Report on Some Experiments Made at the Physics Institute in Göttingen

Wilhelm Weber

Editor's Note: English translation of Wilhelm Weber's 1858 paper "Bericht über einige im physikalischen Institute in Göttingen gemachte Versuche", [Web58].

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1 Weber: Report on Some Experiments Made at the Physics Institute in Göttingen

By Wilhelm Weber[1,2,3,4]

Presented to the Königl. Societät on April 10, 1858.

In the Physics Institute of this University, in addition to the regular course of physics lectures, practical physics exercises[5] are held, in which the members of the mathematics-physics seminar take part. Those who choose physics as their main subject and have acquired greater practice will find the opportunity to do special work for themselves, such as for example in last year was done by Dr. Arndtsen and Dr. Christie from Christiania,[6] who will make their carried out work known in more detail in Poggendorff's *Annalen*.[7] Their results will be reported here briefly.

In view of the particular interest that *diamagnetism* still arouses as one of the latest discoveries promising information about the inner nature and coherence of bodies,[8] and in the view of the still existing lack of *quantitative* determinations, the *diamagnetometer*[9] manufactured by Mr. Leyser in

[1][Web58].

[2]Translated by Peyman Ghaffari, IMAAC-next, Tech Park of Fuerteventura, Puerto del Rosario, Las Palmas 35600, Spain; Center for Research and Development in Mathematics and Applications (CIDMA), Department of Mathematics, University of Aveiro, 3810-193 Aveiro, Portugal; pgsaid@fc.ul.pt. Edited by A. K. T. Assis, www.ifi.unicamp.br/~assis.

[3]The Notes by H. Weber, the editor of the fourth volume of Weber's *Werke*, are represented by [Note by HW:]; the Notes by Peyman Ghaffari are represented by [Note by PG:]; while the Notes by A. K. T. Assis are represented by [Note by AKTA:].

[4][Note by HW:] Nachrichten von der G. A. Universität und der Königl. Gesellschaft der Wissenschaften zu Göttingen. April 16. 1858. No. 6. p. 67-76.

[5][Note by PG:] In German: *praktische physikalische Uebungen*. By "exercise" it is meant "practical physics exercises" during studying physics at University. This system still exist in the German University system.

[6][Note by AKTA:] Hartvig Caspar Christie (1826-1873), a Norwegian mineralogist and physicist, who studied in Göttingen under Weber from 1857 to 1859. He measured, for instance, diamagnetism in bismuth. Adam Arndtsen (1829-1919), a Norwegian professor and physicist, who also studied in Göttingen under Weber in 1857. Cristiania is the former name of Oslo, the capital of Norway.

[7][Note by AKTA:] See, for instance, [Chr58].

Johann Christian Poggendorff (1796-1877) edited the *Annalen der Physik und Chemie* from 1824 to 1876, where many of Weber's papers were published. The modern *Annalen der Physik* is the successor to this Journal.

[8][Note by PG:] The German word "Körper" is translated as "body".

[9][Note by AKTA:] In the original: *Diamagnetometer*.

Leipzig,[10] according to specifications by Professor Weber, with which Mr. John Tyndall made many interesting experiments in London and reported them in the Philosophical Transactions for 1856 (Further Researches on the Polarity of the Diamagnetic Force),[11] and of which a second copy is in the local Physics Institute, was used as a measuring device for some *quantitative* determinations on diamagnetism.

In his experiments, Mr. Tyndall had found an almost equal deflection of the astatic magnetic needle[12] by the diamagnetic body when the diamagnetism was excited by a current from *two*, *three* or *four* cells,[13] whereby the *proportional growth* of the diamagnetic force with the force which excites diamagnetism has been questioned. This doubt does not exist anymore due to more complete *measurements* of Dr. Christie performed with the same instruments, in that Dr. Christie associated a determination of *sensitivity*[14] of the astatic needle with each observation of *deflection*, from which the sensitivity resulted *variable* with the current intensity. From this it followed that the observed deflections first had to be reduced to the *same sensitivity*, before they could serve as a measure of the excited diamagnetism. After this reduction and after precise measurements of the *current intensities* (which, as is well known, must not be set proportional to the number of cells) with the help of the *tangent galvanometer*,[15] the law of the proportionality of the diamagnetic force with the galvanic force that excites it has been carefully tested and confirmed. The current intensity, determined according to known absolute measures, was increased from 16 to 44 units.

The same instrument now offered at the same time the opportunity, to measure more accurately the constant relationship between the diamagnetic force and the galvanic force that excites it. This ratio is called the *diamagnetic constant*,[16] and was determined by Professor Weber with an instrument which was constructed according to the mentioned principles, but which

[10] [Note by AKTA:] Georg Moritz Ludwig Leyser (1816-1881).

[11] [Note by AKTA:] John Tyndall (1820-1893). See, for instance, [Tyn54], [Tyn55b], [Tyn55a], [Tyn55c] and [Tyn56].

[12] [Note by AKTA:] The adjective "astatic" is used in physics with the meaning of something having no tendency to take a definite position or direction. An astatic needle can be a combination of two equal and parallel magnetized needles with their poles turned opposite ways. The arrangement protects the system from the influence of terrestrial magnetism.

[13] [Note by PG and AKTA:] In the original *Becher*. Weber is referring here to a voltaic cell, element, battery or pile producing an electromotive force.

[14] [Note by PG:] In German: "Empfindlichkeit".

[15] [Note by PG and AKTA:] In the original: *Tangenten-Boussole*. The tangent galvanometer was invented by J. J. Nervander (1805-1848), [Ner33] and [Sih21].

[16] [Note by PG:] In German: *Diamagnetische Konstante*.

had not received such a fine mechanical execution, for the first time in the [paper] "Electrodynamic Measurements" (*Abhandlungen der mathematisch-physischen Klasse der Königl. Sächs. Gesellschaft der Wissenschaften*, Vol. I, Leipzig 1852).[17,18] A repetition of this measurement with a finer measuring instrument therefore seemed of particular interest and was also carried out by Dr. Christie.[19]

This measurement was given a special sharpness[20] by the fact that it was not based on a comparison of the diamagnetic bismuth with magnetic iron, which apart from other circumstances, is not capable of much sharpness because of the different distribution of magnetism in iron and diamagnetism in the bismuth, but was based on a comparison of the diamagnetic bismuth with a *solenoid* (a spiral-shaped wire), through which passes a weak current precisely measured by the tangent galvanometer. This solenoid had a cylindrical shape of the same diameter and height as the used bismuth-cylinder. From the number of its spiral windings and the strength of the passing current, the torque[21] could be determined, with which it acted from the same place as the diamagnetic bismuth-cylinder on the astatic needle; the current could also be easily regulated in such a way that this effect was close to that of the bismuth-cylinder.

From these measurements it has been shown that one unit of the exciting force (according to absolute measure, after which the horizontal earth magnetic force in Göttingen is at present = 1.81) in 1 milligram bismuth produces a moment, which according to the Gaussian absolute measure[22] is

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[17] [Note by HW:] Wilhelm Weber's *Werke*, Vol. III, p. 473.

[18] [Note by PG and AKTA:] In German: *Elektrodynamischen Maassbestimmungen*. This paper is the third of Weber's major eight Memoirs with the general title of Electrodynamic Measurements, [Web52a] with English translation in [Web21].

[19] [Note by AKTA:] [Chr58].

[20] [Note by PG:] In German "Schärfe" meaning accuracy and sharpness.

[21] [Note by PG:] In German: "Moment". That is, "torque" or "moment of force".

[22] [Note by AKTA:] In German: *Gauss'schen absoluten Maasse*. That is, Gaussian absolute measure or unit.

Gauss's work on the intensity of the Earth's magnetic force reduced to absolute measure was announced at the Königlichen Societät der Wissenschaften zu Göttingen in December 1832, [Gau32] with English translation in [Gau33a] and [Gau37a], see also [Rei02, pp. 138-150].

The original paper in Latin was published only in 1841, although a preprint appeared already in 1833 in small edition, [Gau41b] and [Rei19]. Several translations have been published. There are two German versions, one by J. C. Poggendorff in 1833 and another one in 1894 translated by A. Kiel with notes by E. Dorn; a French version by Arago in 1834; two Russian versions, one by A. N. Drašusov of 1836 and another one by A. N. Krylov in 1952; an Italian version by P. Frisiani in 1837; an English extract was published in 1935, while a complete English translation by S. P. Johnson and edited by L. Hecht

= 0.000 001 488 5, while the same moment for iron was found by Professor Weber = 5, 6074.[23] The diamagnetism of the bismuth is thus 3.8 million times smaller than the magnetism of iron. This result is somewhat smaller than that found by Weber, which, apart from the greater precision of the measurement which the instrument used here permits, is explained by the difference in bismuth, which in both cases could not have been obtained of absolute purity. — To give a clear idea of the size of these diamagnetic forces, it should be noted that 1 milligram of steel from a strong magnetic needle has on average about one moment = 400 according to the same units, which is 269 million times greater than the aforementioned moment of bismuth.

Finally, in third place, Dr. Christie used the same instrument to investigate the polarity of diamagnetic bodies, which Weber and Tyndall had put beyond doubt, by studying the *distribution of diamagnetism* more closely. It has been shown that, according to Gauss's principle of the *ideal distribution*[24] in a cylindrical bismuth rod, in which everywhere the same exciting force acts parallel to its axis, almost all diamagnetism can be thought of as being distributed over the two circular end faces, a result which is entirely in accordance with what seems to be expected with the theory.

In all these experiments carried out with the mentioned *diamagnetometer*, only one circumstance remained in the dark, namely, from where the *sensitivity* of this instrument results being so *variable*, which, according to its theory, if all the prescribed conditions were exactly fulfilled in the construction and regulation,[25] there would be no reason for it. It is now evident that by this construction and regulation of the instrument, a compensation of very large forces, which excited diamagnetism, should be achieved in such a way that they have no influence at all on the extremely sensitive astatic magnetic needle; while the forces then to be measured with the instrument, namely the diamagnetic forces themselves, are very small, accordingly it can be expected that the required compensation cannot be produced practically with the required accuracy. More precisely, the production of the required

appeared in 2003; and a Portuguese version by A. K. T. Assis was published in 2003: [Gau33b], [Gau34], [Gau36], [Gau37b], [Gau94], [Gau35], [Gau52], [Gau75], [Gau03] and [Ass03].

In 1832-1833 Gauss introduced the absolute system of units for magnetism and obtained the intensity of the horizontal component of terrestrial magnetic force in Göttingen in absolute measure as given by $T = 1.78$.

[23] [Note by AKTA:] This value can be found in [Web52a, Section 27] with English translation in [Web21, Section 27]; and [Web52b] with English translation in [Web53] and [Web66].

[24] [Note by AKTA:] [Gau39] with English translations in [Gau41a] and [GT14].

[25] [Note by PG and AKTA:] In German: "Regulirung". This word can also be translated as adjustment.

compensation breaks down into two different tasks, namely *first* in relation to the equilibrium position of the astatic needle, and *second* in relation to its sensitivity. In relation to the *first*, after both problems had been approximately solved, a *finer correction* had been made, without which the astatic needle with telescope, mirror and scale could not have been observed. As regards the *sensitivity*, however, a finer correction was dismissed in order not to complicate the instrument too much, due to the fact that lack of the same does not make any significant contribution to the measurements, if only the variation in sensitivity are precisely determined and taken into account. However, since these variations in sensitivity were of an unexpected size and importance, it was necessary, in order to fully control all the essential elements in these fine measurements, to examine and investigate the causes of these variations more precisely. This actual fine examination has been carried out by Dr. Arndtsen with the best results, and it has emerged from this, how these variations can be mastered and, if found necessary, can be eliminated altogether. With the accuracy with which these variations can be taken into account, there is usually no reason to avoid them, rather, since it is entirely up to one to decide whether the sensitivity of the instrument is to be increased or decreased by the variation, one can often benefit from this for the measurements themselves. Since here the description of the instrument has to be dispensed, so the theory of these experiments cannot be discussed in more detail.

On the other hand, another investigation from Dr. Arndtsen made with the same instruments should be mentioned. It is clear that the same instrument which is used to examine the polarity of diamagnetic bismuth can also be used to examine the magnetic polarity of those bodies which were previously thought to be non-magnetic or weakly magnetic, in order to obtain *quantitative* determinations which are still completely lacking for those bodies. In particular, it seemed important to investigate whether in these bodies, just as Joule,[26] Müller[27] and Weber have found in iron, a deviation of the magnetism from the proportionality of the magnetizing force can be demonstrated with increasing magnetizing force, as this circumstance is of great importance for the study of the inner causes of magnetism and its variations. These tests were carried out by Dr Arndtsen with *iron-sulfate*,[28] *iron-chloride solution*, *cyan-iron-potassium* and *nickel*. It should be noted that the magnetizing force that acted on these bodies, and which was not generated by electromagnets, but by mere galvanic currents, could be brought only up to

[26] [Note by AKTA:] [Jou40].
[27] [Note by AKTA:] [Mül51b] and [Mül51a].
[28] [Note by PG:] In German the word "Eisenvitriol" was used, i.e. iron-sulfate or $FeSO_4$.

the strength = 600 by available means according to absolute measure (after which the horizontal earth-magnetic force was presently in Göttingen = 1.81), whereas in the carried-out experiments with iron by Weber it had been driven up to over 3000. Add to this, that this measured magnetizing force can be described as an *external* force, and that in *pure iron* also a significant *inner* force resulting from the magnetic interaction applies on the *individual* particles, which disappears almost completely in the above-mentioned bodies. According to this, it would therefore to be expected that in the above-mentioned bodies the questioned deviation from proportionality usually under the same condition would be perceptible later than in the case of pure iron, namely only when the *external* force alone acted just as strongly as the *external* and *internal* force combined in the case of iron.

Under these circumstances it is not surprising that in several of the bodies examined there was no deviation from the proportionality noticeable; it is more interesting however, that with *nickel* it has emerged that this deviation from proportionality occurs much earlier than with iron, so that the *nickel-magnetism* has almost reached its highest limiting value as a result of magnetizing forces, at which the iron-magnetism hardly deviates noticeable from the initial proportionality.

In addition to these experiments, Dr. Arndtsen also carried out a comprehensive investigation into the *resistance*[29] of metals with special consideration of their *temperature*, of which the following Table gives a brief overview of the results. Under the title *Resistance*, the resistance of a cylinder with 1 millimetre in height and 1 millimetre in diameter at 0° temperature is given in absolute measure; under the title *Correction due to the temperature*, the factor is given by which the resistance at 0° temperature must be multiplied in order to obtain the resistance at t degrees on the scale divided by 100 parts.

[29] [Note by PG:] In German: "Leitungswiderstand".

Metal	Resistance	Correction due to the temperature
Silver	241 190	$1 + 0.003\,414\,20 \cdot t$
Copper	244 370	$1 + 0.003\,940\,25 \cdot t$
Aluminum No. 1	476 218	$1 + 0.003\,407\,90 \cdot t$
Aluminum No. 2	427 616	$1 + 0.003\,638\,60 \cdot t$
Brass	949 086	$1 + 0.001\,661\,9 \cdot t$ $+ 0.000\,002\,734 \cdot t^2$
Argentan	1 289 815	$1 + 0.000\,387\,36 \cdot t$ $+ 0.000\,000\,557\,8 \cdot t^2$
Iron	1 626 643	$1 + 0.004\,130\,4 \cdot t$ $+ 0.000\,005\,271\,3 \cdot t^2$
Lead	2 631 490	$1 + 0.003\,767\,68 \cdot t$

Also Dr. Christie made a few more magnetic observations and experiments, which gave interesting results. The local mechanic, Inspector Meyerstein,[30] constructed the instruments for two complete magnetic observatories on the order of the Brazilian government, for scientific expeditions, tested by Dr. Christie. The set-up of the associated portable magnetometer for measuring *declination* and *intensity* is described in detail elsewhere. Only the *induction-magnetometers* for measuring the *inclination*, which, according to Professor Weber, were made on a smaller scale in order to be used on the journey, should deserve a mention, as the ones tested by Dr. Christie have shown that the same advantages are achieved for measuring the *inclination* not only in fixed observatories, but also on a journey, as the other magnetometer for *declination* and *intensity*. — The observations and experiments made by these induction magnetometers have now also given cause for Dr. Christie to determine anew the variability of needle magnetism, which is important for measuring the intensity, with the needle in *normal* and *transverse* positions. This determination was made by Professor Weber with the help of *magnetic induction* for only smaller needles, in his treatise in the 6th volume of the treatises of our society (Göttingen 1855);[31,32] but it seemed important that the same determination should be used again for the two larger needles with which all measurements of the intensity in the local magnetic observatory since 1834 have been carried out. These attempts have led to the results, which are given in the last column under the title *"Change"*. There

[30] [Note by AKTA:] Moritz Meyerstein (1808-1882). See [Hen04], [Hen05], [Hen07] and [Hen20].

[31] [Note by HW:] Wilhelm Weber's *Werke*, Vol. II, p. 333.

[32] [Note by AKTA:] [Web56], see also [Web54].

the factor is given by which the magnetic directive force,[33] expressed in absolute units, must be multiplied in order to obtain the change in the magnetic moment of the needle produced by it. Since now, during the transition from the *transversal* position to the *normal*, the horizontal earth-magnetic force (presently = 1.81) begins to act on the needle, it follows that one obtains the increase in needle magnetism associated with that transition by multiplying the factor specified in the last column by 1.81.

Needle number	Weight in gram	Magnetic moment	Change
1	1 770	$714 \cdot 10^6$	450 000
2	1 750	$674 \cdot 10^6$	462 000

[33] [Note by AKTA:] In the original: *magnetische Direktionskraft*. The concept of "directive force" was introduced by Gauss in 1838, [Gau38, p. 4] with English translation in [Gau41c, p. 254].

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