_4$ is the difference of temperature at the secondary electrodes, E_l a constant.

The flow of heat, only arising if a difference of temperature does exist between the secondary electrodes, in which case also occurs a thermo-electric current, this effect may be considered as a variation of the thermoelectric current by the magnetic field. Measuring accord

[1]) See NERNST, Thermomagnetische Ströme. Longitudinal effect. Wied. Ann. 31 p. 779.

ing to our method all influence falls away as we always close the magnetizing current before the primary current, thus acquiring a new point of rest with respect to which we determine the equivalence of the Hall-current and the compensative current.

Otherwise this effect would produce an apparent dissymmetry for the opposite directions of the magnetization.

3. Differences of temperature at the secondary electrodes, arising in the magnetic field by the primary current. (Galvanomagnetic difference of temperature of von Ettingshausen) [1]).

For this one may give the law:

$$t_3 - t_4 = E_e\, M\, I$$

E_e is a new constant.

This difference of temperature produces a thermo-electric current depending in the same way on M and I as the Hall-current itself, which therefore cannot be easily separated from it.

This error will show itself in its full magnitude, if using the former method of deflection. Our method however being momentary, we may judge of the strength of the Hall-current at the first moment. If we have introduced too much resistance in the compensative current, we shall first see the Hall-current preponderate. But after the primary current has passed a while, the deviation observed will change sign, the secondary current having diminished. By the deviation however, which has appeared the first moment, we know that too much

[1]) Wied. Ann. 31 p. 737.

resistance had been introduced in order to compensate the Hall-current alone.

Group B. *Other errors.*

1. Variation of the primary current during the measurements.

As we always measure $\frac{e}{I}$, all influence falls away.

2. Variation of the magnetic field, in which the galvanometer-needle is moving, by accidental causes.

This produces a deviation of the point of rest, which causes errors in the former methods, the deflection to be measured needing some time to become constant, whilst in using our method the Hall-current is measured at the same moment it occurs.

3. Variation of the magnetic field in which the galvanometer needle is moving, by exciting and reversing the electromagnet. Even if a deviation of the point of rest has not been wholly avoided, yet all influence falls away, if we first close the magnetizing current and note the new point of rest. This also is applicable to the methods used by others.

The exciting and the reversing of the magnetic field generally will change the sensibility of the galvanometer; with our arrangement this happened to be even so in a high degree. Using however our method of measuring, we need not mind the sensibility, as the equivalence of the secondary and the compensative current may be observed at each sensibility. Only if the equivalence is not complete, the then appearing deviation will depend on the sensibility existing.

4. Variation of the magnetic field, in which the gal-

vanometer needle is moving, by exciting and reversing the primary current.

The deviation of the point of rest, as far as it arises by a wrong situation of that part of the primary circuit, which admits no reversing of the current, would bring about an apparent difference of the Hall-effect for the opposite directions of the magnetic field, apparently a dissymetry.

As far as it arises in that part of the primary circuit, which does admit reversing, the error may be eliminated by taking the mean of the values, obtained for the two directions of the primary current.

Variations of the sensibility of the galvanometer by this cause has no influence for the reasons explained in 3.

5. Variation of the magnetic field in which the plate of bismuth has been placed. This always will produce some error. The only remedy is to keep the magnetizing current as constant as possible, testing this with the aid of an Ammeter. The current having varied somewhat, one may regulate it again by somewhat increasing or diminishing the resistance.

6. Thermo-electric currents, which exist already by some difference of heat at the secondary electrodes. If the thermo-electric current is constant during the course of the measurement, it does not produce any error. Only the variations of it produce some errors. Our observation however being momentary, this error wholly falls away.

Moreover the constancy of the thermo-electric current is still favoured by the circumstance that the secondary

circuit always may remain closed during the principal measurements (see n°. 9).

7. Thermo-electric currents, which arise by the passing of the primary current.

a. The heat, which develops at the contacts of the primary circuit according to JOULE's law may be propagated irregularly to the secondary electrodes. So a thermo-electric current arises. Since the primary current, if using our method, is closed only one moment, the thermo-electric current wants the necessary time to amount to a perceptible value.

The influence exercised upon the observations would produce a different value of the Hall-effect for the opposite directions to the primary current.

b. The heat, which develops at the contacts according to the law of PELTIER can also produce thermo-electric currents.

The same remarks may be made as in *a*, but the reversing of the primary current will not reverse this effect and the influence of it would produce a dissymmetry for the opposite directions of the magnetic field.

8. Differences of potential which may occur at the secondary electrodes even in a zero magnetic field, when the primary current passes.

These arise by not fastening the secondary electrodes to the plate at wholly symmetrical places. The error proceeding from it may be avoided in various manners.

a. By first closing the primary circuit, then determining the point of rest and after that closing the magnetizing current. The great objection however is that, in acting so, several other errors occur (See A 2).

b. By measuring the difference of potential with the aid of the compensative current, afterwards deducting the amount of it. This I performed sometimes, in order to control the method described in *d*.

c. By neutralizing the difference of potential with the aid of a branch-circuit, containing a DANIELL-element. The branch-current passes through the secondary wires. The objection to this method, is that we neutralize the difference of potential for only one fixed strength of the primary current.

d. By introducing the by-current according to the idea of BOLTZMANN, joining also the primary and the secondary electrodes by means of a great resistance, chosen exactly.

The last method was generally used.

9. Currents, induced by the variation of the magnetic force during an experiment.

These troubled the results of SHELFORD BIDWELL [1]), who used elements of GROVE in the magnetizing current. Therefore instead of one of the secondary electrodes he used a wire, divided into two parts (see the scheme II) [2]).

Now we have the magnetic force sufficiently constant so that we need not fear the induction currents, but the arrangement with the double wire is very practical as the magnetic field may now be reversed, whilst the secondary current always remains closed, without producing any inconvenient shock.

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[1]) Phil. Magaz. 5. 17. 1884. p. 249—265.

[2]) Engraving II.

10. Variation of the resistance of the secondary circuit in consequence of the temperature. As to the plate of bismuth the variation is not to be taken into consideration, as the resistance is but 0,0004 Ohm, the whole circuit having a resistance of 1 Ohm.

The resistance of the contacts at the two electrodes however amounts to 0,2 Ohm in the most disadvantageous case. It ought therefore to be measured at various temperatures.

11. Variation of the resistance by the magnetization is not to be taken into consideration, as it only influences the resistance of the plate of bismuth, which is very small.

12. Influence of the remanent magnetism.

The remanent magnetism will render it more implicate to determine the value of the resistance in the by-current, which ought to be chosen for a zero-magnetic field. We now determine the resistance for the remanent magnetism of the opposite directions, and take the mean of the two values acquired.

13. The magnetic force, which arises by the passing of the primary current alone, may yet bring about that after all the choice of the resistance in the by-current has been made not for a zero magnetic field, but for the magnetic field excited by the primary current itself. The arising Hall-effect does not change sign, if we reverse the primary current, as the magnetic force reverses also.

We however convinced ourselves that the effect is too small to be observed.

One might show the action existing by first using a very weak primary current in order to choose the resistance in the by-current. If we thereafter make the primary current stronger, then another choice of the resistance would be necessary. We however did not observe any difference.

Dr. A. LEBRET. *Dissymmetry of the Hall-effect in bismuth for the opposite directions of the magnetic field.*

In all the plates of bismuth I used, the Hall-current, proved not to be of the same strength for the two opposite directions of magnetization.

Always using the described method of observation, I was urged to introduce for one direction of magnetization (A) an amount of resistance, wholly different from that for the opposite direction (B).

(The amount of the resistance to be chosen for the opposite directions of the primary current differed but very little, and was independent of its strength) [1]).

If we trace the cause, which may produce this dissymmetry, we meet under B 7 b in the list of errors in the preceding communication thermo-electric currents, produced by the PELTIER-effect.

Since these only arise after the primary current ha passed a while, and as our method is a momentary one, it is not to be accepted that the right explanation should be found in them, chiefly on account of the great amount of the dissymmetry.

[1]) The primary current could vary from 1.5 till 7 ampères. The strength of the magnetic field was about 3000 (c. g. s.).