# Opening the Circuit to the Body, more Options, and Ambiguity:
## *Charles Grafton Page's Experiment with a Spiral Conductor*

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### Introduction

By the mid-nineteenth century, telegraph lines linked cities and towns in Europe and in America but in 1836, the relevant electrical technologies were emergent. There were no telegraph systems, no packaged batteries, no pre-insulated wire, no switches and no standardized electrical parts. An intense period of prototype telegraphy and electromagnetic apparatus was just commencing at the hands of a loosely-knit diverse community of innovators. The following year, Charles Wheatstone and William Cooke in London, and Samuel Morse and Leonard Gale in Washington demonstrated electromagnetic telegraphy in public; and in related work Nicholas Callan in Ireland, William Sturgeon in London, and Charles Grafton Page near Boston produced streams of sparks and strong shocks with small battery-run electromagnetic coils that they switched by hand-crank.[1] The telegraph inventors' notoriety grew with the commercial interests in information transport, while the coil experimenters' names passed from view.

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[1] Ken Beauchamp, *History of Telegraphy*, (London, 2001); David Paul Hochfelder, "Taming the Lightning: American Telegraphy as a Revolutionary Technology, 1832-1860", Dissertation, Case Western Reserve University, 1999); Elizabeth. Cavicchi, "Nineteenth century developments in coiled instruments and experiences with electromagnetic induction", *Annals of Science* 63 (2006): 319-61.

More than the other makers of prototype coils, Charles Grafton Page (Figure 1) moved into the next era: developing original electromagnetic machines; collaborating with Boston instrument-maker Daniel Davis junior in their manufacture; critiquing and supporting others' inventions through his position as US Patent Examiner, and even starring as key witness in the 1848 Morse *vs* O'Reilly lawsuit. Political connections cultivated after Page's 1838 relocation from Salem Massachusetts to Washington DC advanced his inventive aspirations. A US Senate allocation of $20,000 launched his electromagnetically powered locomotive whose fortunes ended with its beleaguered 1851 test run. Still, in the final year of his life he appealed directly – and successfully -- to the US Congress for a retrospective patent on his foundational yet rudimentary spiral device of 1836 and his subsequent double coils. The "Page Patent", sweepingly interpreted to cover circuit breakers and other essential telegraphic apparatus, garnered a fortune for Page's heirs and ill will from the telegraphic community.[2]

[2] Robert C. Post, *Physics, Patents & Politics: a biography of Charles Grafton Page* (New York, 1976); "The Page Locomotive: Federal Sponsorship of Invention in Mid-19th-Century America", *Technology and Culture* 13 (1972): 140-69; "Stray Sparks from the Induction Coil: The Volta Prize and the Page Patent," *Proceedings of the IEEE* 64 (1976): 1279-86. Telegrapher's irate views on the Page patent are represented in "The Page Patent – The Attempts to Enforce it to be Resisted", *Scientific American* 27 (October 26, 1872) APS Online p. 256.

**Figure 1. Charles Grafton Page.**

This paper explores Page's 1836 explorations of a spiraled conductor during his student days. By reconfiguring the spiral circuit in novel ways, Page gained access to electrical effects not identified before. Lacking explanations of these effects, Page worked within an environment of *ambiguity*.

To respect ambiguity within research is a way of retaining connectedness between what is learned as knowledge, and processes of learning involving bodily engagement. Such connectedness fractures where science/mind/product is elevated above technology/body/process. Historical neglect of Page's contributions is one resulting outcome. Page's biographer Robert Post dissents from this tradition of neglect. He reinterprets the absence of abstract theoretical claims in Page's writing as evidence of his awareness of "the baffling complexity of things", rather than showing any deficiency.[3] This paper studies Page's experimentation with spiral conductors and argues that ambiguity in understanding phenomena, amplified by the inherent ambiguity of the experimenter's body, can itself become a source of inventive creativity.

My approach to exploring ambiguity is to engage with historical accounts and real materials similar to those that Page might have encountered. I constructed experiments similar to those Page describes and attempted to observe some of the phenomena that Page reports. What he tried, felt, inferred, and went on to do are presented here alongside my own experiments done with similar materials in an educational lab.[4] I too encountered ambiguous behavior while redoing some of Page's test cases. Although my activities differ from Page's in many respects, confusions that arose for me deepened my involvement with his experiment. Some of these observations pertain to the role of the experimenter's body.

Formalized accounts of science often omit the role of the human body. A reader might miss textual clues to bodily involvement. Bodily usages of the past become evident when historians conduct research by redoing old experiments that put their present bodies into relations with materials.[5] Going beyond the limits of texts, these researchers reconstruct apparatus along with the bodily coordination needed to use them; similarly in this study, historical texts and experimental observations provide mutually informative resources.

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[3] Quote from Charles and Mary Beard, *The Rise of American Civilization*, 1940, appearing in Post, *Physics, Patents & Politics* 27.

[4] The Edgerton Center at MIT provided a supportive environment through James Bales' active encouragement. Thomas Cavicchi, Chen Pang Yeang, and Markus Zahn discussed my experiment's analysis; Alva Couch wrote plot programs; Grant Suter, Lourenco Pires, Wayne Ryan, Ed Moriarty, Anthony J. Caloggero, Fred Cote and the Edgerton Center staff provided technical support.

[5] W.T.S. Tarver's reconstruction of a medieval siege engine demonstrated that to launch a volley of rocks, a volunteer crew needed to pull their ropes in rhythm ;W. T. S. Tarver, "The Traction Trebuchet: A Reconstruction of an Early Medieval Siege Engine", *Technology and Culture* (1995): 136-67. Performing bodily motions in the complete darkness critical for astronomical observation proved more challenging to Klaus Staubermann than operating a nineteenth century telescope photometer; Klaus Staubermann, "Controlling Vision—The Photometry of Karl Friedrich Zöllner", Dissertation, Darwin College, Cambridge UK 1998. Suspecting that his body's electrical charge affected a needle within his replicated Coulomb torsion balance, Peter Heering encased it in a Faraday cage; Peter Heering, "The replication of the torsion balance experiment: The inverse square law and its refutation by early 19th century German physicists," in Christine Blondel and Matthias Dörries, *Restaging Coulomb: Usages, Controverses et Réplications autour de la balance de torsion*, (Florence Italy 1994). An alternative replication of the Coulomb experiment is Alberto Martinez, "Replication of Coulomb's Torsion Balance Experiment", *Archive for History of Exact Sciences* 60 (2006): 517-63.

Cultural mores about bodies and knowledge accompany any experimental use of a body, often imposing contradictory or complex messages. Christopher Lawrence and Steven Shapin's collection of scientific biographies, *Science Incarnate*, illustrates how such contrasting stances are managed.[6] They found that while research was ongoing, cultural practices functioned to protect a scientist's body and health. But once that research became public, the culture regarded any bodily role in knowledge production as degrading, and suppressed its record. The knowledge product split from its originating process. In parallel, the mind's achievement shed its bodily form. Shapin interprets this product-process/mind-body divide as a concerted act of Western culture, having longstanding roots in Greek philosophers' denial of bodily needs and in Christian asceticism. To disembody knowledge meant to elevate its status and impart to it "truth, objectivity and potency". With this elevation of knowledge went a "cultural portrayal" of investigators' bodies as impediments to the search for truth.[7] The split between 'pure' knowledge and base means of production widened as American scientific culture professionalized in the decades after Page's death. Regarding a professional's pure intent as demonstrated by willingness to undergo bodily harm, this culture accentuated the privilege accompanying bodily denial.[8]

Early publications about electromagnetism reflect the unbalancing effects of this dichotomous tradition. Parisian academician André-Marie Ampère structured his publications around circuital analysis, not around his confused explorations.[9] British mathematical instructor Peter Barlow propounded "the law of electromagnetism", [10] yet it yielded nothing practical. Others demurred from exclusive formalism, such as the author of the text Page studied as a Harvard undergraduate: "I have thought it proper to give the observations of M. Ampère, without adopting his explanation".[11] The cultural bias for rendering knowledge as explanation might not override the "insufficient data" and uncertainties that electromagnetism presented.

This paper follows Page in taking these uncertainties into his hands literally, grasping with each hand a conductor of unknown electrical intensity. Through his senses came new findings about electricity; his actions educed previously untested options for configuring and probing a circuit.

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[6] Christopher Lawrence and Steven Shapin, *Science Incarnate: Historical Embodiments of Natural Knowledge*, (Chicago, 1998).

[7] Steven Shapin, "The Philosopher and the Chicken: On the Dietetics of Disembodied Knowledge", in Lawrence and Shapin, 21-50, quotes p. 23.

[8] According to Rebecca Herzig's analysis of this later period, a scientific man's freely chosen submission to bodily suffering during research was viewed as advancing both pure science and his status, whereas harm incurred by involuntary, low-status subjects benefited neither science nor themselves; Rebecca Herzig, *Suffering for Science: Reason and Sacrifice in Modern America*, (New Brunswick NJ, 2005).

[9] For Ampère's initial exploratory process, see Friedrich Steinle, "The Practice of Studying Practice: Analyzing Research Records of Ampère and Faraday," in *Reworking the Bench: Research Notebooks in the History of Science*, Frederic L Homes, Jürgen Renn and Hans-Jörg Rheinberger, eds., (Boston, 2003), 93-117; Ampère's publications include: "Mémoire…le 2 octobre 1820.." *Annales de Chimie et de Physique* 15 (1820): 59-76; *Exposé…sur L'électricité et le Magnétisme*, (Paris, 1822).

[10] Peter Barlow, *Magnetic Attractions…and the laws of Electromagnetism*, (London, 1824), 232.

[11] Post, *Physics, Patents & Politics* (n. 2 above), 14 notes that Page studied from the Cambridge Physics text; John Farrar, *Elements of Electricity, Magnetism, Electromagnetism*, (Cambridge, 1826), 362-3. Other early texts which downplay Barlow's law and instead emphasized electromagnetic apparatus and effects include Francis Watkins, *A popular sketch of electro-magnetism, or electro-dynamics*, (London, 1828) and P. M. Roget, *Electricity, galvanism, magnetism, and electro-magnetism*, (London, 1831) who wrote "nothing illustrates more forcibly the proneness of the human mind to draw general conclusions from insufficient data, than the various opinions so confidently maintained …on this subject [electromagnetism]" (p. 2).

Page's body, crucial in initial phases of experimenting, assumed a lesser role as he revised apparatus using other means to detect electricity. Yet this reduction in bodily usage did not remove experimental ambiguity for either Page or me. Ambiguity emerged as a link between Page's world and mine, seeding openings for research with more questions and experimental options to explore.

Below, I revisit the accounts of Charles Grafton Page's investigations of electromagnetic phenomena, how he engaged with materials, and how his body played a role in the experimental process. Interwoven with this story, I report my own observations in repeating his experiments or similar ones, and describe how that helped me understand his experimental understandings. Throughout this study, confusions, ambiguity, and a willingness to use the body as an instrument contributed both to discovery and innovation. My questioning into how knowing relates to processes of knowing underlies this exploratory discussion.

**Practices of Putting the Body in the Galvanic Circuit**

Eighteenth century Italian investigators used body parts to complete their circuits of dissimilar metals and moist substances. While everything stayed in contact, these bodies reacted unmistakably, exhibiting a newfound electricity. Luigi Galvani regarded the frog leg's twitch as an electricity originating in life processes. Convinced otherwise, Alessandro Volta substituted a sensitive instrument for the frog and still detected electricity. But Volta soon realized that this instrument's internal materials produced some of the electricity it detected. By stacking metals and liquids in analogy to the electric fish's anatomy, Volta eventually constructed a chemical battery whose enhanced potency he demonstrated by using only himself to close its circle.[12] The body was back in Volta's circuit, but he viewed its function as only to manifest shock, not to generate it.

Putting the body in the circuit made it subject to excesses. Germans Alexander von Humboldt and Johann Ritter increasingly focused on their own bodily capacity for electrical stimulation. Each intrusively probed their body's limits to pain by plunging electrodes into scalpel incisions, open wounds, and the eye. These ordeals were self-inflicted and self-examined. Ritter felt at unity with electrical nature, but this achievement came at too excruciating a cost for public access or assessment.[13]

Through medicine, the body gained more acceptable routes into the electrical circuit. Electricity discharged by eighteenth-century friction machines was widely used for nervous disorders. As voltaic electricity became available around 1800, it was tested clinically. In contrast with friction-generated electricity, the lower tension (voltage) and greater quantity (current) of voltaic electricity made it more difficult and risky to administer.[14] Wounds were imposed on patients'

[12] Giuliano Pancaldi, *Volta: Science and Culture in the Age of Enlightenment*, (Princeton, 2003), 183.
[13] For the self-experimenting of Humboldt and Ritter, see Stuart Strickland, "The Ideology of Self-Knowledge and the Practice of Self-Experimentation", *Eighteenth-Century Studies* 31 (1998): 453-71; Michael Dettelbach, "The Face of Nature: Precise Measurement, Mapping, and Sensibility in the Work of Alexander von Humboldt", *Studies in History and Philosophy of Biology and Biomedical Science* 30 (1999): 473-504; Roberto de Andrade Martins, "Orsted, Ritter and Magnetochemistry", in *Hans Christian Oersted and the Romantic Quest for Unity: Ideas, Disciplines, Practices*, Boston Studies in the Philosophy of Science, 241, R.M. Brain and O. Knudsen, eds. (forthcoming).
[14]See the essays in *Electric Bodies: Episodes in the history of medical electricity*, P. Bertucci and G. Pancaldi, eds. (Bologna, 2001); on eighteenth century practices: Paula Bertucci, "The Electrical Body of Knowledge: Medical Electricity and Experimental Philosophy in the Mid-Eighteenth Century" and Oliver Hochadel, "`My Patient told me how to do it': The Practice of Medical Electricity in the German

bodies to receive electrodes and circumvent the body's high surface resistance. British surgeon Charles Wilkinson innovated the more humane placement of metal discs (attached to electrodes) over moist skin. [15] The standardization of this technique spawned specialized implements for body parts and orifices.

An experimenter's own body provided the most convenient detector of electricity, but sometimes this detection was inadvertent. British amateur Mr. William Jenkins got shocked upon disconnecting a battery from a coiled helix whose ends he grasped in either hand. He had not expected this; experimenters working with direct current ordinarily felt no shock. Jenkins told Michael Faraday. Faraday realized it related to his seminal 1831 finding that a changing current induces currents in nearby separate conductors. But the case manifested by Jenkins' shock was different: the changing current acts on *itself* and induces another current in that *same* wire which exhibits *differing* electrical properties. Faraday explained how the body's reception of that shock depended on good contact:

> "On holding the two copper handles tightly in the hands, previously moistened with brine, and then alternately making and breaking the contact of the ends of the helix with the electro-motor [*battery*], there was a considerable electric shock felt…"[16]

As French physicians reintroduced the Chinese method of acupuncture into Western medical practice, the electric circuit intruded further into bodies.[17] Since acupuncture sometimes felt like shocks, the French interpreted its needle "as a true lightning rod" accessing the body's inherent electricity. They extended traditional practice by attaching a voltaic pile's terminals to acupuncture needles that convulsed tissue intervening between them. [18] While Page was in medical school, these techniques gained notice in America: "acupuncture is entitled to far more attention than it has yet received in the United States".[19]

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Enlightenment"; on first uses of continuous electricity: Marco Bresaldo, "Early Galvanism as a Technique and Medical Practice".

[15]"Shilling"-sized electrodes are described in Charles H. Wilkinson, *Elements of Galvanism in Theory and Practice* (London, 1804) 2, 444.

[16] Michael Faraday, "On the Magneto-electric Spark and Shock, and on a peculiar Condition of Electric and Magneto-electric Induction", *Philosophical Magazine* 5 (1834): 349-54, quote 351. Faraday's Ninth Series expands this work as "On the influence by induction of an Electric Current on itself:-- and on the inductive action of Electric Currents generally", (1835), in *Experimental Researches in Electricity* (London, 1839). Also see Iwan Morus, *Frankenstein's Children: Electricity, Exhibition, and Experiment in Early-Nineteenth-Century London* (Princeton, 1998), 61-7. Faraday reported that Jenkins's observation was the only case in which an amateur provided him with a worthy subject of research.

[17] Lu Gwei-Djen and Joseph Needham, *Celestial Lancets: A History and Rationale of Acupuncture and Moxa* (London, 1980/2002), 295-302.

[18] Quote from M. Morand, *Memoir on Acupuncturation*, Franklin Bache, trans. (Paris-Philadelphia, 1825), 30. Cloquet's electrification of the needles is described in Morand, 36. The introduction of "electropuncture" is attributed to Jules Cloquet, Jean Baptist Sarlandière and Fabré-Palaprat in 1825 by Lu Gwei-Djen and Needham, and by Margaret Rowbottom and Charles Susskind, *Electricity and Medicine: History of Their Interaction* (San Francisco, 1984). Boston physician William Channing credited it to M. Berlioz, in 1816, *Notes on the Medical Application of Electricity* (Boston, 1849).

[19] Quote from William Markley Lee, "Acupuncture as a Remedy for Rhuematism", *Boston Medical and Surgical Journal* 15 (September 14, 1836): 85-7; reprinted from the *Southern Medical and Surgical Journal* 1 (1836): 129-33. Other contemporary American discussions of acupuncture as a method of galvanic medicine included a summary of Pouillet's work, "On the Electromagnetic Phenomena observed in Acupuncture", *Boston Medical Intelligencer* 3 (November 1, 1825), APS Online p. 98 and Robert Peter's address to the Lexington KY Medical Society, "On the application of galvanic electricity to medicine", *Transylvania Journal of Medicine and the Associate Sciences* 9 (Oct.-Dec. 1836) APS Online p. 641.

When Page put his body into the copper spiral's circuit, he applied these experimental and medical practices in new ways. Like Faraday and Jenkins, Page took the shock hand-to-hand directly through his body's core, improving contact with salt solutions. In some configurations of his test circuit, Page barely felt the shocks, so he amplified his sensitivity by plunging needles into his fingertips. Without either the therapeutic intent, or the direct battery current, which characterized medical "electropuncture" techniques, Page's experimental use of these needles was innovative.[20] No other detector than his body would as compellingly report the marginally observable electricity induced in the spiral's outer regions.

Although Page used his own body experimentally, he regarded the spiral as a potential medical tool. Completing a Harvard medical degree at the time, he actively participated in the local medical community.[21] He sent a one-paragraph notice about his research on "Medical Application of Galvanism" to the *Boston Medical and Surgical Journal*.[22] Without disclosing the apparatus' spiral design, Page promoted its suitability for a French electropuncture technique where needles burned flesh between them, or transmitted medicines.[23] In doing so, he demonstrated conversancy in novel treatments that were outside conventional medical instruction.[24] A medical journal based in Atlanta, Georgia registered frustrated interest in Page's vague wording. The Boston journal republished the southern medical society's query and its offer of a fifty-dollar premium for such a device. Page never responded in print.[25]

Bodies and circuits combined in fluid relation. That relation shifted from Galvani's assumption that the frogs' twitching originated within their bodies, to Volta's exploitation of shock to demonstrate his pile, to Ritter's obsession with his body's reactions. With voltaic electricity's expanding use, experimenters like Faraday routinely took shocks to check their circuit and clinicians applied it in therapies. As Page drew on both these experimental and therapeutic practices, he participated in the trend toward direct involving the body in its medical treatment that Michel Foucault has identified.[26] Eighteenth century doctors diagnosed without touching patients. French physician Bichat broke from this tradition by establishing diagnosis criteria that related pathologies inside patients' bodies to a disease's usual progression, as charted through autopsies. Devices like Page's spiral intervened further by directing electricity into the body.[27]

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[20] C. G. Page, "Method of increasing shocks, and experiments, with Prof. Henry's apparatus for obtaining sparks and shocks from the Calorimotor", *American Journal of Science* 31 (January 1837): 137-141. Acupuncture needles were available in Boston at that period from medical instrument supplier Charles White, *Boston Medical and Surgical Journal* (predecessor of *New England Journal of Medicine*) 1 (April 1, 1828) APS Online p.112.

[21] Praise of Page's electromagnetic inventions and teaching of a chemistry course in chemistry appeared in the *Boston Medical and Surgical Journal* April 26, 1837, 195 and November 22, 1837, 256.

[22] Page's letter to the editor of the *Boston Medical and Surgical Journal,* dated June 18, 1836, appeared in the issue of June 22, 1836, "Medical Application of Galvanism", 333. His second notice in that journal was "Insect Dissections", issue of July 13, 1836, 364-5.

[23] Page referred to "M. Palabrat's discovery …transmission of remedial substances…" in his letter, 333; Fabré Palaprat described his electropuncture technique in Michael La Beaume, *Du galvanisme appliqué à la médicine et de son efficacité dans le traitment…* (Paris 1828) 36-61. William Channing summarized it in his *Notes on the Medical Application of Electricity* (Boston, 1849) 38-9.

[24] Joseph Eve, "Medical Education", *Southern Medical and Surgical Journal* 1 (1836): 216-23

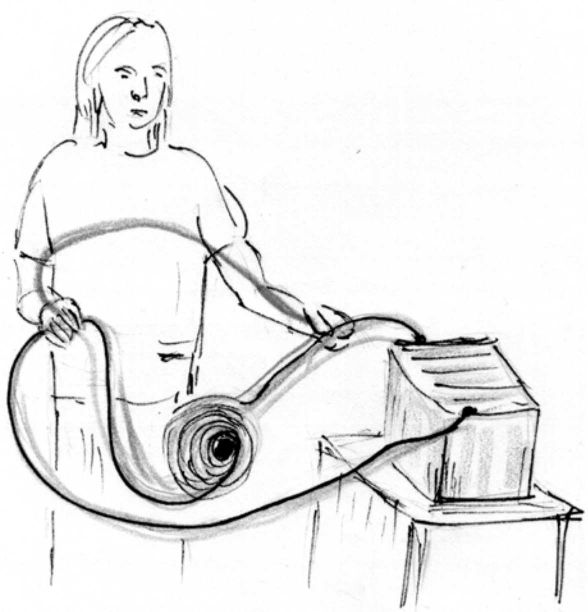
[25] Charles Grafton Page, "Medical application of Galvanism", *Southern Medical and Surgical Journal*, 1 (1836): 183-5; an excerpt reprinted in *Boston Medical and Surgical Journal* (September 21, 1836): 113. The Medical Society of Augusta Georgia offered a $50. premium for the invention of a convenient instrument for medical galvanism.

[26] Michel Foucault, *The Birth of the Clinic: An Archaeology of Medical Perception* (London. 1973; French original 1963).

[27] Page, "Medical application of Galvanism", 183.

**Opening up the Spiral's Options**
Page constructed his apparatus with many extra connectors inserted along the extent of its spiraled conductor. This design was innovative. Usually each connector in an electrical device joined one pre-specified battery terminal to complete a fixed circuit. By contrast, Page's design accommodated flexible possibilities for connection, resulting in circuits with multiple loops. As Page began to realize and extend more of these options while researching them, intriguing new electrical phenomena arose.

The simplest circuits have one loop, such as the loop running from one end of Volta's pile where he held it, through his body to where he held the pile's opposite end in his other hand. Adding on a second loop produces a total of three loops along which electricity can pass, as Mr. Jenkins' unexpected shock (see above) demonstrated. The first loop consisted of a coil connected across a voltaic cell; the second loop added his body across that cell (Figure 2). During steady current flow in the first loop, the body's high resistance kept current in this second loop to an imperceptible level. But when the switch opened, battery current stopped going in the first loop and instead current arose in a third loop -- the loop uniting body and coil. In Faraday's interpretation, the ceasing current in the first loop's coil induced "a counter current" of high enough intensity (voltage) to pass through the body and shock it.[28] If no body was present to provide a third loop, this high intensity electricity sparked through the switch's air gap, briefly re-completing the first loop.



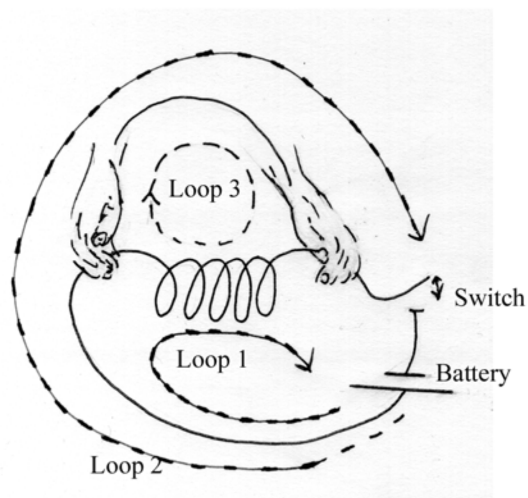



**Figure 2. Left: A person holding both ends of a coil feels shock when the coil breaks its connection to the battery. Right: current traverses Loop 1, from the trough battery, through the spiral or coil, and back. The person adds a second Loop 2, running from battery and then through their body. When the switch opens, the shock takes Loop 3, running between the person and the coil.**

[28] Michael Faraday, "On the Magneto-electric Spark and Shock, and on a peculiar Condition of Electric and Magneto-electric Induction", *Philosophical Magazine* 5 (1834): 349-54, quote p. 351.

When Princeton professor Joseph Henry read Faraday's first report about getting shocked from opening a circuit, he felt defrauded. His own prior, but rudimentary, observation was not acknowledged. Faraday's report prodded Henry to investigate it. Henry found that substituting a spiraled copper ribbon for Faraday's wire coil intensified the shock. Anxious not to lose more ground to Faraday, Henry hastily published a brief notice saying that the spiral increased shocks "to an extent not yet determined". [29]

This claim, that Henry made for the spiral caught Page's eye. Page improvised with materials at hand. Lacking copper ribbon, he constructed strips from four sheets of copper, two foot square. He did this by alternately cutting partway into each sheet from opposite ends and then unfolding from it a single, zigzaged 55' strip (Figure 3). The strip then had to be bent over itself at each reversal, to bring it into a line, but this was preferable to soldering potentially fallible joints between many short segments. Page joined the four strips end to end. He spiraled the whole with fabric insulation. At 220' in length, Page's first spiral more than doubled the length of Henry's.

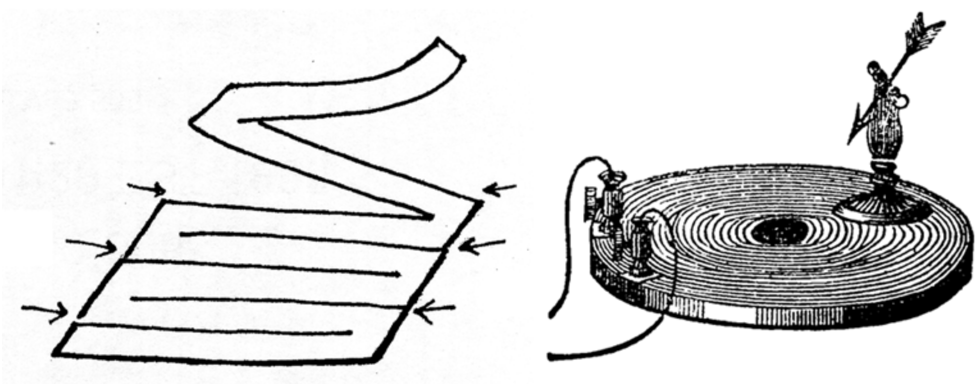


**Figure 3. Left: My diagram of the Page's method of slitting a copper sheet from opposite sides (arrows) so that it would open as a zig-zag strip. Right: A spiral later made for sale ($.75 to $1.00) by Page's collaborator Daniel Davis Jr. The terminals connect to the spiral's inner and outer ends and the arrow is a magnetic compass. From Davis' *Catalogue of Apparatus,* (Boston, 1848), Fig. 112, p. 23.**

At each joint between strips, Page soldered supports for the thimble mercury-filled cups then used for electrical connections. The staggering of these cups at different radial positions provided diverse options for connecting the spiral with battery and body. By contrast, in the circuits of Faraday and Henry, only the entire conductor (coil or spiral) could be connected to the battery and body (Figure 4). To test a longer (or shorter) conductor required substituting a different

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[29] Joseph Henry (later the Smithsonian's first director) first observed the heightened electricity occurring when a coil's battery connection broke, while working with his great electromagnet: "On the Production of Currents and Sparks of Electricity from Magnetism", *American Journal of Science* 22 (1832): 403-8; reprinted in *The Scientific Writings of Joseph Henry* (Washington DC, 1886) vol. 1. Joseph Henry's formal publication is "On the Influence of a Spiral Conductor in increasing the Intensity of Electricity from a Galvanic Arrangement of a Single Pair", *American Philosophical Society Transactions* (1837): 223-31; reprinted in *The Scientific Writings of Joseph Henry* (Washington DC, 1886) vol. 1. Henry presented his work with the spiral on February 6, 1835, but his full paper was not published until 1837. To secure credit for Henry while Faraday was publishing related work, Alexander Bache composed an abstract "Facts in reference to the Spark, &c. from a long conductor uniting the poles of a Galvanic Battery" by Joseph Henry for immediate publication in the *Journal of the Franklin Institute* (March 1835): 169-70, and *American Journal of Science* 28 (July 1835): 327-9, along with a brief "Appendix to the above", also by Henry, 329-31. Quote p. 328.

one. With Page's intermediately placed cups, the same conductor could bear current along a short or long segments.

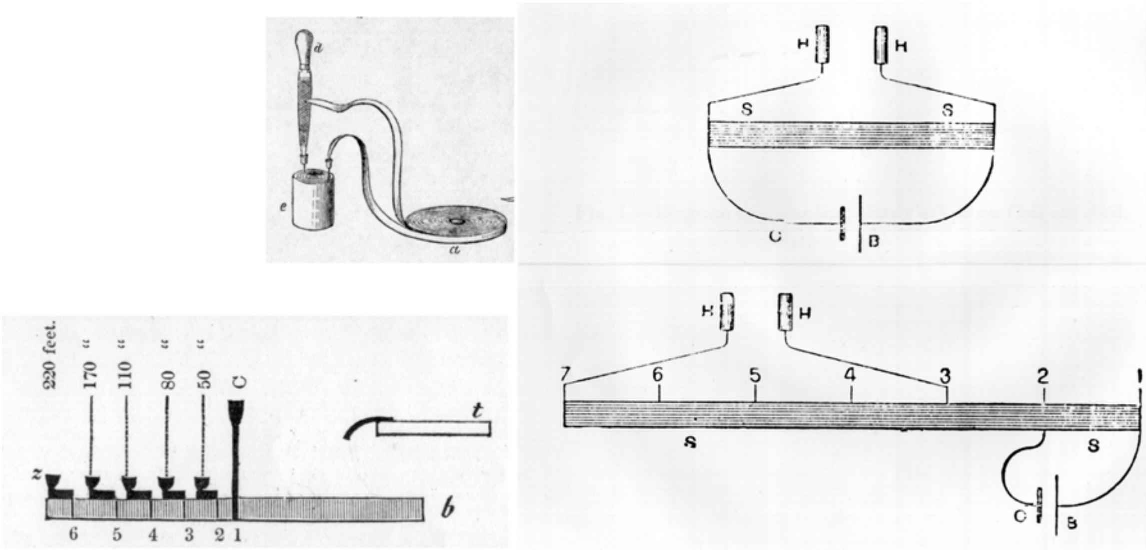


**Figure 4. Left Top: Henry's sketch of his spiral, battery, and rasp interrupter, from his 'Contributions to Electricity and Magnetism: On Electro-Dynamic Induction' No. III, *Transactions of the American Philosophical Society* 6 (1839), 303-337, fig. 1, 304. Left Bottom: side view of Page's spiral showing connector cups spaced across its length, from his paper (n. 20), 137. Right Top: Henry's spiral unwound; the shock is taken across the handles *HH*, while the battery is applied across the same span. Right Bottom: Page's spiral unwound; the shock may be taken across parts of the spiral that may differ from the segment carrying the battery current. From J. A. Fleming, *The alternate current transformer in theory and practice*, (London, 1892) vol. 2, p. 6, Figs. 1 and 2.**

Page explored the effect of extending the span of the spiral that current traversed. Fixing one battery terminal on the innermost cup (1), he immersed the other battery terminal briefly in the next cup (2). On removing it, he observed sparks. He repeated the same procedure for each mercury cup in succession (cups 2 through 6). At cup 3, the sparks flared brightest and electricity snapped loudest. Adding more segments (at cups 4, 5, 6) diminished the spark and snap. In a footnote, Page suggested soldering cups on every turn in the spiral to "accurately" determine the turnaround in spark brightness.[30]

Setting up the apparatus to take shocks was more complicated than watching sparks, and the comparative findings came out different. Page grasped in each hand a metal handle having a prong that dipped into a mercury cup. Since his hands were occupied, he needed an assistant to open the circuit by removing the outermost battery terminal from its cup. Page kept one hand in cup 1, where the inner battery terminal stayed. Page put the other hand in each mercury cup in succession (2 through 6). As the assistant raised the terminal from each of these cups, Page experienced shocks of increasing severity. Unlike sparks whose brightness peaked with half the spiral in the battery loop, shocks strengthened as that loop extended out to the entire spiral.

Page then perceived another set of experimental options. The battery's connectors and the body's connectors could be inserted across *different* spans of the spiral, independent of each other. On

[30] Page (n.20 above), 138.

testing these configurations, Page obtained outcomes that startled him even more: "curious …difficult to explain".[31]

First, he put the battery's connectors only across the spiral's inner turns (cups 1 and 2). One hand grip remained always at the inner cup (cup 1); the other was placed at each of the other cups in turn. The loop defined by the battery connections remained fixed; the loop passing through his body traversed more of the spiral. When the battery connection broke, Page reported a greater shock than if his hands spanned just the cups that took the battery current. This shock increased as his hands encompassed more of the spiral. The instrument delivered its greatest shock when the battery current traversed half the spiral (from cup 1 to 4) while his hands spanned it all (from cup 1 to 6). The lesser shock produced when current passed throughout the spiral suggested to Page that in other cases, spiral turns beyond the current's path operated electrically by some means which he termed "lateral cooperation".[32]

Page was further astonished by what happened next. "Contrary to expectation", upon stopping battery current through the inner turns (cups 1 and 3), he felt shock while his hands spanned *only* the outer ones (4 and 6). The shock was so feeble that Page amplified his sensitivity to an "extremely painful" level by piercing needle conductors into his thumb and finger.[33] This electropuncture technique enabled Page to reduce the battery to a modest size from a great "calorimotor" like Henry's that output high currents.[34]

Something was happening even where no direct current had passed. Whatever it was, it differed from direct battery current which gave no shocks. Page checked that this was so by putting a small part of his body *in series* with the battery's high current – omitting the spiral. Inserting "fine needles deep into the thumb and fore finger", Page restricted the current path to one hand and did not pass it across his heart.[35] He felt nothing. But the sudden stopping of current within the spiral gave rise to a momentary electricity of high enough intensity to shock a body placed across it.

Page regarded the spiral *plus* voltaic cell as a multipurpose "battery, from which shocks of all grades can be obtained".[36] Its compact size made it practical for traveling physicians, unlike the large friction machines that were otherwise needed to administer high tension shocks. Page improved his instrument's function by innovating the first contact breaker, a rotating switch that repetitively made and broke the circuit as its tines spun in and out of mercury. The intermittent sparks where switch tines left the mercury shone with beautiful color in the dark, but the successive flurry of its shocks could be intolerable (Figure 11).[37]

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[31] Ibid., 139.
[32] Ibid., 139.
[33] Page did not specify the dimensions of his initial "calorimotor". Page followed Henry's preliminary notice, which was vaguely worded in recommending "one of Dr. Hare's Calorimotors"; Henry, "Facts in reference to the Spark, &c." (n. 29 above), 329. Henry later stated that he employed one pair of large plates having 1.5 square feet of zinc surface area; Henry, "On the Influence of a Spiral Conductor" (n. 29 above), 224. See Elizabeth Cavicchi, "Sparks, Shocks and Voltage Traces as Windows into Experience: The Spiraled Conductor and Star Wheel Interrupter of Charles Grafton Page", *Archives des Sciences* 28 (2005): 123-36, 125.
[34] Page (n.20 above), 141.
[35] Ibid., 140.
[36] Ibid., 141.
[37] Page's spur wheel was an adaptation of Barlow's wheel, first described by Peter Barlow in "A curious electro-magnetic Experiment", *Philosophical Magazine* 59 (1822): 241-2.

Encountering behaviors which genuinely surprised him, Page explored them productively while lacking explanations or other guides. Starting with a circuit which was already the forefront research of Faraday and Henry, Page took it further by opening it up and comparatively probing its internal and external paths. Functioning as conductor, detector, and potential beneficiary, his body was part of the expanded circuit and at the same time an agent of change in the experiment. The knowledge that Page generated kept his experiment going, providing means by which he tried new tests, invented apparatus, and compared observations.

## Reconstruction: Spiraled Copper Tape and its Confusing Signals

As Page started out by redoing what he understood of Joseph Henry's experiment, so I began from my preliminary grasp of his. While Page and Henry shared similar materials, practices and interpretations, I was an outsider. I sought to redo physical effects as a common ground, where my questions and understandings could grow in relation to Page's. The spiral's heightened electricity intrigued both of us, but we saw that differently. Page valued shock as a treatment and experimental tool that he did not hesitate to take it himself. My curiosity about high self-induced voltages originated in my physics background. I never considered taking the shock – or needing to know about its effects. [38]

Guided by my interest in the physical effects. I did not seek to rebuild Page's spiral in its original dimensions. I found in something premade an electrical analog to it: the copper tape of stained glass artists. Its conductive foil spirals outward in an unbroken path, while its paper backing insulates successive turns. At intervals along the spiral, I soldered copper strips like Page's cup supports. In place of mercury cups, I used alligator clipleads to connect my spiral to other apparatus. Two *D* cell flashlight batteries or a 3 V power supply substituted for Page's "calorimotor" and a mechanical switch broke the circuit (Figure 5). My spiral's compactly wound foil was inductively responsive to weaker currents than the amperes of early calorimotors.

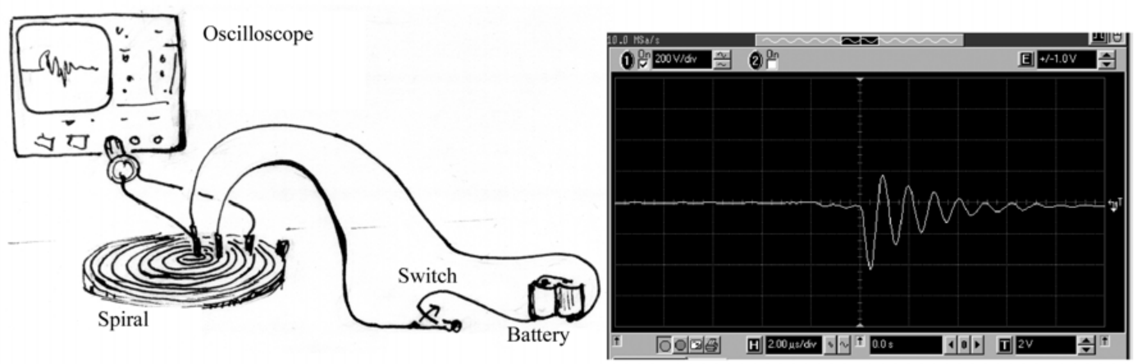


**Figure 5. Left: in my test circuit, the battery connects across part of the spiral via a switch, while a high voltage probe from the oscilloscope connects across another spiral interval. Right: A typical oscilloscope screen image showing voltage (vertical) induced in the spiral when the switch opens.**

To see what happened electrically when current stopped flowing in my spiral, I connected probes from a storage oscilloscope across various parts of the circuit. [39] On the oscilloscope screen, I

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[38] On safety issues with shock, see William Butterfield, "Electric Shock—Safety Factors When Used for the Aversive Conditioning of Humans", *Behavior Therapy* 6 (1975): 98-110.
[39] I worked with the following storage oscilloscopes in successive phases of my study: HP 54600B; Lecroy 9450A; HP Infinium 54810A.

observed each transient event as a trace line overlaying a grid whose horizontal axis is time, and vertical is voltage. A typical trace shows a voltage spike of several hundred volts, followed by lesser peaks declining within a damped envelope and having periodicity in the microsecond range (Figure 5, right).

Page was taken aback by the spiral's behaviors but I thought I knew what to do and expect. For example, to redo the configuration whose shocks most astonished Page, I inserted the oscilloscope probe across intervals entirely outside the current's direct path. The small voltage spikes that appeared on the screen when I switched the current off accorded with my expectation that the voltages would be less than when the probe covers current-bearing intervals. Where ever Page reported a shock that heightened as his body spanned more spiral turns (both current-bearing and not), I placed probes across comparable intervals in my spiral and looked for an increase in the peak values of voltage. But my expectation, that the voltage peaks would clearly rise with each inclusion of more spiral turns in the probe's span, was not borne out in observation. Instead, the voltage peaks vary widely, sometimes greater, sometimes not. Even when I keep the probe fixed in place and simply open the switch repeatedly, these peaks vary.

This variability holds my interest as I explore the spiral's electrical properties during more than 90 lab sessions across four years. My analytic and instrumental methods evolve continually. I started by using an analogue oscilloscope and sketching voltage traces by hand. Moving over to a digital oscilloscope made it possible to save the trace data as files of paired time and voltage values that could be plotted in Excel. As I proceeded to apply computation functions that act on data while the oscilloscope takes it, new experimental questions and analyses arose for me. Eventually, limitations in some inbuilt oscilloscope functions obstructed what I wanted to observe. To work around those constraints, I submitted the raw data to programs in the engineering software Matlab. Along with the digital oscilloscope and its high voltage and current probes, other electrical test equipment came to include pulse and frequency generators, and an inductance meter. As my experiment went on, I modified the spiral and made others of different lengths and insulations. My questions about the switch's role gave rise to explorations with mechanical and electronic switching, and a project to emulate Page's rotary switch by constructing a toothed wheel to spin so its teeth dip into a liquid-metal trough. [40]

I began by viewing individual traces, captured singly and frozen temporarily on the screen. What gave rise to their changing appearance? [41] In my first encounters with this confusing behavior, I shifted from ignoring the now-unconventional element in Page's circuit, to associating the unexpected ambiguity with it. What if Page's *body* contributed to the electrical behaviors he described? Was my reconstruction remiss in omitting the body? In my circuit, the oscilloscope's probes stood in for Page's body, but presented very high resistance.[42] In acting upon these questions, I inserted electrical substitutes for the human body into the circuit, in parallel with the

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[40] I used the liquid metal galinstan, a product of Geratherm Medical Diagnostic Systems, a safe substitute for mercury. It will, however, be mistaken for mercury by security detectors (eg. airports). For more description of the reconstructed spiral and wheeled switch, see Cavicchi, 2005 (n. 33 above), 131-4.

[41] In my previous studies with homemade double and single coils having iron cores, I observed consistency in traces showing the coils' response to intermittent current; see Elizabeth Cavicchi, "Experimenting with Wires, Batteries, Bulbs and the Induction Coil: Narratives of Teaching and Learning Physics in the Electrical Investigations of Laura, David, Jamie, Myself and the Nineteenth Century Experimenters -- Our Developments and Instruments", Dissertation, Harvard University, 1999; see also Cavicchi (n. 1 above), fig. 14, 346. The discrepancy, between trace variability with the activated spiral, and trace consistency with iron-core coils, remains a still-open question for me.

[42] Presenting 1MΩ to the test circuit, the oscilloscope is designed not to perturb it. However, I found that signals were affected (diminished) when two probes were applied at once to overlapping parts of the spiral.

oscilloscope probe (Figure 6). Starting with resistors as substitutes, I found that when the resistor's value was high, the traces resembled those produced with no resistor. By contrast their shape was different when the resistor's value was low. In all cases, the persistent variability remained.[43]

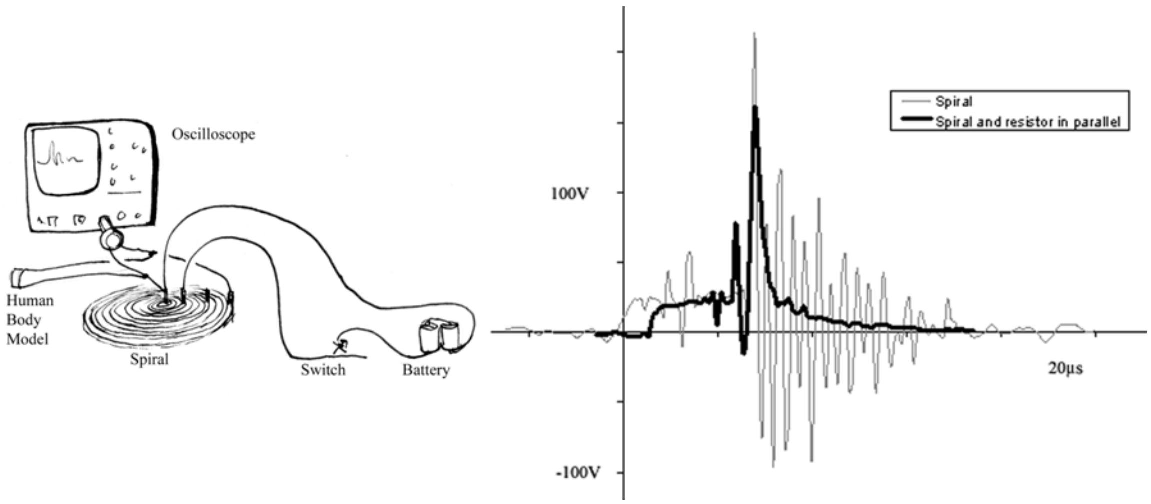


**Figure 6. Left: The human body model (such as a resistor) is connected in parallel with the oscilloscope probe. Right: The light gray line represents the voltage induced across a part of the spiral when the switch opens. The dark line shows the voltage induced across the same portion of the spiral when a resistor (1kΩ ) is put in parallel with the probe.**

For a time, I suspended experimenting. The fleeting signals did not register my interventions with the circuit and each sequence of trials seemed undifferentiated. Through watching myself I learned that these conditions can stall experimenting.

On resuming, I doubled the spiral's length, improved connections, and took up using a digital oscilloscope.[44] The digital oscilloscope immediately transformed my data collection methods, while its analytic features took longer to notice and explore. Analogous to the extra tabs in Page's spiral, the oscilloscope opened new experimental options and windows on what goes on within circuits.

Now the effect of putting an electrical substitute for the body into the circuit showed distinctively (Figure 6, right). Instead of the familiar periodic ringing (lighter line), these traces exhibited a narrow spike (darker line) that quickly declined. This characteristic held for traces produced with the many other substitutes for the body that I tested.[45] Without removing the overall ambiguity,

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[43] I varied the resistor's value from a low of 330Ω to a high 560kΩ. These values correspond to those tabulated for the human body's resistance to current: dry skin ~500kΩ; wet skin ~1KΩ; internal body length ~ 400Ω; for example, see "Biological effects of electric shock", Jefferson Lab, http://www.jlab.orb/ehs/manual/EHSbook-397.html

[44] HP Infinium 54810A.

[45] In addition to the resistors, these substitutes included neon bulbs; a metal-oxide varistor; a resistor in series with a capacitor, and several variations on the Siconolfi model referenced below. For convenience I settled on Siconolfi's substitute based on NASA data taken from human subjects: Steven Siconolfi et al, "Determining blood and plasma volumes using bioelectrical response spectroscopy", *Medicine and Science in Sports and Exercise* 28 (1996): 1510-6. This human body model consists of a resistance in series with a capacitance, in parallel with another resistance in series with an inductance. Steven Siconolfi provided data enabling me to construct models. A 1.87kΩ resistor is in series with a 2.2nF capacitor; this is then in parallel with a 510Ω resistor and an inductance (of 27µH in parallel with 56µH). For more extensive empirical and modeling studies of the human body's impedance, see J. Patrick Reiley, *Applied*

these body substitutes altered the signal trace by reducing peak voltages and damping out the ringing of subsidiary peaks. [46]

The variability between successive trials, illustrated by plotting successive voltage traces on top of each other (Figure 7, left), reflects an element in common between Page's experiment and my bodiless rendition: the mechanical switch. Viewed microscopically, a switch's contact surfaces are jagged; as they separate the current stops and restarts irregularly, inducing greater or lesser momentary voltages in the circuit. I explore effects of switching in the spiral circuit in two ways: with mechanical switches including rotary wheels that I constructed after Page's; and by substituting periodic electronic pulses for switched battery current. [47] Pulses generators output one well-defined waveform at a time, whereas all mechanical switches, from Page's time to today, produce complex signals composed from innumerable frequencies and amplitudes. Periodicity is a way of exploring the spiral's features in different frequency domains while mechanical switching exposes its response to diverse waveforms all at once.

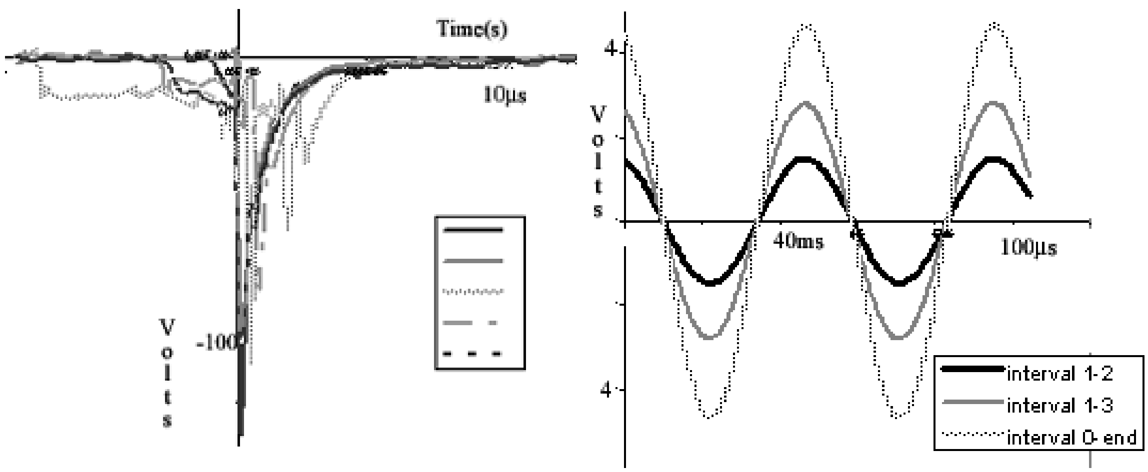


**Figure 7. Left: A constant frequency of 20kHz was applied to three intervals of the spiral in succession (inner, middle, outer). The observed voltage is superimposed, showing an increase in peak voltage across the spiral. Right: An overlay plot showing variation in voltage traces taken across one spiral interval (with a resistor in parallel) when the circuit is mechanically switched by a toothed wheel.**

Voltage traces induced in the spiral under mechanical switching contrast with those resulting from periodic stimulation. Like an animated movie of fluctuations, successive voltage traces appear on the oscilloscope screen while I manually turn my wheeled switch in and out of liquid metal. The peaks dance, nothing is steady. But with periodic pulsing, successive traces are nearly identical to my watching eye while the screen's margin displays a running account of the lesser variations in their numerical values. Mechanical switching underlies the variability that I observe. This variability confuses any inferences I try to make about whether voltage peaks

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*Bioelectricity: From Electrical Stimulation to Electropathology* (New York, 1998). Observed impedances range from over a kΩ at low frequency, to below 500Ω at high frequency.

[46] Traces obtained with the electrical human body model resembled a trace produced when a human volunteer put his hands across my spiral in parallel with the oscilloscope probe. The volunteer felt no shock, however the spiral shocked me when I ran it with wet hands.

[47] I use the HP33120A function/arbitrary wave generator for sine and square waves up to 15 MHz. For higher voltage square pulses (up to 150 V at periods down to .01ms), I used a Grass S44 Stimulator, of Grass Medical Instruments, Quincy MA.

increase when more the probe covers more of the spiral, analogous to Page's hands reaching across wider spans.

Periodic pulsing removes this ambiguity, but each test's finding holds only for the specific frequency of its application. With a pure 20 kHz sine wave, I first recorded a case where voltage increases as the probe is put across more of the spiral than the current-bearing segment (Figure 7, right). But I could not replicate this behavior with higher frequency inputs until I gained more with the instruments. With an inductance meter, I directly measured the electrical property relating induced voltage to the changing current which gives rise to it. As with periodic pulsing, the meter operated only at one frequency at a time. At low frequencies, the inductance increased across the spiral (Figure 8 left).[48] An anomaly that arose above 1 megahertz intrigued me; I investigated it and found my spiral is remarkably admissive to megahertz disturbances (Figure 9).[49] In another kind of test, I applied a narrow spike pulse across the spiral's inner turns and observed its change of shape as the probe interval encompasses more of the spiral (Figure 8, right). Further out, the pulse spreads in time and rings with echo peaks of decreasing height.

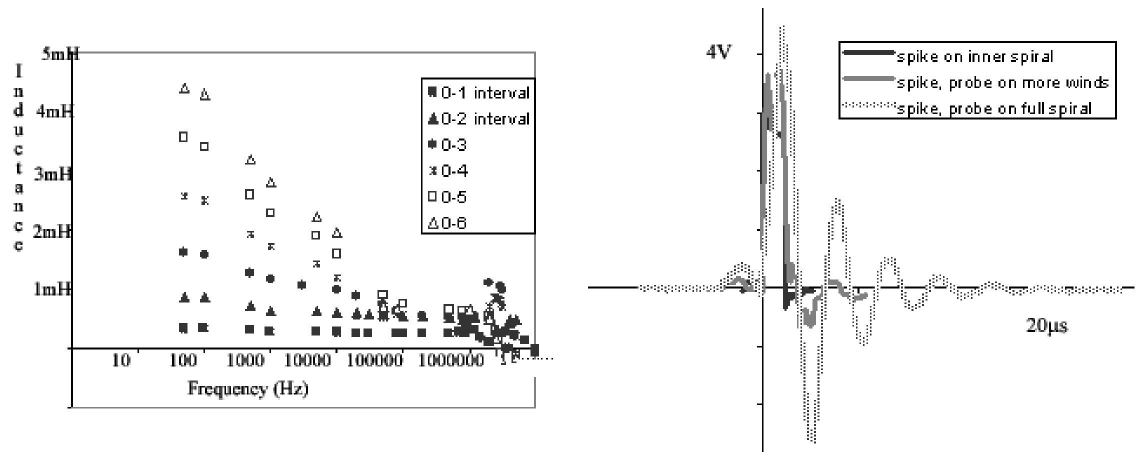


**Figure 8. Left: When inductance is measured for different spiral intervals, its value increases as more of the spiral is covered. Overall, these values decline as frequency rises, and an anomaly appears above 1MHz. Right: The spiral's inner interval is stimulated by a narrow voltage spike; when viewed across more of the spiral, the observed signal stretches out in time, and may increase in voltage.**

[48] A HP 4192A impedance analyzer was used. The spiral's overall inductance was on the order of 4mH at low frequency; its resistance went from 5.6Ω at low frequency, into the kΩ range at 50kHz.
[49] The electrical property of admittance is the reciprocal of impedance. Impedance (measured in Ω) is the ratio of the complex voltage, *V*, to the complex current, *I*; where both these are real, that ratio is the familiar electrical resistance. Impedance depends on frequency. I compute spectrums of spiral impedance from the ratio of the fast fourier transform (FFT) of a voltage trace to that of a simultaneously observed current trace. As inputs for stimulating these traces, I use square waves generated at selected frequencies, as well as excitations made by dipping the spur wheel into liquid metal. Present results suggest that the megahertz regime where the spiral impedance drops may represent a transition from capacitive to inductive behavior.

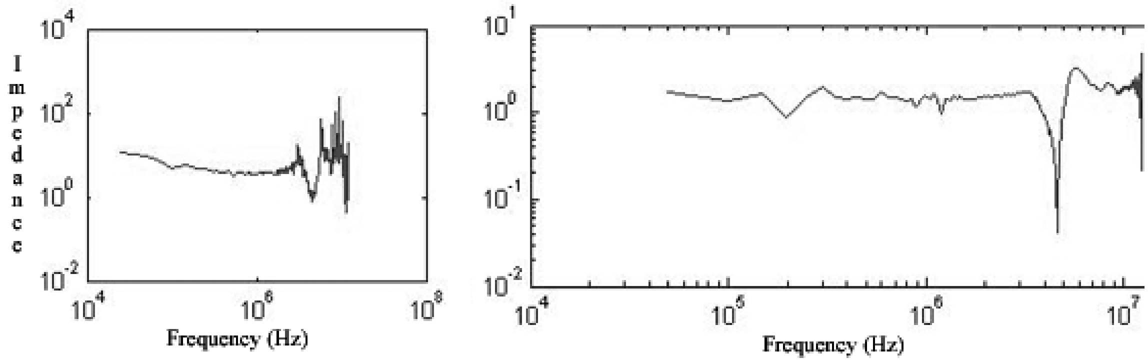


**Figure 9. A distinctive dip in electrical impedance (or, conversely, a rise in electrical admittance) occurs at about 4MHz in these log-log plots of observations taken across the same spiral interval. Left: the spiral was mechanically switched by the star wheel; Right: the spiral was stimulated by a square wave.**

Ambiguity overwhelmed any trend of voltage increase whenever I switched the circuit mechanically. Although the screen displays only one event at a time, I attempted by many methods to apprehend the set of traces that repeated switching produces at a fixed probe position. I looked for trends in sequences of these sets. While visually watching the screen, I try to remember patterns and select representative events to save and plot. Often while turning the wheeled switch, high signals flitted past too quickly to capture and save them. After more experience, I learned to save data from successive events in real time. Taking sets of many hundred events, the oscilloscope functions that compute averages, integrals and record maximal values produce stabilized curves that contrast with the erratic variability among single events contained in those sets. For example, the function that automatically records extremal voltages (high and low) occurring at each time position yields an upper and lower boundary envelope for the sampled traces (Figure 10, left). The separation between paired boundaries represents maximal voltages induced across spiral intervals over many iterations. Using this analysis, the case that corresponds to greater spiral coverage exhibits greater values in its voltage envelope, than the case that covers only the spiral's inner spans. I wonder if these methods of averaging and accumulating sequences of hundreds of traces (Figure 10,right) are more similar to an averaging or blurring within Page's sensation of shock over many spins of the wheel, than are separate transient voltage traces.

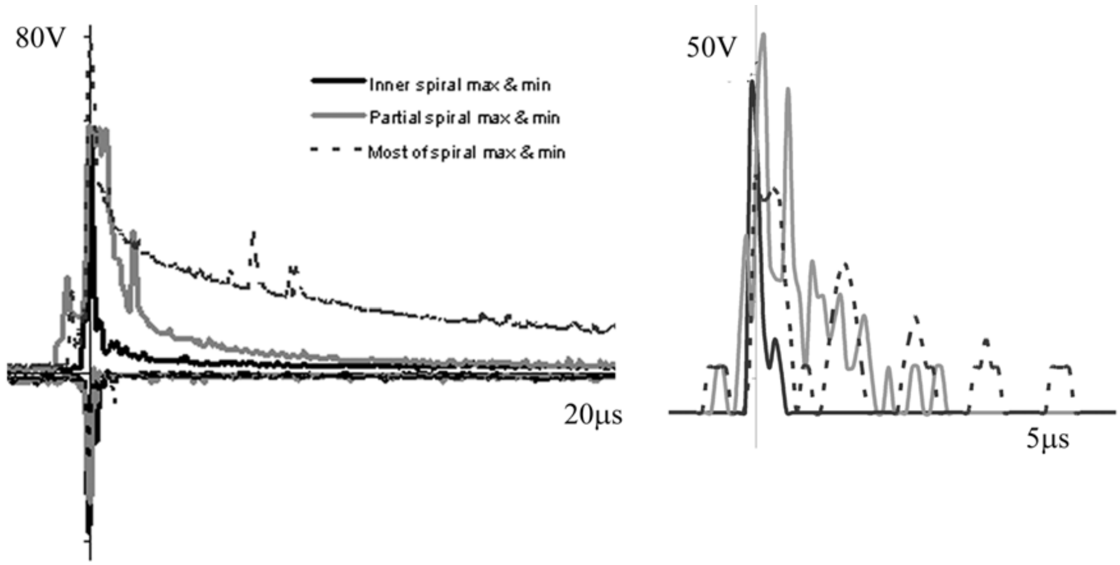


**Figure 10. Overlay plots of mechanically switched voltages observed across inner spiral (black), midspiral (gray), entire spiral (dashed) Left: Envelope curves for maximal and minimal values show a voltage increase as more of the spiral is stimulated (a resistor models the body and damps the signal). Right: Averaged absolute value rises and then falls but spreads in time. Here, the probe is put over more of the spiral than the battery current (no resistor is included).**

The rotary toothed switch made it possible for me to observe colored sparks and hear electrical snaps like those Page described (Figure 11). I found I could not compare sparks and sounds unless the room was dark and quiet; this work in the dark posed other logistical challenges. Although Page discerned brightest sparks where battery connection broke from half of the spiral's length, again, I experienced confusion and ambiguity. I could not tell whether sparks were brighter when the whole spiral was interrupted, or just the half. Only when I reduced the battery source from two cells to one, did overall sparking diminish to where the midpoint brightness stood out from dimmer glows at other points.

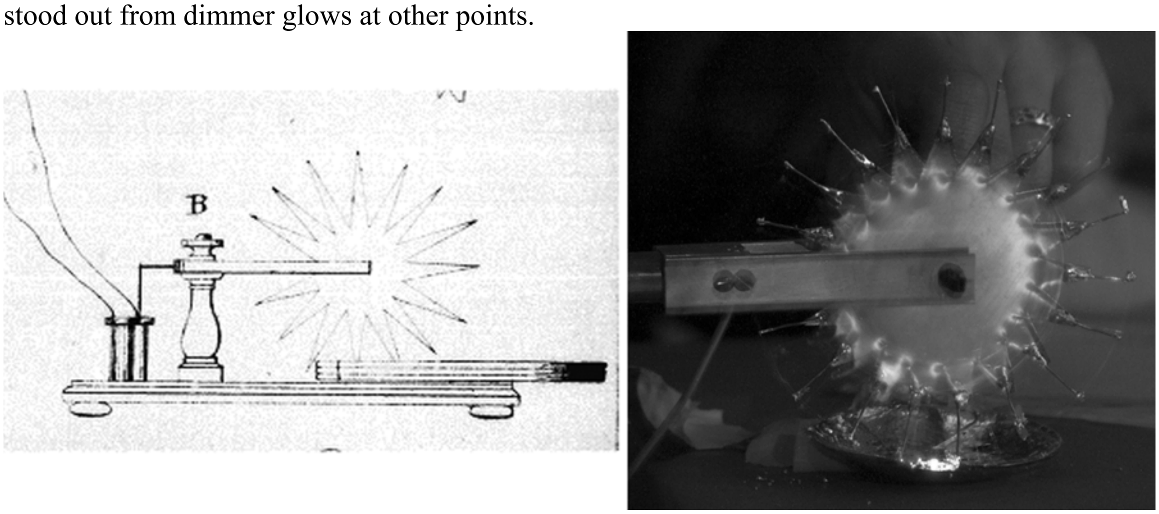


**Figure 11. Left: Star wheel contact breaker developed by Page; diagram from E. M. Clarke, "Description of Electrepeter", *Annals of Electricity*, 1, 1837, 65-6, plate viii, Fig. 55. Right: Sparks appear in my replication of Page's interrupter where the star points exit a pool of liquid metal. Photo by Jeff Tinsley.**

In looking into the spiral by innumerable means not available to Page, like him I find electrical behaviors and patterns to wonder about. Always, the overall effect is amazing: on putting a spiral into the circuit, the voltages induced exceed my flashlight batteries' 3V output by over two orders of magnitude. This heightened voltage, its variations in degree, and its presence in winds outside the battery current's direct path, had most intrigued Page and was unmistakable for me.

Following these effects instrumentally across ever-wider spiral intervals did not immediately confirm Page's sensations of heightened shock as I initially expected. Instead, I face variability, ambiguity, and confusion that I can only address through multiple approaches such as activating the spiral with periodic and switched events, and picturing the data in alterative views and domains. The uncertain paths of experimenting may seem as erratic and noncohering as the fitful voltage traces. That diversity put the experimental ambiguities – including from the human body – into relief, and allowed for multiple ways of probing and analyses that sometimes cohere as trends in the phenomena. In this sense, my experimental journey makes a full replication of Robert Post's interpretation that Page engaged with "the baffling complexity of things"[50].

## Revisiting the Spiral

As Page continued working with the spiral, electrical interests displaced medical ones[51] In the process, his understanding of electricity deepened. This electrical experience was then unusual in America, and it became the basis for his later work as US patent examiner, patent advisor, and independent inventor.[52]

A year later when Page next reported on it, the spiral was 100 feet longer, with four more connection cups.[53] Acknowledging Ampère, Page named it the "Dynamic Multiplier" and described its function as "Electro-dynamic". While investigating its behavior under series and parallel battery configurations, he conducted original research on the battery that resulted in a more compact, stable cell.[54] To replace the human operator's action in opening the circuit, Page pioneered the self-actuated switch: "I have tried a variety of means and succeeded in the contrivance of several beautiful pieces of apparatus."[55]

These innovations heightened the instrument's effects so that it was no longer essential to put the body in the circuit. Page alluded to the body only in indirectly mentioning "acupuncture" shocks.[56] But even if the body was superceded, the *role* it had fulfilled as a detector remained essential to experimental development. For example, Page found the faster the contact breaker went, the more ferociously foamed bubbles of water decomposed by the spiral's induced electricity. Just as differing shock intensities had enabled Page to evaluate successive placements

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[50] Post, *Physics, Patents & Politics* (n. 2 above), 23.
[51] Page never established a serious medical practice after graduation. Post, *Physics, Patents & Politics* (n. 2 above), 14-5.
[52] See Post, *Physics, Patents & Politics* (n. 2 above).
[53] C. G. Page, "On the use of the Dynamic Multiplier, with a new accompanying apparatus", *American Journal of Science*, 32 (1837): 354-60.
[54] Going beyond the acid battery, Page also activated the spiral with a thermo-electric source (where potential difference evolves across a joint of dissimilar materials held at different, fixed temperatures); Ibid., 358.
[55] Ibid., 355. Roger Sherman discusses Page's rocking and spring-loaded switches, and the improvements made by Boston instrument-maker Daniel Davis Jr. in "Charles Page, Daniel Davis, and their electromagnetic apparatus", *Rittenhouse* 2 (1988): 34-47.
[56] As before, Page used the acupuncture technique to sense electricity in the spiral's outer segments, in this case when a thermo-electric source activated it. Page, "On the use of the Dynamic Multiplier", (n. 53), 358.

of his hands across the spiral, so he used this bubbling as feedback while improving the interrupter. He achieved greatest rapidity with a toothed wheel electromagnetically powered by its own miniature battery, which opened and closed the main battery's circuit as its teeth passed through mercury. The turning wheel's motionless appearance under "its own light"[57] – the spark induced when each tooth broke from mercury – yielded a striking early observation of stroboscopic effects.

In the widening range of experimenting brought about by the spiraled conductor, Page observed yet another new phenomenon , one which contributed to the future of telephony. Instead of resting the spiral horizontally, Page mounted a light-weight spiraled wire vertically, so that it resided edgewise within the horizontally oriented gap between a horseshoe magnet's poles. On each interruption of current through the spiral, the magnet rang with a characteristic musical tone; different sized magnets gave different tones.[58] Forty years later, Alexander Graham Bell opened his ground-breaking lecture on the telephone by crediting Page's 1837 discovery of 'galvanic music' with kindling world-wide inquiry on sounds associated with magnetization.[59]

But the magnet's singing merited only passing notice in a retrospective commemoration of his life. Page was long out of the top ranks of American science when he died penniless of sufferings likely exacerbated by chemical exposures. Public laurels in telegraphy and telephony rested on others, both during Page's abbreviated life and subsequently. In contesting this injustice, biographer Robert Post sheds light on culturally imposed expectations about the conduct befitting a scientist, whose violation by Page resulted in marginalization during his own day, and in succeeding historical assessments.[60]

## Extending and Interpreting the Spiral's Inductive Effects

Through communicating about the spiral, Page came into contact with a broader community of experimenters. Two of these figures, one foreign, one local, are discussed below. London-based experimenter William Sturgeon reprinted Page's papers in his journal, adding his own commentary; Boston instrument-maker and investigator Daniel Davis Jr. adapted Page's designs into production apparatus.[61] Stimulated by both men, Page developed understandings and instruments of a scope not previously accessible to him. In the process, he left the spiral behind.

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[57] Ibid., 358. Also in 1836, Charles Tomlinson produced similar effect with a sparking motor, in "On an Optical Illusion observed during the action of Professor Ritchie's horizontal artificial voltaic magnet", *Annals of Electricity* 1 (1837): 108-11. In 1831, Faraday used a slotted spinning wheel to explore optical deceptions associated with the persistence of vision which rendered Page's wheel apparently stationary; see Ryan Tweney, "Stopping Time: Faraday and the Scientific Creation of Perceptual Order" *Physis*, 29, (1992): 149-64.

[58] Page followed his first report, "The Production of Galvanic Music", *American Journal of Science* 32 (1837): 396-397, with a second one where an electromagnetic bar substituted for the spiral; "Experiments in Electromagnetism", *American Journal of Science* 33(1838): 118-120. In my unsuccessful attempt to reproduce 'galvanic music', the spiral mounting was so insecure that the current-bearing spiral moved into contact with the horseshoe magnet's pole.

[59] Alexander Graham Bell's lecture at the American Academy of Arts and Sciences on May 10, 1876 was printed as "Researches in Telephony", *Proceedings of the American Academy of Arts and Sciences* 12 (1876-7): 1-10.

[60] (Jonathan Homer Lane), "Charles Grafton Page", *American Journal of Science* 48(1869): 1-17. Bryon Sunderland, *Funeral Address*, May 7, 1868, unspecified publication, (Library of Congress collection). Post, *Physics, Patents & Politics* (n. 2).

[61] See Post, *Physics, Patents & Politics*, (n. 2 above), 207-213, for a list of Page's scientific papers, including those republished in Sturgeon's journal, *Annals of Electricity, Magnetism, Chemistry and*

On hearing about Page's shocking device from an American traveler, Sturgeon sought to replicate its heightened electricity without copying its spiral.[62] Conjoining two helical coils, he sent current through one and took shocks from it alone, and both together (Figure 12, left). The second coil failed to enhance shocks and he dispensed with it. Later, on receiving Page's actual text, Sturgeon grasped the geometry he misconstrued before. That experience of confusion focused him in explaining the shocking electricity as something induced by the "electromagnetic lines" collapsing with the battery's ceasing current. Sturgeon appended this explanation to his republication of Page's paper – which had no analysis.[63] Sturgeon admitted that he had not formerly understood that the wire bearing "primitive" battery current needed to be located "within the influence of" the "secondary" wire carrying the shocking effect. Only after Sturgeon overwound the secondary directly over his current-bearing coil, was the combined coil's shock greater than that of the original alone (Figure 12, right).[64]

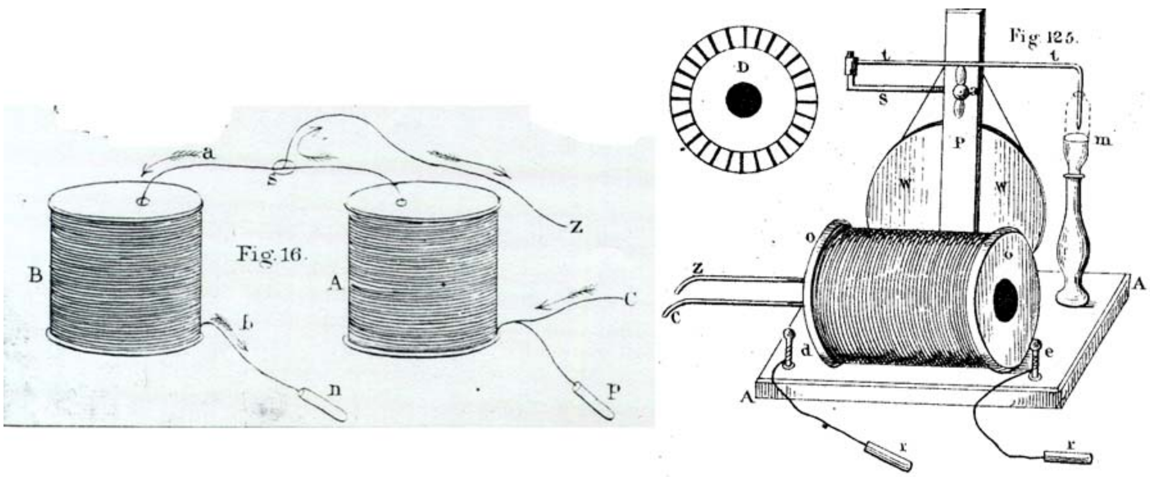


**Figure 12. Left: Sturgeon's two linked coils A and B; he found the shock was not increased by adding coil B. From *Annals of Electricity*, 1, 1837, plate ii, Fig. 16. Right: Sturgeon's shocking coil where current flows through an inner coil and shock is taken from the handles *rr* of a second coil that is wound over the inner one. From *Annals of Electricity*, 1, plate xv, fig. 125.**

Sturgeon's commentaries moved Page's thinking. Subsequent experimenting developed Page's ideas so far as to reject an earlier, now "irrational", view that conjoining "primitive and secondary" currents (as in the spiral) was what produced shocks:

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*Guardian of Experimental Science*. For a discussion of Sturgeon's life and times, see Morus, *Frankenstein's children*, (n. 16 above). On Page and Davis, see Sherman (n. 55) and Post *Physics, Patents & Politics* (n. 2).

[62] Sturgeon described his encounter with "a scientific American gentleman" on p. 67 in "On the Electric Shock from a single Pair of Voltaic Plates, by Professor Henry, of Yale College, United States: Repeated, and new Experiments" (Sept. 28, 1836), *Annals of Electricity* 1, (1837): 67-75, reprinted in William Sturgeon, *Scientific researches, experimental and theoretical in electricity, magnetism, galvanism, electro-magnetism and electrochemistry* (Bury 1850), 282-289; see also Cavicchi (n. 1 above). Page used Sturgeon's publication to retrospectively support his own priority claims in (Charles Grafton Page), *The American Claim to the Induction Coil and its electrostatic developments* (Washington, 1867); footnote p. 11.

[63] William Sturgeon, "Explanation of the Phenomena, &c.", *Annals of Electricity* 1 (1837): 294-295; Page's paper is republished in the preceding pages, 290-294.

[64] See Cavicchi (n. 1 above) for more discussion of Sturgeon's apparatus and interpretations.

> …the sparks and shocks indicating a new and secondary current are directly consequences of the dissolution of the primitive current…due solely to magnetic excitation, and have no connexion with that primitive, except that of cause and effect.[65]

Secondary currents did not offshoot directly from battery current, but instead arose from changes in a magnetic medium surrounding them, as represented in what Page called Sturgeon's "beautiful theory of electro-magnetic lines".[66] Page's acknowledgment of Sturgeon's contribution meant much to the recipient; Sturgeon excerpted it in the last publication of his life, adding "I know of no philosopher more capable of close reasoning on electro-magnetics and magnetic-electrical physics than Prof. Page, M.D."[67]

As spatial relations among coils and magnets became increasingly critical in Page's experimenting, he consulted the "ingenious" Daniel Davis Jr., first American manufacturer of electromagnetic demonstration instruments.[68] Their collaboration was reciprocal. Davis refined Page's prototype devices and marketed them through his shop, trade catalogues, and textbook. Page illustrated his scientific papers with Davis' distinctive apparatus and acknowledged Davis' contributions to his work. The instruments and understandings that Page and Davis developed together elucidated electromagnetic phenomena elegantly and went into wide instructional use.[69]

A shocking coil that may represent the early Page-Davis association is now in Dartmouth College's Allen King Collection of Scientific Instruments (Figure 13).[70] Although Dartmouth's coil does not exemplify Davis's high craft, design features link it to Page and materials correlate

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[65]Page, "Researches in Magnetic Electricity and new Magnetic Electrical Instruments", *American Journal of Science* 34 (1838): 364-373, quote on 366.

[66] Ibid., 367.

[67] Sturgeon 1850 (n. 62), vii.

[68]Daniel Davis Jr. trained in William King's Boston firm for electrical apparatus and lightning rods at 54 Cornhill St.; see Cavicchi (n. 1 above). In 1837, Davis set up a philosophical instrument-making shop nearby at 11 Cornhill, which relocated to 428 Washington St. around 1846. Advertising notices for Davis appeared in *Boston Recorder* (eg . 23 (January 5, 1838) APS Online p. 3); *American Journal of Science* (42 (Jan.-Mar. 1842) APS Online p. 5); *Boston Medical and Surgical Journal* (27 (October 5, 1842) APS Online p. 159); and weekly in *Scientific American* in 1846. Davis' instrumental work, "unrivaled in this country", merited a gold medal of the Massachusetts Charitable Mechanics Association, "Medical Miscellany", *Boston Medical and Surgical Journal* 22 (Mar. 18, 1840) APS Online p. 98. The "ingenious" Davis was also considered "an accurate philosophical investigator, whose opinion commands respect", "Medical Application of Electricity", *Boston Medical and Surgical Journal* 34 (March 18, 1846) APS Online p. 143. Many original Davis instruments survive today in college museums and physics departments; a compilation by Thomas Greenslade is provided at http://www2.kenyon.edu/depts/physics/EarlyApparatus/

[69] For the association between Page and Davis, see Sherman, (n. 55). Daniel Davis' trade publications include *Catalogue of Apparatus* (Boston, 1838), *Manual of Magnetism* (Boston, 1842), each in multiple subsequent editions. Physician Samuel Boyd Toby credited a Page-Davis instrument with curing a child, "Partial Paralysis of a Face in a Child", *Boston Medical and Surgical Journal* 27 (January 25, 1843) APS Online p. 415. Page's papers illustrated with Davis' instruments or other reference to Davis include: Page "Researches…" 1838 (n. 65 above); "New Magnetic Electrical Machine of great power…", *American Journal of Science* 34 (1838): 163-9; "Observations on Electricity", *American Journal of Science* 36 (1839) 353-4; "Magneto-Electric and Electro-Magnetic Apparatus and Experiments", *American Journal of Science* 35 (1839): 252-68

[70] The Dartmouth instrument, accession number 2002.1.35088, was listed in an 1870s inventory as 'Page's apparatus for shocks with mercury break'. This coil, with its possible links to Page and Davis, is described in Richard L. Kremer, David Pantalony and Francis J. Manasek, *Study, measure, experiment: Dartmouth's Allen King Collection of Scientific Instruments* (Norwich VT, 2005), p. 157-9 and Cavicchi (n. 1 above), 351-3.

with Davis' work. A similar, presumably subsequent, coil was first offered for $8.00 in Davis' 1838 catalogue and illustrated in Page's 1839 paper and Davis' 1842 textbook (Figure 14).[71] These publications describe an instrument having two separate, concentric coils: one for battery current; the other for shock. The Dartmouth instrument is wired differently. A solder joint affixes the secondary coil directly to the current-bearing coil. Shock may be taken either across the secondary alone, or across the combination of both coils.

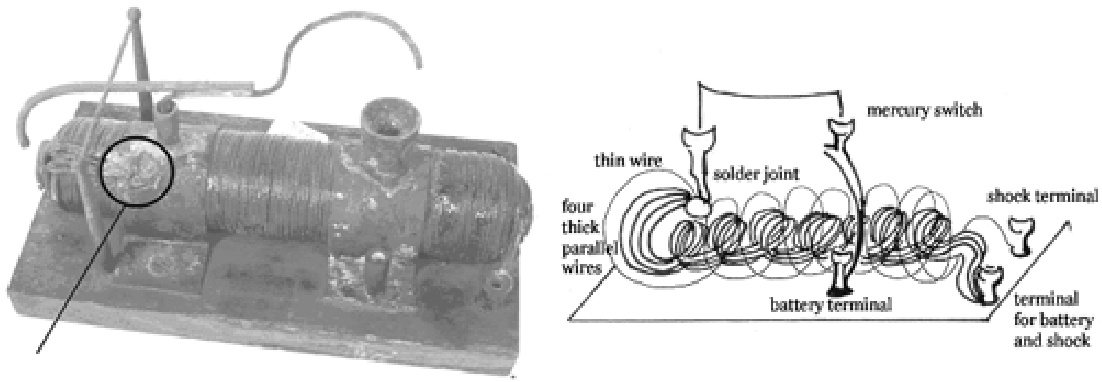


**Figure 13. Left, photo of shocking coil number 2002.1.35088 in the Allen King Collection of Scientific Instruments, Dartmouth College. The black line encircles a solder joint on the Dartmouth shocking coil which unites the thick current bearing wiring to one terminus of the thin "secondary" wiring. Right, my diagram shows the coil's solder joint and wiring.**

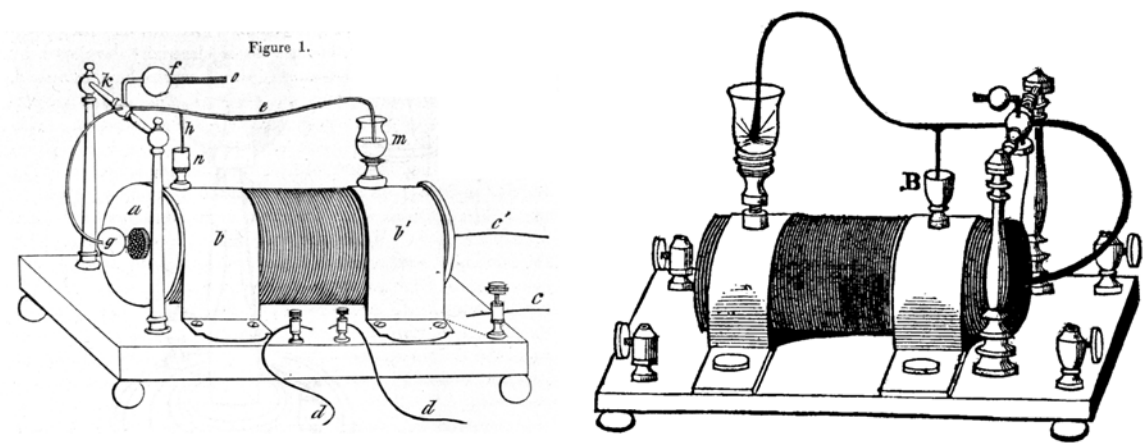


**Figure 14. Left: Page's double helix coil, where *cc'* are battery terminals and *dd'* are connectors for taking shock. The rocking wire *e* interrupts the primary circuit when the coil's magnetism attracts iron ball *g*, lifting *e* from mercury cup *m*, giving rise to sparks in cup *m* and shocks at *dd'*. From Page's paper "Magneto-Electric and Electro-Magnetic Apparatus and Experiments", *American Journal of Science* 35, 1839, 252-268, Fig. 1, p. 258. Right: The instrument appears for $8.00 in Daniel Davis Jr.'s *Catalogue of Apparatus,* (Boston, 1848), Fig. 183, p. 37.**

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[71] The editions of Davis' *Catalogue* and *Manual* (n. 69 above) and his *Medical Application of Electricity* (Boston 1846) describe the electromagnetic coil. Page's scientific paper on the coil is "Magneto-Electric and Electro-Magnetic Apparatus and Experiments", 1839. His 1868 patent model of this instrument is on display in the National Museum of American History in Washington DC, catalogue no. 309 254, accession no. 89 797. Boston physician William Channing described Page-Davis coils, (n. 23 above) 20; Page-Davis coils are illustrated in Alfred Garratt, *Guide for using Medical Batteries* (Philadelphia, 1876) 49, 50, 53.

This solder joint preserves the continuity between secondary and primitive paths that Page's spiral first exhibited. It embodies the transitional moment before Page rejected as "irrational" the notion that the elevated, shocking electricity depends on continuity between these two paths. While the solder joint reflects ambiguity in understanding electromagnetic behaviors, it also accommodates multiple options regarding which parts of the coil can be used for taking shocks. Those multiple options, originating in the intermediate tabs of Page's spiral, are eliminated in Davis' commercial version of Page's coil (and spiral, Figure 3, right), where shock was taken only across the secondary. Being constructed to reproduce pre-existing effects, not create new ones, the commercial apparatus closed off experimental space and access to ambiguity.

Successors to Page's electromagnetic coils became popular for therapy, [72] while the spiraled conductor played a role in wireless electrical transmission.[73] A half-century after Page's spiral, Heinrich Hertz found that direct electrical stimulation of one spiral induced sparking between a distant spiral's terminals. [74] Applying this finding, early wireless transmissions rode on the high frequencies amplified through spiral resonances. No body mediated the electrical signals; the interdependence between human bodies and experimental circuits was diminishing.

## Ambiguity in Experimenting

Page's spiral experiment opened up options for electricity's paths and these paths showed themselves to be more complex than simple flow between two endpoints. Electricity arose interactively inside conductors: Page experienced it as shocks from spiral intervals where he did not expect electricity to be. His body was both a constituent of those new paths, and a reporter on what was going on. It filled in where no measuring apparatus then available could, by sensing momentary pulses induced in the spiral's many turns.

Body and circuit are partners, with each being a locus for inquiry and intervention, in the experimenting of Page and his peers. The instruments bear out this partnership: medical acupuncture needles became electrodes, and coiled conductors therapeutic aids. The analogy goes further; Page opening up the spiral to probe its interior resembles a physician looking into the body. His thought experiment to put a mercury cup on every spire applies surgical precision to circuital intrusions. Once inside, both body and circuit were baffling; the sensational observations disclosed electrical activity, but left the workings obscure. Page communicated his observations in all their ambiguity, proffering no explanations until a community extended his findings with their own.

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[72] John B. Zabriskie, physician in Flatbush, Long Island, reported on his experimental spirals in "Experiments upon the Induction of Metallic Coils", *American Journal of Science* 32 (1837): 308-13, but the spiral did not become a standard medical device. The electromagnetic coil's medical context is described in reference to physician Golding Bird in Morus (n. 16 above), also see G. M. Beard and A. D. Rockwell's text, *Medical and Surgical Uses of Electricity* (New York, 1871).

[73] Joseph Henry mounted a battery-interrupted spiral on one side of a wall and put a spiral with handles on the other side so that someone grasping its handles received mysterious shocks; "Contributions to Electricity and Magnetism: On Electro-Dynamic Induction" No. III, *Transactions of the American Philosophical Society* 6 (1839): 303-37; also No. IV, in the same journal, 8, (1843): 1-35.

[74] The sparks' high frequencies (hundred megahertz) represented wavelengths long enough to make lab experimenting practical. This pivotal observation launched Hertz' research of the electric waves that Maxwell predicted. Hertz described his work with "Reiss or Knochenhauer spirals" in *Electric Waves,* D. E.Jones, trans., (London, 1900), 2. The experiment is discussed in Jed Buchwald, *The Creation of Scientific Effects: Heinrich Hertz and Electric Waves* (Chicago, 1994), 217-227. Further references to historical experimenting with spirals are given in Albert Gluckman, *The Invention and Evolution of the Electrotechnology to Transmit Electrical Signals without Wires* (College Park MD, 1996).

Multiple factors confounded in the effects Page used and detected, and these melded together for him. Only through extensive experimenting did he work out how change in both time and space matter to electromagnetic induction. Page's spiral exemplified this by the *timing* of its switching and by its spiral extent in *space*. Time, space and magnetic lines changing in that space came to have interactive roles in Faraday's more mature thinking about fields.[75] Yet in the late 1830s, Page, Sturgeon, Davis and others engaged productively with electromagnetic effects and ambiguities to develop instruments that manifested and amplified inductive behaviors.

Although it might seem that our present instrumentation and analyses would rule out the ambiguities that Page experienced, with my lab project it is otherwise. Electrical test equipment can specify a circuit's input and in its output analyze voltages and time-dependences across many decades of values. Yet where precise conditions operative in the historical case are unknown – including a human body – having this kind of control widens the search space across multiple domains in time and space. The ambiguity rears even larger when periodic inputs are replaced by the vagaries of mechanically switching current flow into a homemade spiral. Along each of many experimental paths lies more to learn about electricity and history, such as my spiral's high frequency resonance with possible echoes into the past of Hertz' wireless transmissions.

Diverse experimental options, together with ambiguity in what is observed, provide fertile grounds for exploring and understanding processes that are too complex to render neatly in conclusive terms. Other historical studies concur.[76] Friedrich Steinle documented explorative creativity on the part of both Faraday and Ampère in their initial responses to Oersted's 1820 announcement about conducting wires' magnetism.[77] Gooding discerned that subsequently Ampère abandoned his preliminary openness and focused on bolstering his theoretical commitments whereas Faraday persisted in puzzling over what he did *not* understand: the magnetism's circularity.[78] By staying with that physical ambiguity – exploring it further – Faraday brought about experiences foundational to his invention of the first motor, a device that uses electromagnetism's circular action to revolve a conductor around a fixed magnet.[79] An

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[75] Faraday's experiments with a great electromagnet and development of field analyses are described in: David Gooding, "Final steps to the field theory: Faraday's study of magnetic phenomena, 1845-1850", *Historical Studies in the Physical Science* 11 (1981): 231-75; David Gooding, "Faraday, Thomson and the concept of the magnetic field", *British Journal for the History of Science* 13 (1980): 91-120; Elizabeth Cavicchi, "Experimenting with magnetism: Ways of learning of Joann and Faraday", *American Journal of Physics* 65 (1997): 867-82.

[76] Alberto Martinez discusses how negative and imaginary numbers were unintelligible to some nineteenth century mathematicians such as Carnot who objected to algebraic practices having no geometrical interpretation, such as subtracting numbers from zero. Others, accepting these ambiguities, found that negative and imaginary numbers extended the possibilities of what they could do in algebra. Martinez, *Negative Math: How Mathematical Rules can be Positively Bent* (Princeton, 2006). Other historical studies wherein ambiguity offers productive value include Elizabeth Cavicchi, "Experiences with the magnetism of conducting loops: Historical instruments, experimental replications, and productive confusions", *American Journal of Physics* 71 (2003) 156-67; Ryan Tweney, "Discovering Discovery : How Faraday Found the First Metallic Colloid", *Perspectives on Science* 14 (2006) 97-121.

[77] Friedrich Steinle, "Entering New Fields: Exploratory Uses of Experimentation", *Philosophy of* Science, Proceedings 64 (1997): S65-S74.

[78] David Gooding, *Experiment and the Making of Meaning: Human Agency in Scientific Observation and Experiment* (Dordrecht 1990), 46-7, 118

[79] David Gooding, "'In Nature's School': Faraday as an Experimentalist", in *Faraday Rediscovered: Essays on the Life and Work of Michael Faraday 1791-1867*, D. Gooding and Frank A.J.L. James, eds., (New York NY, 1985).

example from early twentieth century biology researched by Evelyn Fox Keller illustrates a mode of development inverse to Faraday's, where ambiguity in the means of thought supported the investigators in recognizing and tolerating ambiguity in what they observed. The amorphous term 'gene action' gave biologists a way to research hereditary transmission before they had access to explanatory mechanisms, such as DNA.[80] Faraday and the biologists extended their experimenting by sustaining generative relationships with ambiguity in the phenomena and in their thinking. They did not seek to eliminate ambiguity by settling prematurely on analyses whose definite structure might preclude promising interpretative options.

We accept uncertainty and risk whenever we join bodies into circuits or accept ambiguity in research. In doing so, our actions run afoul of culturally constructed polarizations, such as mind versus body or product versus process. Each of these pairings assumes a hierarchical structure, like mind over body or product over process. Anyone's contact with the lesser item in the polar construct tends to demean them, making them ineligible for the status and privilege conferred by, and desired under, that culture.[81] To project the image of certainty while maintaining these polarizations requires artificial controls that short circuit out of visibility all the bodies, questions, and other realities that are troublesome in the context of cultural constructions.[82] But everyday experience is deeply embedded in the world, our bodies, and unexpected change. When, like Page adding intermediate tabs to the spiral, we give access to new experimental possibilities, our experience opens to options not prefigured in advance. Acting on these options involves more than putting ourselves into the circuit and passively waiting for a result. With this openness comes an active responsibility to face the uncertainties that emerge, and to persist at working to understand all their potential meanings and impacts for the broader community.

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[80] Evelyn Fox Keller, *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines* (Cambridge, 2002) 123-47.

[81] Feminist and critical theory analyzes how dualistic constructs operate in society at large to privilege some, and oppress others, as a prelude to seeking more embedded, inter-relational foundations for knowledge and action that respect the complexity and ambiguity of human experience. Evelyn Fox Keller, *Reflections on Gender and Science* (New Haven, 1985); Naomi Scheman, "Though this be method, Yet there is madness in it: Paranoia and Liberal Epistemology" (1993), in *Feminism and Science*, Evelyn Fox Keller and Helen Longino, eds., (Oxford, 1996); Patricia Collins, *Black Feminist Thought: Knowledge, Consciousness and the Politics of Empowerment* (New York, 2000).

[82] Kenneth Caneva observes that professional and pedagogical practices make it difficult to refuse to divide product from process; *The Form and Function of Scientific Discoveries* (Washington DC, 2000).