Contributions from

The Museum of History and Technology:

Paper 38

# The Earliest Electromagnetic Instruments

*Robert A. Chipman*

ELECTROSTATIC INSTRUMENTS BEFORE 1800 123

INSTRUMENTING VOLTAIC OR GALVANIC ELECTRICITY, 1800–1820 124

ELECTRICAL INSTRUMENTATION, 1800–1820 125

OERSTED'S DISCOVERY 126

BEGINNINGS OF ELECTROMAGNETIC INSTRUMENTATION 126

CHRONOLOGY AND PRIORITY 127

ORIGINAL ELECTROMAGNETIC MULTIPLIERS 129

CONCLUSIONS 135

ACKNOWLEDGMENTS 136

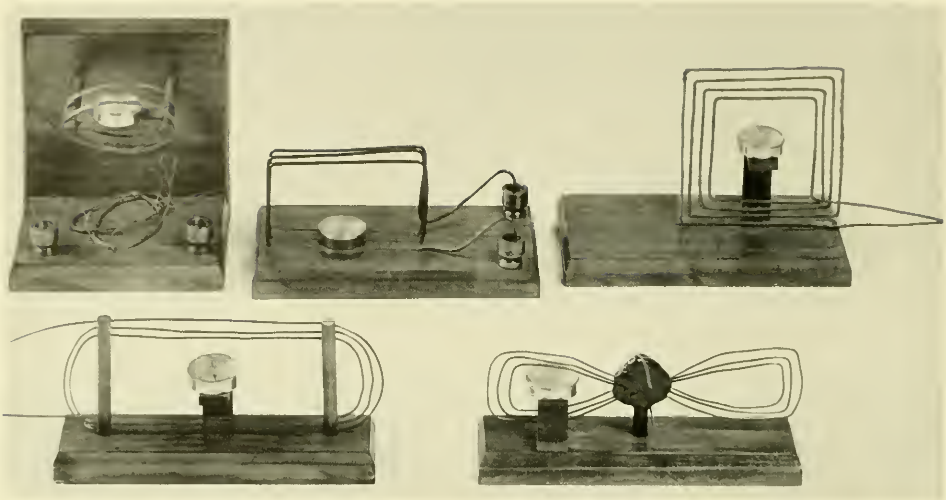

Figure 1.—Models of various electromagnetic instruments created by Schweigger, Poggendorf and Cumming in 1821, made for an exhibit in the Museum of History and Technology, Smithsonian Institution. (Smithsonian photo 49493.)

*Robert A. Chipman*

# THE EARLIEST ELECTROMAGNETIC INSTRUMENTS

*The history of the early stages of electromagnetic instrumentation is traced here through the men who devised the theories and constructed the instruments.*

*Despite the many uses made of voltaic cells after Volta's announcement of his "pile" invention in 1800, two decades passed before Oersted discovered the magnetic effects of a voltaic circuit. As a result of this and within a five-month period, three men, apparently independently, announced the invention of the "first" electromagnetic instrument. This article details the merits of their claims to priority.*

THE AUTHOR: *Robert A. Chipman is chairman of the Department of Electrical Engineering at the University of Toledo in Toledo, Ohio, and consultant to the Smithsonian Institution.*

## Electrostatic Instruments before 1800

IT IS THE FUNDAMENTAL PREMISE of instrument-science that a device for detecting or measuring a physical quantity can be based on any phenomenon associated with that physical quantity. Although the instrumentation of electrostatics in the 18th century, for example, relied mainly on the phenomena of attraction and repulsion and the ubiquitous sparks and other luminosities of frictional electricity, even the physiological sensation of electric shock was exploited semiquantitatively by Henry Cavendish in his well-known anticipation of Ohm's researches. Likewise, Volta in 1800[1] described at length how the application of his pile to suitably placed electrodes on the eyelids, on the tongue, or in the ear, caused stimulation of the senses of sight, taste and hearing; on the other hand, he reported that electrodes in the nose merely produced a "more or less painful" pricking feeling, with no impression of smell. The discharges from the Leyden jars of some of the bigger frictional machines, such as van Marum's at Leyden, were found by 1785 to magnetize pieces of iron and to melt long pieces of metal wire.[2]

[1] A. VOLTA, "On the Electricity Excited by the Mere Contact of Conducting Substances of Different Kinds," *Philosophical Transactions of the Royal Society of London* (1800), vol. 90, pp. 403–431.

[2] Some little-known but delightful observations in the prehistory of electromagnetism are described in a letter written by G. W. SCHILLING from London to the Berlin Academy on July 8, 1769, published as "Sur les phénomènes de l'Anguleil Tremblante" [*Nouveaux Mémoires de l'Académie Royale des Sciences et Belles-Lettres*, 1770 (Berlin, 1772), pp. 68–74], translated to French from the original German. The letter recounts a multitude of experiments with various electric eels. The two observations of electromagnetic interest are that a piece of iron held by the hand in the eel's tank could be felt quivering even when the fish was stationary several inches away, and a compass needle showed a deflection, both in the water near the fish, and outside the tank, also with the fish stationary.

The useful instruments that emerged from all of this experience were various deflecting "electrometers" and "electroscopes" (the words were not carefully distinguished in use), including the important gold-leaf electroscope ascribed to Abraham Bennet in 1787.[3]

In 1786, Galvani first observed the twitching of the legs of a dissected frog produced by discharges of a nearby electrostatic machine, thereby revealing still another "effect" of electricity. He then discovered that certain arrangements of metals in contact with the frog nerves produced the same twitching, implying something electrical in the frog-metal situation as a whole. Although Galvani and his nephew Aldini drew from these experiments erroneous conclusions involving "animal electricity," which were disputed by Volta in his metal-contact theory, it is significant from the instrumentation point of view that the frog's legs were unquestionably by far the most sensitive detector of metal-contact electrical effects available at the time. Without their intervention the development of this entire subject-area, including the creation of chemical cells, might have been delayed many years. Volta himself realized that the crucial test between his theory and that of Galvani required confirming the existence of metal-contact electricity by some electrical but nonphysiological detector. He performed this test successfully with an electroscope, using the "condensing" technique he had invented more than a decade earlier.

## Instrumenting Voltaic or Galvanic Electricity, 1800–1820

In his famous letter of March 20, 1800, written in French from Como, Italy, to the president of the Royal Society in London, Volta made the first public announcement of both his "pile" (the first English translator used the word "column"), and his "crown of cups" (the same translator used "chain of cups" for Volta's "couronne de tasses"). The former consisted of a vertical pile of circular disks, in which the sequence copper-zinc-pasteboard, was repeated 10 or 20 or even as many as 60 times, the pasteboard being moistened with salt water. The "crown of cups" could be most conveniently made with drinking glasses, said Volta, with separated inch-square plates of copper and zinc in salt water in each glass, the copper sheet in one glass being joined by some intermediate conductor and soldered joints to the zinc in the next glass.

Volta considered the "crown of cups" and the "pile" to be essentially identical, and as evidences of the electrical nature of the latter, said:

> . . . if it contains about 20 of these stories or couples of metal, it will be capable not only of emitting signs of electricity by Cavallo's electrometer, assisted by a condenser, beyond 10° or 15°, and of charging this condenser by mere contact so as to make it emit a spark, etc., but of giving to the fingers with which its extremities (the bottom and top of the column) have been touched several small shocks, more or less frequent, according as the touching has been repeated. Each of these shocks has a perfect resemblance to that slight shock experienced from a Leyden flask weakly charged, or a battery still more weakly charged, or a torpedo in an exceedingly languishing state, which imitates still better the effects of my apparatus by the series of repeated shocks which it can continually communicate.[4]

The "effects" provided by Volta's pile and crown-of-cups are therefore electroscope deflection, sparks, and shocks. Later in the letter, he describes the stimulation of sight, taste, and hearing as noted earlier, but nowhere does he mention chemical phenomena of any kind, or the heating of a wire joining the terminals of either device. Hence, except for the additional physiological responses, he adds nothing to the catalog of observations on which instruments might be based. His familiarity with the moods of the torpedo (electric eel) seems to be intimate.

The reading of Volta's letter to the Royal Society on June 26, 1800, its publication in the Society's *Philosophical Transactions* (in French) immediately thereafter, and its publication in English in the *Philosophical Magazine* for September 1800,[5] gave scientists throughout Europe an easily constructed and continuously operating electric generator with which innumerable new physical, chemical, and physiological experiments could be made. Editor-engineer William Nicholson read Volta's letter before its publication and, by the end of April, he and surgeon Anthony Carlisle had built a voltaic pile. Applying

---

[3] Abraham Bennet, *Philosophical Transactions of the Royal Society of London* (1787), p. 26.

[4] Op. cit. (footnote 1), p. 403.

[5] *Philosophical Magazine* (1800), vol. 7, pp. 289–311. [For a facsimile reprint, see *Galvani-Volta* (Bern Dibner's Burndy Library Publication No. 7), Norwalk, Connecticut, 1952.]

a drop of water to improve the "connection" of a wire lying on a metal plate, they happened to notice gas bubbles forming on the wire, and pursued the observation to the point of identifying the electrical decomposition of water into hydrogen and oxygen.

Within two or three years innumerable electrochemical reactions had been described, some of which, one might think, could have served as operating principles for electrical instruments. Although the phenomena of gas formation and metal deposition were in fact widely used as crude indicators of the polarity and relative strength of voltaic piles and chemical cells during the period 1800–1820 (and the gas bubbles were made the basis of a telegraph receiver by S. T. Soemmering), the quantitative laws of electrolysis were not worked out by Faraday until after 1830, and not until 1834 was he satisfied that the electrolytic decomposition of water was sufficiently well understood to be made the basis for a useful measuring instrument. Describing his water-electrolysis device in that year, he wrote:

> The instrument offers the only *actual measurer* [italics his] of voltaic electricity which we at present possess. For without being at all affected by variations in time or intensity, or alterations in the current itself, of any kind, or from any cause, or even of intermissions of actions, it takes note with accuracy of the quantity of electricity which has passed through it, and reveals that quantity by inspection; I have therefore named it a VOLTAELECTROMETER.[6]

In passing, Faraday commented that the efforts by Gay-Lussac and Thenard to use chemical decomposition as a "measure of the electricity of the voltaic pile" in 1811 had been premature because the "principles and precautions" involved were not then known. He also noted that the details of *metal deposition* in electrolysis were still not sufficiently understood to permit its use in an instrument.[7]

The heating of the wires in electric circuits must have been observed so early and so often with both electrostatic and voltaic apparatus, that no one has bothered to claim or trace priorities for this "effect." The production of incandescence, however, and the even more dramatic combustion or "explosion" of metal-foil strips and fine wires has a good deal of recorded history. Among the first to burn leaf metal with a voltaic pile was J. B. Tromsdorff of Erfurt who noted in 1801 the distinctly different colors of the flames produced by the various common metals. In the succeeding few years, Humphry Davy at the Royal Institution frequently, in his public lectures, showed wires glowing from electric current.

Early electrical instrumentation based on the heating effect took an unusual form. Shortly after 1800, W. H. Wollaston, an English M.D., learned a method for producing malleable platinum. He kept the process secret, and for several years enjoyed an extremely profitable monopoly in the sale of platinum crucibles, wire, and other objects. About 1810, he invented a technique for producing platinum wire as fine as a few millionths of an inch in diameter, that has since been known as "Wollaston wire." For several years preceding 1820, no other instrument could compare the "strengths" of two voltaic cells better than the test of the respective maximum lengths of this wire that they could heat to fusion. One can sympathize with Cumming's comment in 1821 about "the difficulty in soldering wires that are barely visible."[8]

## Electrical Instrumentation, 1800–1820

The 20 years following the announcement of the voltaic-pile invention were years of intense experimental activity with this device. Many new chemical elements were discovered, beginnings were made on the electrochemical series of the elements, the electric arc and incandescent platinum wires suggested the possibilities of electric lighting, and various electrochemical observations gave promise of other practical applications such as metal-refining, electroplating, and quantity production of certain gases. Investigators were keenly aware that all of the available means for measuring and comparing the *electrical* aspects of their experiments (however vaguely these "electrical aspects" may have been conceived), were slow, awkward, imprecise, and unreliable.

The atmosphere was such that prominent scientists everywhere were ready to pounce immediately on any reported discovery of a new electrical "effect," to explore its potentialities for instrumental purposes. Into this receptive environment came H. C. Oersted's

[6] MICHAEL FARADAY, *Experimental Researches in Electricity*, vol. I (London, 1839), paragraph 739, dated January 1834.
[7] Ibid., sec. 741.

[8] JAMES CUMMING, "On the Application of Magnetism as a Measure of Electricity," *Transactions of the Cambridge Philosophical Society* (1821), vol. 1, pp. 282–286. [Also published in *Philosophical Magazine* (1822), vol. 60, pp. 253–257.]

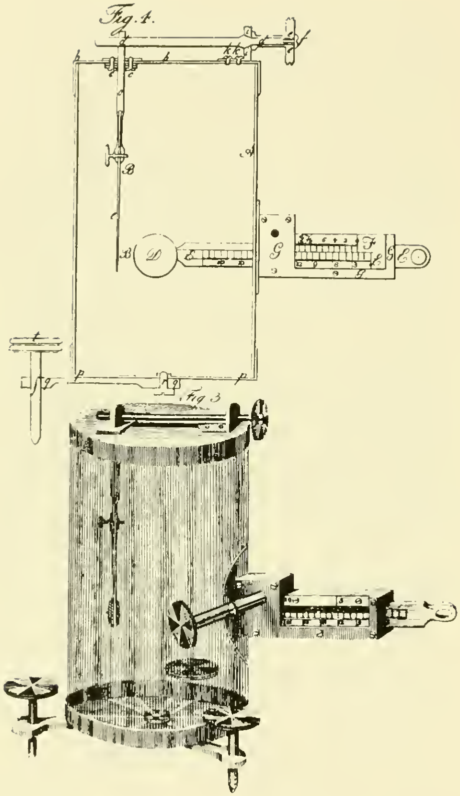


Figure 2.—"GALVANOMETER" WAS THE NAME given by Bischof to this goldleaf electrostatic instrument in 1802, 18 years before Ampère coupled the word with the use of Oersted's electromagnetic experiment as an indicating device.

announcement of the magnetic effects of a voltaic circuit, on July 21, 1820.[9]

## Oersted's Discovery

Many writers have expressed surprise that with all the use made of voltaic cells after 1800, including the enormous cells that produced the electric arc and vaporized wires, no one for 20 years happened to see a deflection of any of the inevitable nearby compass needles, which were a basic component of the scientific apparatus kept by any experimenter at this time. Yet so it happened. The surprise is still greater when one realizes that many of the contemporary natural philosophers were firmly persuaded, even in the absence of positive evidence, that there *must* be a connection between electricity and magnetism. Oersted himself held this latter opinion, and had been seeking electromagnetic relationships more or less deliberately for several years before he made his decisive observations.

His familiarity with the subject was such that he fully appreciated the immense importance of his discovery. This accounts for his employing a rather uncommon method of publication. Instead of submitting a letter to a scientific society or a report to the editor of a journal, he had privately printed a four-page pamphlet describing his results. This, he forwarded simultaneously to the learned societies and outstanding scientists all over Europe. Written in Latin, the paper was published in various journals in English, French, German, Italian and Danish during the next few weeks.[10]

In summary, he reported that a compass needle experienced deviations when placed near a wire connecting the terminals of a voltaic battery. He described fully how the direction and magnitude of the needle deflections varied with the relative position of the wire, and the polarity of the battery, and stated "From the preceding facts, we may likewise collect that this conflict performs circles . . . ." Oersted's comment that the voltaic apparatus used should "be strong enough to heat a metallic wire red hot" does not excuse the 20-year delay of the discovery.

## Beginnings of Electromagnetic Instrumentation

The mere locating of a compass needle above or below a suitably oriented portion of a voltaic circuit created an electrical instrument, the moment Oersted's "effect" became known, and it was to this basic

[9] H. C. OERSTED, *Experimenta Circa Effectum Conflictus Electrici in Acum Magneticam* (Copenhagen, July 21, 1820).

[10] Full details of Oersted's work and publications are in *Oersted and the Discovery of Electromagnetism* (Bern Dibner's Burndy Library Publication No. 18), Norwalk, Connecticut, 1961. The original Latin version and first English translation are reproduced in *Isis* (1928), vol. 34, pp. 435–444.

juxtaposition that Ampère quickly gave the name of galvanometer.[11] It cannot be said that the scientists of the day agreed that this instrument detected or measured "electric current," however. Volta himself had referred to the "current" in his original circuits, and Ampère used the word freely and confidently in his electrodynamic researches of 1820–1822, but Oersted did not use it first and many of the German physicists who followed up his work avoided it for several years. As late as 1832, Faraday could make only the rather noncommittal statement: "By current I mean anything progressive, whether it be a fluid of electricity or vibrations or generally progressive forces." [12]

Nevertheless, whatever the words or concepts they used, experimenters agreed that Oersted's apparatus provided a method of monitoring the "strength" of a voltaic circuit and a means of comparing, for example, one voltaic battery or circuit with another.

It was perfectly clear, from Oersted's pamphlet, that if a compass needle was deflected clockwise when the wire of a particular voltaic circuit lay above it in the magnetic meridian, the same needle would *also* be deflected clockwise if the wire was turned end-for-end and placed *below* the compass needle, without changing the rest of the circuit. Anyone perceiving this fact might deduce, as a matter of logic, that if the wire of the circuit was first passed above the needle, in the magnetic meridan, then folded and returned in a parallel path below the needle, the deflecting effect on the needle would be repeated, and a more sensitive indicator would result, assuming that any additional wire introduced has not affected the "circuit" excessively.

Since 1821, historical accounts of the origins of electromagnetism seem to have limited their credit assignments for the conception and observation of this electromagnetic "doubling" effect (or "multiplying" effect, if the folding is repeated) to three persons. Almost without exception, however, these accounts have given no specific information as to precisely what each of these three accomplished, what physical form their respective creations took, what experiments they performed, and what functional understanding they apparently had of the situation. The usual statement is simply that a compass needle was placed in a coil of wire.[13] The main purpose of the present review is to recount some of these details.

The following are the three candidates whose names are variously associated with the "invention" of the first constructed electromagnetic instrument, or "multiplier," or primitive galvanometer.

Johann Salomo Christoph Schweigger (1779–1857) in 1820 had already been editor for several years of the *Journal für Chemie und Physik*, and was professor of chemistry at the University of Halle.

Johann Christian Poggendorf (1796–1877) in 1820 had only recently entered the University of Berlin as a student following several years as an apothecary's apprentice and a brief period as an apothecary. Four years later, he succeeded Gilbert as editor of the influential *Annalen der Physik*, a position he held for more than 50 years.

James Cumming (1771–1861) in 1820 was professor of chemistry at Cambridge University.

## Chronology and Priority

The earliest established date in the "multiplier" record is September 16, 1820, when Schweigger read his first paper to the Natural Philosophy Society of Halle. There seems to be no reason to doubt that this report justifies the frequently used label "Schweigger's multiplier."

In an exuberant support of Schweigger's position, Speter [14] with no mention of Cumming and no hint of "invention" details, shows that Poggendorf in 1821 admitted Schweigger's priority, but suffered some lapse of memory 40 years later when writing sections of his biographical dictionary, leaving a distinct

[11] A. M. Ampère, *Annales de Chimie et de Physique* (1820), vol. 15, p. 67. The word "galvanometer" had been used much earlier by Bischof, "On Galvanism and its Medical Applications," *The Medical and Physical Journal* (1802), vol 7, p. 529, for a form of goldleaf electroscope shown here in figure 2, but this use of the word does not seem to have been adopted by others.

[12] Op. cit. (footnote 6), paragraph 283, dated January 1833. A similar attitude was expressed in the same year by Christie, *Philosophical Transactions of the Royal Society of London* (1833), vol. 123, p. 96: "I adopt the word current as a convenient mode of expression, . . . but I would not be considered as adopting any theoretical views on the subject. . . ."

[13] Some prominent examples of this brevity of treatment are in E. Hoppe, *Geschichte der Elektrizitat* (Leipzig, 1884); O. Mahr, *Geschichtliche Einzeldarstellungen aus der Elektrotechnik* (Berlin, 1941); R. S. Whipple, "The Evolution of the Galvonometer," *Journal of Scientific Instruments* (1934), vol. 7, pp. 37–43; William Sturgeon, *Scientific Researches* (Bury, 1850); A. W. Humphreys, "The Development of the Conception and Measurement of Electric Current," *Annals of Science* (1937), vol. 2, pp. 164–178.

[14] M. Speter, "Klärung der Multiplikator-Prioritätsfrage Schweigger-Poggendorf," *Zeitschrift für Instrumentenkunde* (1937) vol. 57, pp. 29–32.

suggestion that the invention was his. Further confusion for later generations resulted from some ambiguous entries in the *Allgemeine Deutsche Biographie* of 1888. The name "multiplier" seems not to have originated with Schweigger himself. Speter credits it to Meineke as "working" editor of Schweigger's *Journal*, but Seebeck seems to have used it much earlier.[15]

Conceding priority of conception to Schweigger (Cumming has not been a real competitor on this point) does not alter the fact that all three seem to have reached their results independently of one another, that the first work of each on this subject was published within a period of five months, that there were significant differences in their conceptions of the uses and the optimum design of their devices and that between them they provided an adequate foundation for the subsequent development of the galvanometer to become the primary electrical-measuring instrument.

In the matter of publication, Schweigger, as editor of what was popularly called Schweigger's *Journal*, had an obvious advantage, and presented his experiments beginnings on page 1 of the first volume of his *Journal* for 1821, published January 1 of that year.[16] Oersted's paper had appeared two volumes previously. He began by referring to Oersted's discovery as "the most interesting to be presented in a thousand years of the history of magnetism." He was, in fact, so impressed with the epochal nature of Oersted's achievement that he commemorated it by giving his *Journal* a second title so that "volume one" of the new title could begin in the year after Oersted's publication.

Poggendorf, as a relatively junior student, had no such easy access to publicity, but he had a staunch admirer in one of his professors, Paul Erman at the University of Berlin. Erman added a seven-page postscript on Poggendorf's invention to his book *Outline of the Physical Aspects of the Electro-chemical Magnetism Discovered by Professor Oersted*, published before April 1821,[17] with an introductory paragraph:

> Herr Poggendorf, who is one of the most excellent ornaments of the lecture room and laboratory of the University here, carried out a very coherent and well-conceived investigation of electro-chemical magnetism, leading step-by-step to a method of amplifying this activity-phenomenon by means of itself.

The postscript begins by referring to the "condenser [*Kondensator*] just brought to my attention by Herr Poggendorf" and explains that he cannot release his treatise "without preliminary announcement of this subject of the highest importance." (It can be inferred from the text that the name "condenser" was chosen because of the device's enhancing of magnetic measurements analogously to the enhancing of electric measurements by Volta's electrostatic "condenser.")

Immediately on reading the book, Schweigger published extracts, mainly of the postcript, with indignant comments on Erman's remissness (or worse) in having failed to mention Schweigger's prior work.[18]

However, Erman was not alone in his unawareness, if it was that, of Schweigger's discovery.

Rival editor Gilbert of the *Annalen der Physik* reviewed Erman at much greater length than Schweigger, reprinting most of the postscript with evident enthusiasm, and stating in his preamble that the invention is attributed to "a young physicist studying here in Berlin, Herr Poggendorf." [19] Only in a footnote is the reader directed to another footnote in the next article in the volume, where Gilbert finally states that he "cannot leave unmentioned the fact that this amplifying apparatus seems to be due to Herr Professor Schweigger." He then quotes rather fully from Schweigger's first two papers. [16] Oersted in 1823 explained the situation thus: "The work of M. Poggendorf, having been mentioned in a book

[15] T. SEEBECK, "Über den Magnetismus der Galvanischen Kette," *Abhandlungen der Koenigliche Akademie der Wissenschaften zu Berlin* (1820–1821), pp. 289–346. The phrase "Schweigger's multiplier" is used on page 319. The many experiments described in this paper added little or nothing to contemporary appreciation of the multiplier as an instrument.

[16] J. S. C. SCHWEIGGER, *Journal für Chemie and Physik* (1821), vol. 31, pp. 1–18, 35–42. Pages 1–6 are the paper presented in Halle on September 16, 1820; pages 7–18 are the paper presented in Halle on November 4, 1820, and pages 35–42 are "a few additional words." The preface to the whole volume is dated January 1, 1821. A somewhat earlier public announcement referring to Schweigger's discovery appeared in the *Allgemeine Literatur-Zeitung* (November 1820), no. 296, cols. 622–624, but this was lacking in detail and seems not to have been noticed by any scientists.

[17] P. ERMAN, *Umrisse zu den physischen Verhältnissen des von Herrn Prof. Oersted entdeckten elektro-chemischen Magnetismus* (Berlin, 1821). Hoppe (footnote 13) states that Erman's book was published in May; however, it is referred to in a letter dated April 3, 1821, by RASCHIG, *Annalen der Physik* (1821), vol. 67, pp. 427–436.

[18] Op. cit. (footnote 16), vol 32, pp. 38–50.

[19] *Annalen der Physik* (1821), vol. 67, pp. 382–426, and footnote on pages 429–430 of same volume. The footnote accompanies the article by Raschig mentioned in footnote 17.

on electromagnetism by the celebrated M. Erman published very shortly after its discovery, became known to many scientists before that of M. Schweigger. This is the reason for the same apparatus carrying different names."[20]

The same confusion is well illustrated by the paper to which Gilbert attached his confessional footnote mentioned above. Written by Professor Raschig of Dresden, on April 3, 1821, the paper is entitled "Experiments with the Electro-magnetic Multiplier," but the device, throughout the paper, is repeatedly referred to in the phrase "Poggendorf's condenser, or rather multiplier," an awkward combination that suggests editorial intervention.[21]

The work of James Cumming at Cambridge is described in two papers which he read to the Cambridge Philosophical Society in 1821, which were then duly published in the *Transactions* of that Society. The first, "On the Connexion of Galvanism and Magnetism," was read April 2, 1821,[22] and the second, "On the Application of Magnetism as a Measure of Electricity," was read a few weeks later on May 21st.[23]

Though he quotes some unrelated 18th-century experiments by Ritter in Germany, an 1807 publication of Oersted's, and electromagnetic experiments with solenoids performed by Arago and Ampère in late 1820, Cumming makes no mention of Schweigger or Poggendorf, and never uses the word "multiplier." It, therefore, seems probable that his work was done without knowledge of the German publications or inventions.

## Original Electromagnetic Multipliers

Of the three sets of instruments made, respectively, by Schweigger, Poggendorf and Cumming, those of Schweigger are the most elementary, and the least realistic from a practical point of view. He makes little effort to investigate the effect of any design parameters, but presents some odd conductor configurations that involve unimportant variations of the basic principle. The following extracts from his first three papers[15] contain the major references to his conception, construction, and use of his multiplier.

PAPER READ IN HALLE, SEPTEMBER 16, 1820

That a powerful voltaic pile is required for these experiments (of Oersted) I have confirmed in my physics lectures, using an electric pile that was so strong it would easily produce potassium metal the second and third day after it was built. However, I soon saw that the electromagnetic effect was related, not to the pile, but to the simple circuit, and I was thereby led to perform the experiment with much greater sensitivity. To amplify these electromagnetic phenomena of the simple circuit it seemed to me necessary to adopt a different arrangement from that initiated by Volta, in order that the electrical phenomena of his simple circuit might be raised to a higher degree.

Since a reversal of the effect occurs according to whether the connecting-wire lies over or under the needle, and likewise according to whether the wire leads from the positive or negative pole, thence I say it is an easy inference that a doubling of the effect is attainable, which is verified in practice.

I present to the Society the simple "doubling apparatus" [*Verdoppelungs-Apparat*], where the compass is placed between two wires passing around it. A multiplication of the effect is easily obtained when the wire is not just once but many times wound around. A single turn suffices, however, to demonstrate Oersted's experiments, using small strips of zinc and copper dipped in ammonium-chloride solution.

Amid innumerable, rambling theorizations (such as, that "hydrogenation affects magnetism as oxidation affects galvanism," or "sulphur, phosphorous and carbon are especially significant in magnetism, since iron in combination with any of these inflammable materials becomes a magnet-material"), Schweigger announces that he looked for the reactive force of the needle on the connecting wire in the simple Oersted experiment, and that he used his "amplifying apparatus" to look for magnetic effects from an electrostatic machine, but without success in both cases. He suggests that he will continue with many more electromagnetic experiments because "with the use of the doubling-apparatus, the needle, instead of needing for excitation a cell capable of generating sparks, approaches more closely the sensitivity of a twitching nerve." However, "additional special experiments are required to find to what limits the amplification can be increased by the method I have created in the construction of this doubling-apparatus, using multiple turns of wire."

[20] H. C. Oersted, "Sur le Multiplier electro-magnetique de M. Schweigger, et sur quelques applications qu'on en a faites," *Annales de Chimie et de Physique* (1823), vol. 22, pp. 358–365.

[21] "Versuche mit dem electrisch-magnetischen Multiplicator," *Annalen der Physik* (1821), vol. 67, pp. 427–436.

[22] *Transactions of the Cambridge Philosophical Society* (1821), vol. 1, pp. 269–278.

[23] Op. cit. (footnote 8).



224-527—67——9

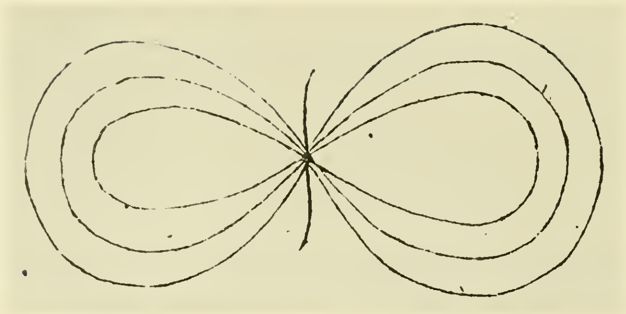

Figure 3.—THIS WIRE "BOW-PATTERN" was the first illustration Schweigger gave of his "doubling apparatus," though he had presented a verbal description of a single-coil arrangement somewhat earlier. The purpose of the bow pattern was to show that compass needles at the centers of the two loops deflected in opposite directions. (From *Journal für Chemie und Physik.*)

PAPER READ IN HALLE, NOVEMBER 4, 1820

[The first half of this paper describes successful observations of the reaction-force of a magnetic needle on the connecting wire of a voltaic circuit, achieved by pivoting the connecting wire in the form of brass needles above and below the compass needle. Though the multiplier configuration of needle and wire is in fact present here, Schweigger does not mention it, evidently regarding this as a separate project. He continues.]

> In my lecture of September 16th, I showed that Oersted's results depend, not on the voltaic cell, but only on the connecting circuit. The principle I have used for amplification of the effects, for the construction of an electromagnetic battery as it were, was the winding of wire around the compass, and I now present to the Society a bow-pattern of multiple-wound, wax-insulated wire, Figure 3." [There were no illustrations with Schweigger's first paper.] "While a single wire, using the weak electric circuit here, deflects the magnetic needle only 30° or 40°, if the compass is placed in one of the openings of this pattern, the needle is deflected 90° to the east, or in the other opening 90° to the west, using the same weak electric circuit . . . .

The "bow-pattern" device has novelty interest only, adding nothing to the elucidation of the multiplier phenomenon. The same is true of Schweigger's next proposal, shown in figure 4. ". . . I will now add another apparatus, which is just an extension of the previous one, whereby the needle can take up any angle from 0° to 180°." A short length of circular glass tubing, of inside diameter large enough to contain a compass needle, stands with its axis vertical and has single or multiple loops of wire wound on it in vertical diametral planes. In the illustration, successive plane coils are inclined at 30° to one another. ". . . the electric current flows through the whole wire, and the needle moves under all of these currents, and coming always into another loop can take any desired angle."

With much further theorizing about "the correlation of magnetism with the cohesion of bodies," Schweigger states again his evaluation of his discovery: "Oersted succeeded in electromagnetic research by using a spark-producing cell, which could make a wire glow. My amplifying electromagnetic device needs only a weak circuit of copper, zinc, and ammonium chloride solution." [24]

[24] The German work *Kette* has been translated as "circuit" throughout. Although the equivalence of these words is clear, for example, in Ohm's work of 1826, the context in which *Kette* is sometimes used in 1820 and 1821 indicates that the concept of a "circuit," in the sense of the wiring external to the source of electricity, has not been established. The wiring is regarded more as something incidental, used to "close" the cell, the cell being considered essentially the whole of the apparatus. This view underlies the many attempts to correlate the Oersted phenomena with cell materials and design, and with the use of such terms as "chemical magnetism" by Erman and others.

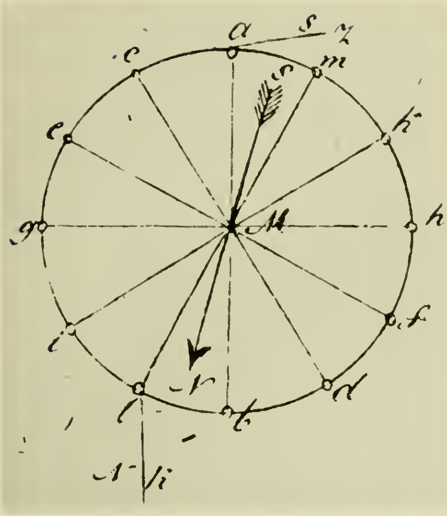


Figure 4.—Schweigger made this peculiar construction of wire coils, wound endwise on a short vertical section of glass tubing with a compass needle inside, merely to startle his Halle audience with the fact that the compass needle could rest in any of several stable positions. (From *Journal für Chemie und Physik.*)

## "FURTHER WORDS ABOUT THE NEW MAGNETIC PHENOMENA"

[This was presumably written between November 4, 1820, and the January 1, 1821, publication date of his *Journal.*]

These wonderful new electrical effects[25] are most easily rendered perceptible with the help of the previously described wire loops. To focus attention on just one of the windings of Figure 3, we sketch a new drawing, Figure 5 . . . . Since it is of major importance that these loops be made of silk-covered wire lying evenly on one another, it is convenient to wind the loops on two small slotted sticks of wood, although it is also possible to hold the wires together with wax or shellac, or to tie them together in an orderly manner with silk thread . . . .

In Figure 5, Aa and Cc represent little slotted rods of wood on which the silk-covered wire is wound. Only three windings are shown in the figure, but I generally adopt three times that many. Now t is connected with the copper and d with the zinc, and the compass B set between the rods Aa and Cc with the coil perpendicular to the magnetic meridian and the terminals d, t at the east.

The instant Z and K are dipped in the ammonium chloride solution, the needle turns around and stays with the north pole point south . . . .

If now the compass is taken out of the coil and put in position b, all effects are reversed, and are considerably weaker, for obvious reasons . . . .

[25] The reference here is to the Oersted-type experiments described in two papers by authors other than Schweigger on pages 19 to 34 of the volume.

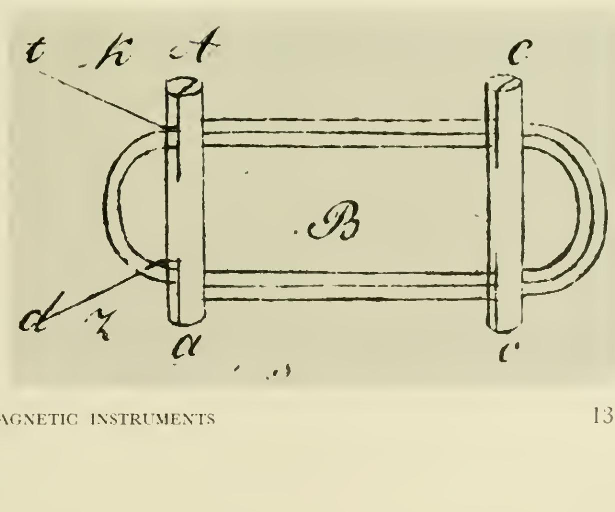


Figure 5.—Schweigger's suggestion of one possible design for an amplifying electromagnetic indicator. The components are wooden rods and insulated wire. Position b referred to in the text is at the bottom of the diagram between the letters a and c. (From *Journal für Chemie und Physik.*)

It is of the same significance whether we bring the compass from B to b in Figure 5, or from mesh 1 to mesh 2 in Figure 3, only that in the latter case, because the compass is enclosed by the two sides, a stronger effect results . . . .

If now the coil is rotated . . . so that the face previously north now faces south, then on connecting the electric circuit there is absolutely no trace of effect on the needle, assuming that the terminal wires are not reversed . . . .

It seems unnecessary to note that our magnetic coil can be placed in the direction of the magnetic meridian or at any arbitrary angle with it . . . .

Following several pages of further talk about the relation of "cohesion to magnetism" and about "unipolar and bipolar conductors," the only additional item of interest is the observation that discharges of a Leyden jar (*Kleistichen Flasche*) strong enough to burn strips of leaf gold and to magnetize an iron rod in a coil, produced no compass-needle deflections, even with the help of the "amplifying apparatus."

Schweigger, therefore, described the basic multiplier idea clearly enough in his first paper, but offered no sketch of the simplest construction until the third paper. In the second paper, meanwhile, he had illustrated two peculiar designs involving the principle in less elementary ways.

His indifference to whether the wire loops lie *in* the magnetic meridian (fig. 3) or perpendicular to it (fig. 5) or "at any other arbitrary angle to it," reveals a poor appreciation of the measuring-instrument potentialities. His conception seems to be primarily that of a detector.

Poggendorf's invention, as first reported by Erman and presented to a wider audience by Gilbert [26] was described as consisting of typically 40 to 50 turns of $\frac{1}{10}$-line diameter, silk-covered copper wire tied tightly together, with the whole pressed laterally to form an elliptical opening in which a pivoted compass needle could move freely while maintaining clearance of about 2 lines from the wire at all points.[27]

"This magnetic condenser can be a great boon to electro-chemistry," said Erman, for "it avoids all the difficulties of electric condensers." He noted that, using the condenser, Poggendorf had already established the electric series for a great number of bodies, discovered various anomalies about conductivities, and found a way of detecting dissymmetry of the poles of a compass needle. On the other hand, even with the condenser, no magnetic effects have so far been obtainable from a strong tourmaline, or from a 12,000-pair, Zamboni dry cell.

[26] Op. cit. (footnote 19), pp. 422–426.

[27] One "line" seems to have been about $\frac{1}{12}$ inch.

Poggendorf's own account of his work finally appeared as a very long article in the journal known as "Oken's Isis." [28] The editorial controversies mentioned earlier may have occasioned this use of a periodical of such minor status in the fields of physics and chemistry.

The source of Poggendorf's vision of the multiplier principle was a little different from Schweigger's inspiration. Aiming at some detailed analysis of Oersted's observation, Poggendorf ran the connecting wire of his cell-circuit along a vertical line to just above or below the pivot-point of the compass needle, then, after a right-angle bend, horizontally above or below one of the poles of the needle. As he studied the deflections produced for all four possible positions of such a wire, with both cell polarities, he came to realize that if a rectangular wire loop in a vertical plane enclosed a compass needle, all parts of the horizontal sides of the loop would produce additive deflections. By a separate experiment, he showed that the vertical sides of the loop would also increase the deflections. He saw at the same time that the effect of additional turns would be cumulative.

The multiple surrounding of the needle by a silk-covered wire, in a plane perpendicular to the long axis of the needle, affords the physicist a very simple and sensitive means of detecting the slightest trace of galvanism, or of magnetism produced by it, so that I have given the name of magnetic condenser to this construction, though I attach no special value to this name . . . .

In analyzing the astonishingly increased power which the condenser gives to the magnetic effect of a circuit, the first question that arises is how the effect varies with the number of turns, whether it increases indefinitely or reaches a maximum beyond which additional turns have no effect. The answer to this first question is linked to the solution of another, viz, whether the degrees deflection are a direct expression of the measure of the magnetic force or not.

To instruct myself on this point I made use of three separate circuits, each containing an 8-turn condenser, and put these as close together as possible in the magnetic

[28] J. G. Poggendorf, "Physisch-chemische Untersuchungen zur näheren Kenntniss des Magnetismus der voltaischen Säule," *Isis von Oken* (1821), vol. 8, pp. 687–710. Most of Poggendorf's numerical data is also in C. H. Pfaff, *Der Elektromagnetismus* (Hamburg, 1824), along with some of Pfaff's own work.

meridian . . . with the needle between the windings. Each single circuit . . . gave a deflection of 45° . . . . When two were connected the deflection was 60°, and when finally all three were put in magnetic operation, the deflection grew to only 70°. It appears clearly from this that the angle of deflection is not in a simple ratio with the magnetic force acting on the needle . . . .

Neither Poggendorf nor Schweigger seems to have ruled out, on logical grounds alone, the possibility of deflections greater than 90°, with the loop-plane in the magnetic meridian, though Poggendorf does add a vague note that if the needle deflected too far it would encounter forces of the opposing sign.

Poggendorf experimented with the size of the circuit wires, finding that larger wires led to greater deflections. He noted that the size of the cell plates and the nature of the cell's moist conductors would certainly have a great effect, but that to investigate these in detail would take undue time, and he therefore proposed to keep this part of the apparatus constant, using one pair of zinc and copper plates 3.6 inches in diameter, separated by cloth soaked in ammonium-chloride solution.

Poggendorf's principal quantitative study of his magnetic condenser used 13 identical coils, each with 100 turns. In order that the turns should all be at approximately the same distance from the needle, the coils were wound of the finest brass wire that could be silk-insulated, the wire diameter being 0.02 lines. On adding coils one at a time across the cell (i.e., connecting them in parallel), the deflections were as follows:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Turns | 100 | 200 | 300 | 400 | 500 | 600 | 700 |
| Deflection in degrees | 45 | 50 | 55 | 59–60 | 62 | 63 | 64 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Turns | 800 | 900 | 1000 | 1100 | 1200 | 1300 |
| Deflection in degrees | 65 | 65½ | 66 | 66 | 66 | 66 |

Adding some coils with fewer turns, and connecting various combinations "as a *continuum*" (i.e., in series), the deflections using the same cell were:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Turns | 1 | 5 | 10 | 25 | 50 | 75 | 100 | 200 |
| Deflection in degrees | 10 | 22 | 27 | 30 | 35–40 | 40 | 40 | 40 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Turns | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| Deflection in degrees | 40 | 40 | 41 | 40 | 40 | 40 | 40 | 40 |

Making a few coils from wire with 1/8-line diameter, the deflections, again using the same cell were:

| | | | | | |
|---|---|---|---|---|---|
| Turns | 5 | 25 | 50 | 100 | Over 100 |
| Deflection in degrees | 20 22 | 40 45 | 45 | 65 | 65 |

Since the needle used in these experiments was almost as long as the inside clearance of the coils, no simple tangent law can be applied, and it is not possible to discover an equivalent circuit in modern terms. However, the constancy of the deflections for large numbers of turns in each case indicates that the cell voltage and resistance were fairly constant, and a rough estimate suggests that the cell resistance was comparable to the resistance of one of the 100-turn coils of fine wire. Such a value means that cell resistance limited the maximum deflections for the parallel-connected multipliers, while coil resistance fixed the limit in the series case.

For all of these reasons, it was impossible that any useful functional law could be obtained from the data.

Poggendorf concluded only that "the amplifying power of the condenser does not increase without limit, but has a maximum value dependent on the conditions of plate area and wire size." He added two other significant comments derived from various observations, that the basic Oersted phenomenon is independent of the earth's magnetism, and that the phenomenon is localized, i.e., is not affected by distant parts of the circuit.

Only a small fraction of Poggendorf's paper is devoted to elucidating the properties of the condenser. A similar amount is concerned with refuting various proposals, such as those of Berzelius and Erman, about distributions of magnetic polarity in a conducting wire to account for Oersted's results. More than half of the paper describes results obtained by using the condenser to compare conductivities and cell polarities under conditions where no effect had previously been detectable. Notable is the observation of needle deflections in circuits whose connecting wires are interrupted by pieces of graphite, manganese dioxide, various sulphur compounds, etc., materials which had previously been considered as insulators in galvanic circuits. Poggendorf gives these the name of "semi-conductor" (*halb-Leiter*).

Cumming's first mention of the multiplier phenomenon, in his paper of April 2, 1921, [22] is quite casual, and describes only a one-turn construction. He speaks first of single-turn ring of thick, brass wire, and after

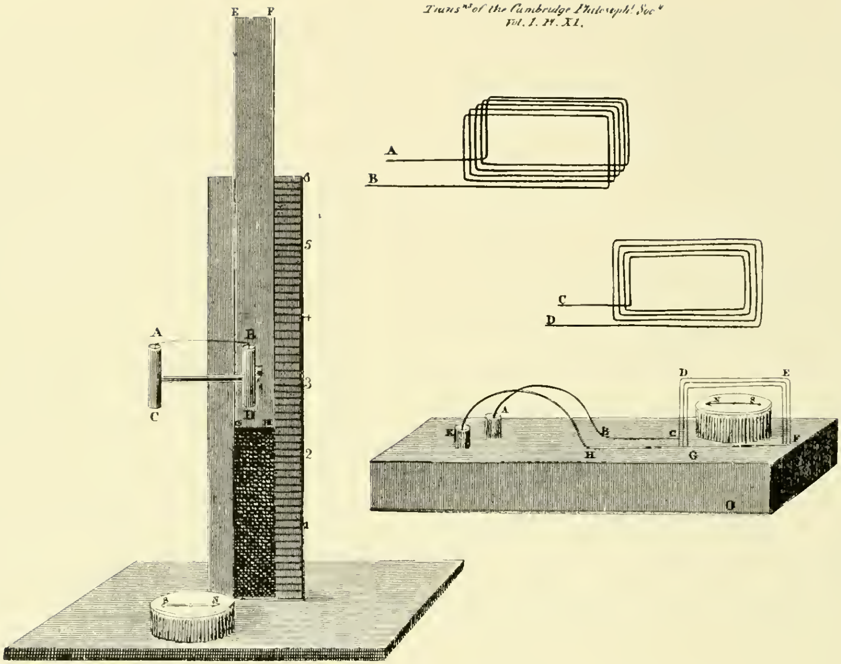


Figure 6.—Electromagnetic instruments of James Cumming, used at Cambridge in 1821. One is a single-wire "galvanometer," following Ampère's definition. Cumming called the multiple-turn construction "galvanoscopes." He showed how to increase their sensitivity by partial cancellation of the earth's magnetism at the location of the compass needle. (From *Transactions of the Cambridge Philosophical Society*, vol. 1, 1821.)

noting that the sides of a circuit produce additive effects on a needle, he comments that a flattened rectangular loop produces nearly quadruple the effect of a single wire. The paper is primarily a review of Oersted's work, with references to electromagnetic observations before Oersted, and accounts of various related but nonmultiplier experiments that Cumming has made. His second paper, of May 21st, contains a fine plate (fig. 6) illustrating arrangements used in investigating the subject of the paper's title "The Application of Magnetism as a Measure of Electricity." (Neither Poggendorf nor any of his commentators ever illustrated his "condenser.")

Although this plate is never referred to in the paper itself, a nearby "Description" gives a few comments. The two wire patterns shown are noted as simply "forms of spiral for increasing the electromagnetic intensity." The mounted wire loop, with enclosed compass needle and terminal mercury cups, is clearly identical in principle with the devices of Schweigger and Poggendorf, and is called a "galvanoscope." The largest structure illustrated does not involve the multiplying effect. It is called a "galvanometer," consistent with Ampère's definition of that word. To use it, two leads of a voltaic circuit are inserted into the mercury cups AC and BD, and the board EFGH carrying the cups is moved vertically until some "standard" deflection is obtained on the compass needle below. The relative "strength" of the circuit is then given by the calibrated position of the sliding section. Uncertainties are undoubtedly introduced by the arbitrary positions of the connecting wires from the test circuit to the mercury cups, but Cumming drew some interesting conclusions from various measurements he made.

Observing needle deflections for various positions of the wire A-B, with a "constant" voltaic circuit, he found that "the tangent of the deviation varies inversely as the distance of the connecting wire from the magnetic needle." Here is a combination of the deflection law for a needle in a transverse horizontal field and the magnetic-force law for a long, straight wire. The latter had been determined experimentally by Biot and Savart, in November 1820, by timing the oscillations of a suspended magnet.[29]

Cumming considers his straight-wire calibrated "galvanometer" to be a device for "measuring" galvanic electricity; on the other hand, his multiple-loop "galvanoscopes" are for "discovering" galvanic electricity. With the multiplier instrument, he found galvanic effects (i.e., needle deflections) using copper and zinc electrodes with several acids not previously known to create galvanic action. A potassium-mercury amalgam electrode created a powerful cell with zinc as the positive electrode, establishing both the metallic nature of potassium and the fact that it is the most negative of all metals.

In a third paper, presented April 28, 1823,[30] Cumming reports use of the galvanoscope in experiments on the thermoelectric phenomena recently discovered by Seebeck. His note that "for the more minute effects a compass was employed in the galvanoscope, having its terrestrial magnetism neutralized . . ." seems to be the earliest mention of this version of the astatic principle, a technique whose dramatic effects were especially valuable in low-resistance thermoelectire circuits, where the extra resistance of additional multiplier turns largely offsets their magnetic contribution. In detail, "the needle is neutralized by placing a powerful magnet North and South on a line with its center; and another, which is much weaker, East and West at some distance above it: by means of the first the needle is placed nearly at right angles to the meridian, and the adjustment is completed by the second."

On varying the length of the connecting wire of the circuit, Cumming found the deflections of the multiplier needle to be in a nearly reciprocal relation. He speaks of the "conducting power of the wire," and seems not far from visualizing Ohm's law, of which no published form appeared until 1826. Ohm's own experiments were made with very similar apparatus.

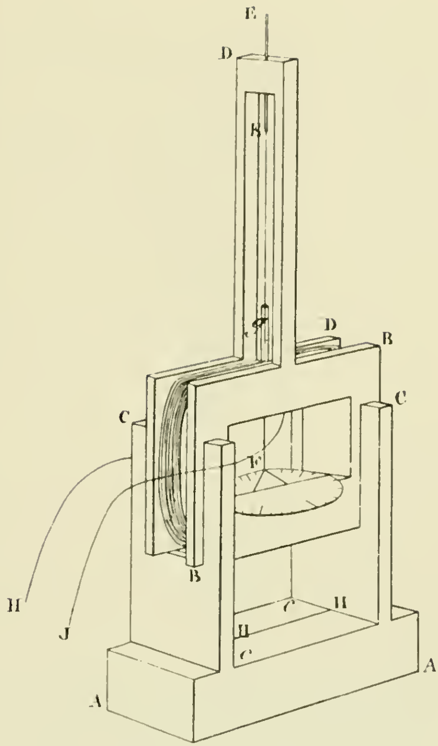


Figure 7.—"Schweigger multiplier" used by Oersted in 1823. A thin magnetic needle is held in a light, paper sling at F, suspended by a fine, vertical fiber. (From *Annales de Chimie et de Physique*.)

## Conclusions

An effort has been made to show that electrical experimenters prior to Oersted's discovery in 1820 were in desperate need of some electrical instrument for galvanic or voltaic circuits that would combine sensitivity, simplicity, reliability, and quick response.

[29] Reported in *Annales de Chimie et de Physique* (1820), vol. 15, pp. 222–223.

[30] "On the Development of Electro-Magnetism by Heat," *Transactions of the Cambridge Philosophical Society* (1823), vol. 2, pp. 47–76.

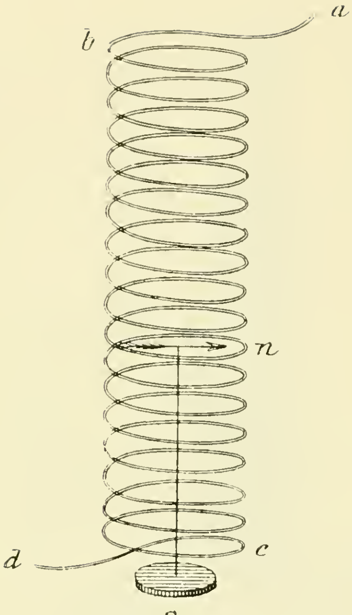


Figure 8.—Completely useless arrangement of vertical coil and horizontal, unmagnetized needle, presented in the *Edinburgh Philosophical Journal* of 1821 as "Poggendorf's Galvano-Magnetic Condenser." Almost every aspect of Poggendorf's instrument has been incorrectly represented.

The nearly simultaneous creation by Schweigger, Poggendorf and Cumming of an arrangement consisting of a coil of wire and a compass needle provided the first primitive version of a device to fill that need.

It appears that Schweigger is clearly entitled to credit for absolute priority in the discovery, but the original sources suggest that both his understanding of the device and the subsequent researches he performed with it were markedly inferior to those of the other independent discoverers. In using the generic label, "Schweigger's Multiplier," there have been historical examples of attributing to Schweigger considerably more sophistication than is justified. Figure 7 shows an instrument designed by Oersted in 1823,[20] which he says "differs in only minor particulars from that of M. Schweigger." On comparing figure 7 with figures 3, 4, or 5, the remark seems overly generous.

The history of the multiplier instruments has had its fair share of erroneous reports and misleading clues. A fine example is the illustration of figure 8, taken from what is often quoted as the first report in English on Poggendorf's "Galvano-Magnetic Condenser."[31] The sketch is the editor's interpretation of a verbal description given him by a visiting Danish chemist who, in turn, had received the information in a letter from Oersted. It incorporates, faithful to the description, a "spiral wire . . . established vertically," with a needle "in the axis of the spiral," yet by misunderstanding of the axial relations and of the ratio of length to diameter for the coil, a completely meaningless arragnement has resulted. The confusion is compounded by the specifying of an *unmagnetized* needle.

Schweigger and Poggendorf, through their editorial positions, were among the best known of all European scientists for several decades. On one basis or another their reputations are firmly established. Comparison of the accounts of the early "multipliers," however, suggests that the Reverend James Cumming, professor of chemistry at the University of Cambridge, was a very perceptive philosopher. This was well understood by G. T. Bettany who wrote in the *Dictionary of National Biography* that Cumming's early papers "though extremely unpretentious," were "landmarks in electromagnetism and thermoelectricity," and concluded that: "Had he been more ambitious and of less uncertain health, his clearness and grasp and his great aptitude for research might have carried him into the front rank of discoverers."

---

[31] "Account of the New Galvano-Magnetic Condenser invented by M. Poggendorf of Berlin," *Edinburgh Philosophical Journal* (July 1821), vol. 5, pp. 112–113.

ACKNOWLEDGMENTS

I wish to thank Dr. Robert P. Multhauf, chairman of the Department of Science and Technology in the Smithsonian Institution's Museum of History and Technology, for encouragement in the writing of this paper and for the provision of opportunity to consult the appropriate sources. To Dr. W. James King of the American Institute of Physic, I am grateful for many provocative discussions on this and related topics.

U S GOVERNMENT PRINTING OFFICE: 1964

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 20 cents