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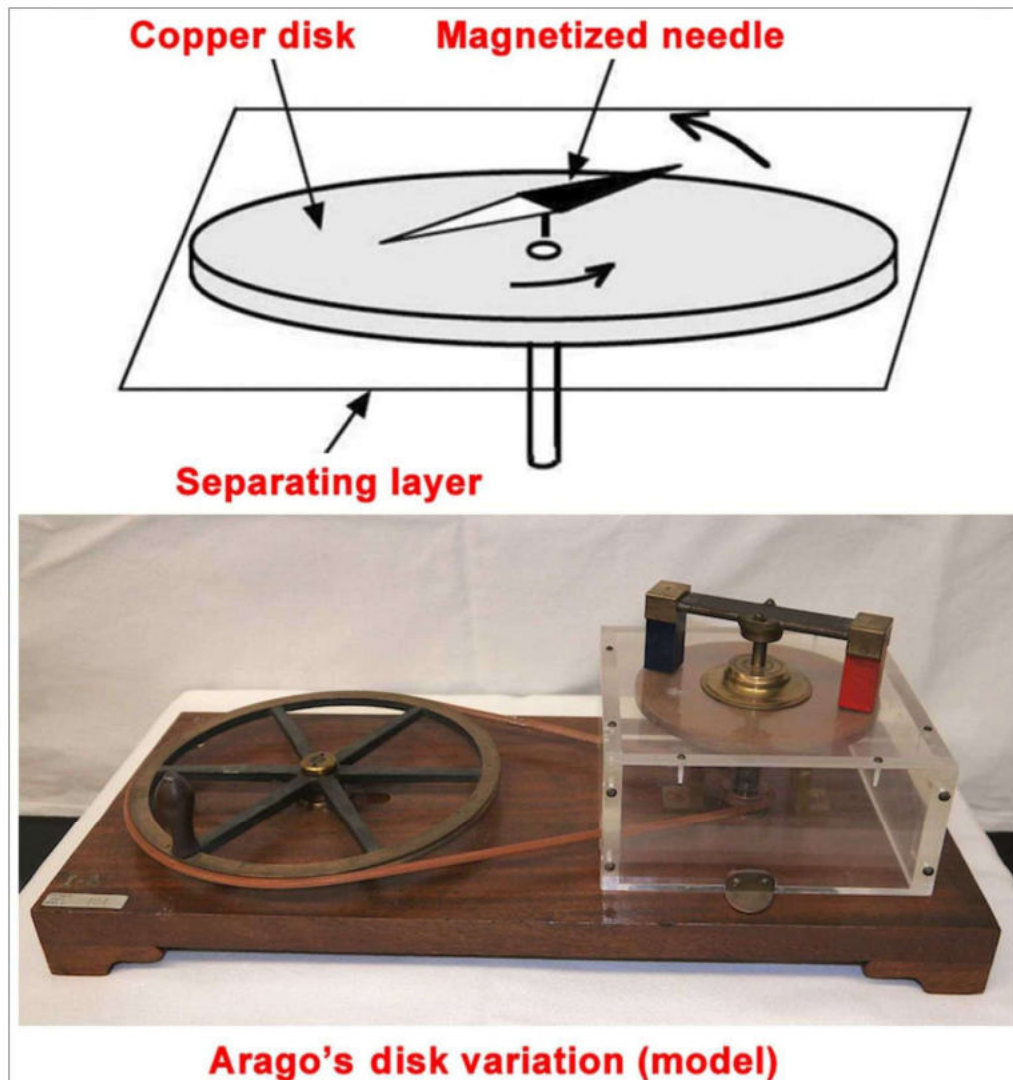
The Road to Radio—Part 6

Introduction

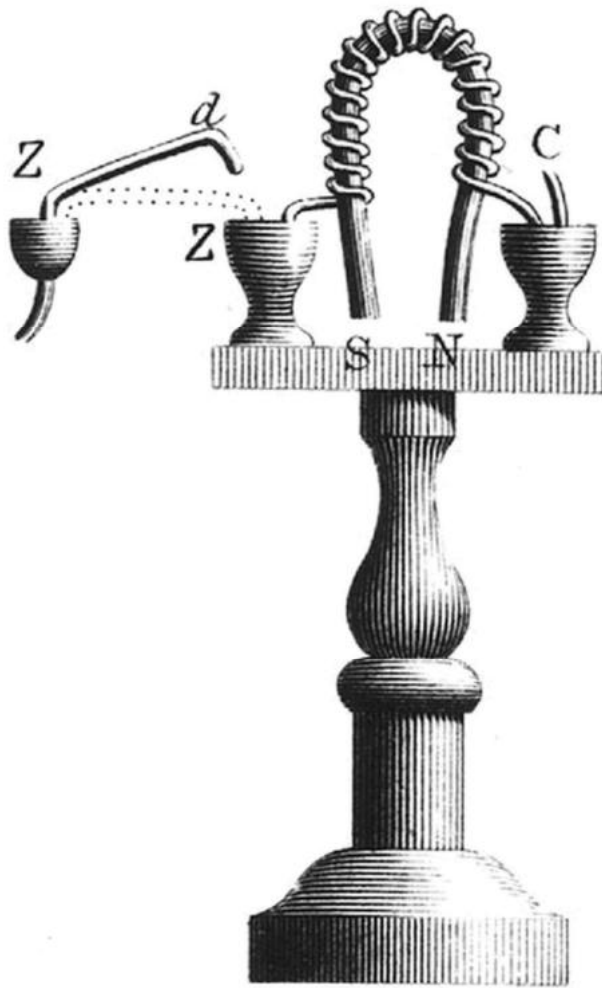
As we leave Michael Faraday's laboratory and jump across the Pond in our time-travelling Humvee, several important events are unfolding around us. In 1824, François Arago—a contemporary of André-Marie Ampère—made a puzzling discovery. When a magnetized needle is suspended just above a copper disc and the disc rotates, the needle begins to rotate in the same direction as the disc without any physical contact or direct magnetic attraction! And if a large bar magnet is suspended just over a copper disc and spins, the disc will also begin to spin in the same direction! This becomes known as *Arago's rotation* or the *magnetism of rotation* (Figure 1, next page). He proposes it is caused by an invisible force that appears only when there is relative motion between the two; however, neither Ampère's nor Hans Christian Ørsted's competing electromagnetic theories can explain why this happens. It is considered "the darkest physical phenomenon of the day".

Figure 1: Arago's Rotations

A thin, clear housing minimized air vortices from affecting the spinning disc or magnet. Credits: Black and white insert from *François Arago: A 19th Century French Humanist and Pioneer in Astrophysics*, James Lequeux, 2008. Working model from Wesleyan University Department of Physics, physics demos.



In 1825, British electrical engineer William Sturgeon invented the first practical electromagnet. He wound several turns of bare copper wire around a soft-iron bar, bent into a horseshoe shape and connected it to a galvanic battery. When electric current flowed through the coil, the iron bar became temporarily magnetized and could lift nearly 4 kilograms of iron—an astonishing feat at the time (Figure 2, next page).



More amazingly, the electromagnet's magnetism could be controlled simply by adjusting the electric current intensity (strength). And when the current stopped, the soft iron immediately lost its magnetism. Sturgeon was a skilled experimentalist, not a theorist. He chose soft iron because it worked best, not because he understood why it did. His motto was, "Experiments are intended to teach, and not to mystify"—meaning he believed experiments should make scientific principles clear, not confusing. He valued empirical clarity—if something worked reliably, it could be trusted, even if its deeper nature was unknown.

Figure 2: Sturgeon's Electromagnetic

When the electric circuit was closed, this basic electromagnet could lift several kilograms of ferrous objects and hold them until the circuit was opened.

"All the world's a stage..."

Oops! Sorry for the rough landing, but hard temporal braking was required to avoid overshooting our destination. We have arrived in Albany, New York, around 1830, give or take a year, perhaps two. It is the state capital, a thriving and wealthy city thanks to its location at the junction of the Hudson River and the newly built Erie Canal, which has transformed it into a major hub of trade and manufacturing. Here we meet Joseph Henry, professor of mathematics and natural philosophy (science) at the Albany Academy. His early life is strikingly similar to that of Michael Faraday and Humphry Davy's, the latter having recently passed away after another series of strokes (see Part 5 for their entwined relationship).

Henry (Figure 3) was born poor, the son of Scottish immigrant parents. When his father died, Henry was only nine, and his mother, Ann, became the head of the struggling household. She persevered with the help of her own mother. Henry also spent a good part of his childhood with his maternal grandmother, who ran a boarding house to support the family. At age thirteen, he was apprenticed to an older cousin as a watchmaker and silversmith—a practical and respectable career path. But Henry's real passion was for the stage! He joined a local theatre group where he acted, wrote plays, designed sets, and even directed productions. So what changed the course of his life so dramatically? As with Faraday, it was a book!

In 1814, a minor accident confined Joseph to his room at his grandmother's. There, he discovered a book a lodger had left on a table called *Lectures on Experimental Philosophy, Astronomy, and Chemistry* by Reverend Dr. George Gregory. Bored, with little else to do, Henry began to read it and was captivated within the first few pages. The book ignited a hidden passion for science that quickly eclipsed his love of the limelight!

Note 1: George Gregory was a progressive British cleric and prolific science writer who saw no conflict between religious faith and scientific inquiry.



Figure 3: Joseph Henry Daguerreotype

Circa 1845. Photographer unknown. Credit: *The Papers of Joseph Henry, Volume 6: 1844-1846, The Princeton Years*, Smithsonian Institution Press, 1972.

Henry's natural genius was shaped by the challenges of his modest upbringing and the resilience of his mother and grandmother. His theatre training gave him a commanding stage presence and eloquence when speaking before audiences. Henry could easily explain difficult concepts to others, whether they were students or other academics. With his cousin's support, he found a job as a teacher in a one-room country schoolhouse, instructing students not much younger than himself. When he had saved enough money, Henry enrolled in a teacher training course at the Albany Academy. Soon after, recognizing his potential, he was awarded a fully-paid tuition as a 21-year-old "overage" student. Then it was a college preparatory school with a curriculum consisting of ancient Latin, Greek, mathematics and science. Henry had no formal education beyond his apprenticeship and limited teaching experience, but he quickly distinguished himself. Yet he still needed to earn extra income, which he did by assisting his professors in class and tutoring students on the side who needed extra help. So exceptional at tutoring, Joseph was eventually hired to teach other professors how to teach effectively!

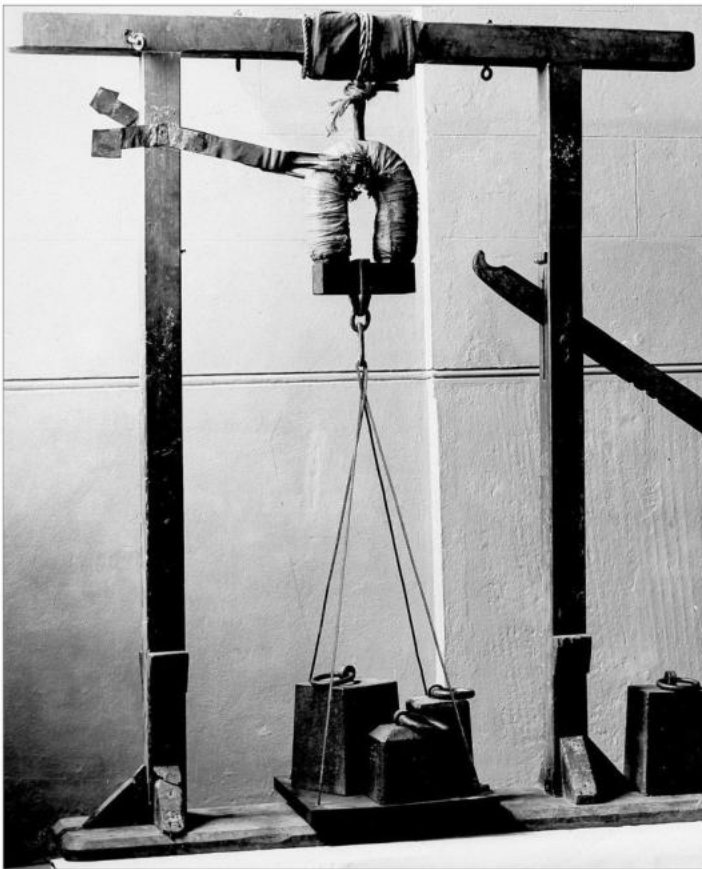
Note 2: The Albany Academy was founded on March 4, 1813 and the Albany Academy for Girls on February 24, 1814. Today, they are known collectively as the Albany Academies—an independent institution teaching gifted students from around the world.

Electromagnetic Experiments and Discoveries

Joseph Henry is now a tenured professor and family man in his early 30s. He is the lead instructor and experimentalist in science and mathematics at Albany Academy. Currently, he is teaching his teenage students about the still mysterious force of electromagnetism. His lessons combine rigorous mathematical theory with hands-on dynamic demonstrations. He has also set about improving Sturgeon's electromagnet with fellow professor Philip Ten Eyck. Through various experiments, they discover that the effectiveness of an electromagnet depends not only on the type of galvanic battery used, but also on the gauge of wire and how the turns are wound, which results in two different types, each optimized for a specific purpose:

1. The Quantity Electromagnet

Wound using multiple turns and several layers of very thick-gauge, cotton-covered copper, insulated with parchment paper between layers, around a long, large-diameter soft-iron bar (Figure 4). Each layer is soldered in parallel with the next layer above it. Driven by a galvanic battery with large area copper and zinc plates placed in a strong acid bath, which produces high current but low voltage. This generates a strong magnetic field over a short distance and is ideal for lifting heavy weights.



**Figure 4: The “Yale”
Quantity Electromagnet**

Built by Henry and Ten Eyck for an April 1831 Yale University demonstration. It could easily lift and hold 1000 kilograms. Credit: Smithsonian Institution Archives.

2. The Intensity Electromagnet

Wound in a single layer using many turns of very thin-gauge, cotton-covered copper wire around a long, small-diameter soft-iron bar (either straight or bent into a horseshoe shape). Driven by a galvanic battery with many small area copper and zinc plates placed in a weak acid bath, which produces low current but high voltage, creating a weak magnetic field that can be remotely controlled from the other end of a long-wire circuit (Figure 5, next page).

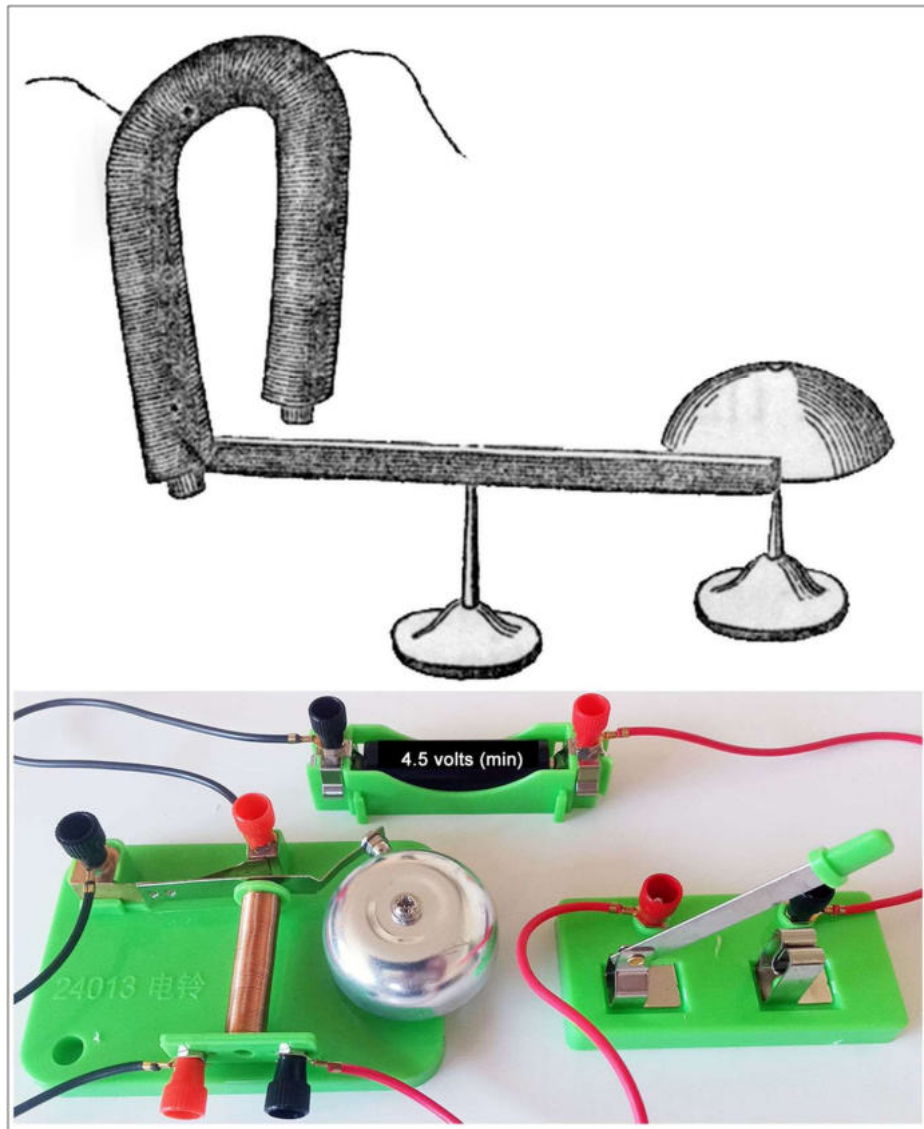


Figure 5: The “Telegraph”

A sketch of the Henry-Ten Eyck “telegraph” (sans connecting circuitry). It was used to demonstrate the concept of electromagnetic telecommunication and remote control. Below is my electricity and magnetism kit’s modern equivalent. Credit: Top image *Smithsonian Institution Annual Report for 1857*.

The “Telegraph”

In 1831, experiments are conducted at the Albany Academy by Ten Eyck and then Henry using approximately 1.6 kilometres of copper wire strung around the walls of the upper rooms, creating a long-wire electric circuit between a low-current galvanic battery and an intensity electromagnet with a magnetized steel rod, aligned to north and free to pivot like a compass needle (Figure 5) at the other end of the circuit.

One leg of the steel rod rests against that of the intensity electromagnet. A small office bell is placed near the other free end of the steel bar. When the electric circuit is closed using a knife-blade switch, the electromagnet is remotely energized and its weak magnetic field is strong enough to repel the now same-polarity end of the steel rod, forcing it to pivot and strike the bell — "ding". But strangely, brief sparks are seen to jump the terminals of the switch if it is rapidly closed and opened. However, no mention of the sparks is made in *Stillman's Journal* (only in laboratory notes). Henry speculates that electric charge continues to move briefly through the wires, producing the sparks, describing it as a kind of "electrical inertia" and "momentum".

Note 3: Scientists of the 19th century did not file patents for their inventions or concepts. They saw themselves as gentlemen scholars and believed that science should serve public knowledge, not private profit. Publishing was the preferred and acceptable way for them to claim credit. Of course, others will take advantage of their altruism; in this case, it will be Samuel Morse and Alfred Vail See my article *Snap Circuits Part 2: Mr. Morse* in the July-August 2023 issue of *TCA*. Also hosted on my website.

The Reciprocating Motor

From *On A Reciprocating Motion Produced by Magnetic Attraction and Repulsion*, *Silliman's American Journal of Science and Arts*, July, 1831 (now the American Journal of Science or AJS).

"To the Editor:

Sir:—I have lately succeeded in producing motion in a little machine by a power, which, I believe, has never before been applied in mechanics—by magnetic attraction and repulsion. Not much importance, however, is attached to the invention, since the article, in its present state, can only be considered a philosophical toy; although, in the progress of discovery and invention, it is not impossible that the same principle, or some modification of it on a more extended scale, may hereafter be applied to some useful purpose..."

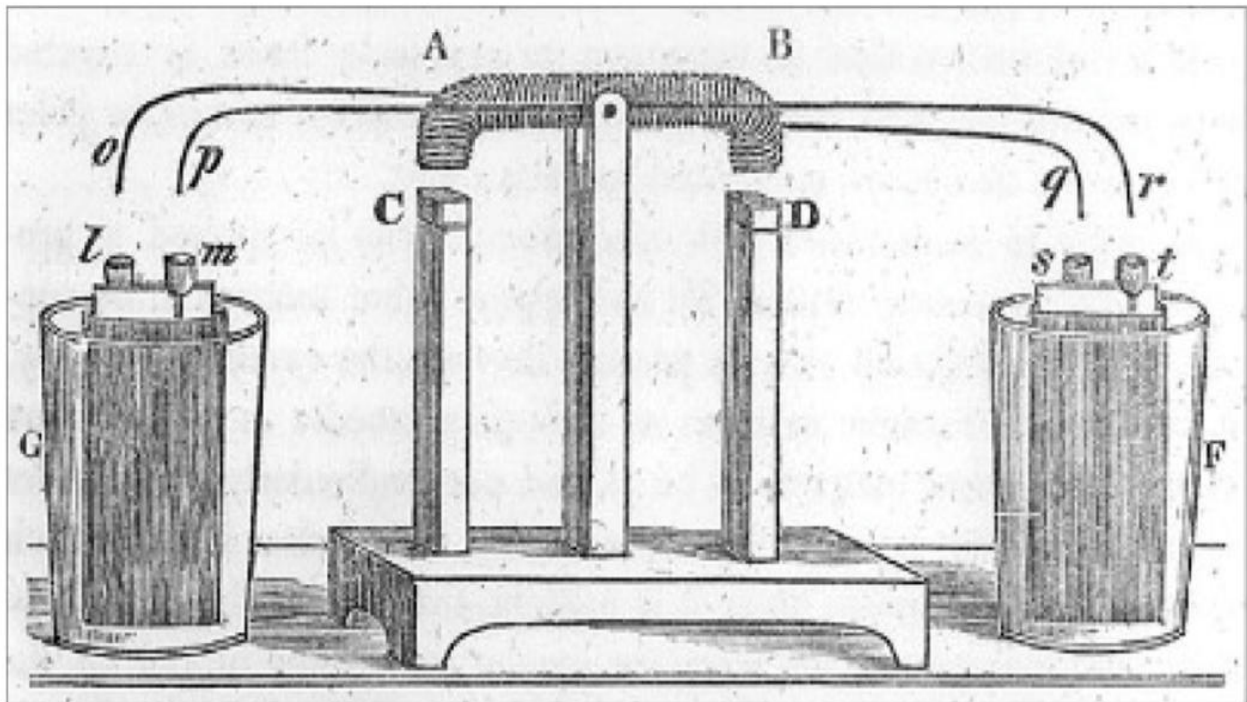


Figure 6: The Reciprocating Motor

Credit: Joseph Henry, 1831.

With reference to Figure 6, Henry's article explains how the reciprocating motion is occurs by using a long, soft iron bar intensity electromagnet free to rock back and forth between the north poles of two upright bar magnets as the polarity of its ends alternately reverse back and forth because of the make-break action between and its two wire electrodes and the battery terminals at each end. It can reach "up to 75 oscillations per minute" with sparks seen being generated between the wire ends and battery terminals during the rapid make-break action, which again, are not mentioned in this article. And yes, he has unknowingly invented a primitive spark-gap transmitter! We know that Henry does not fully understand how his reciprocating motor works because he goes on to say,

"The motion, here described, is entirely distinct from that produced by the electromagnetic combination of wires and magnets; it results directly from the mechanical action of ordinary magnetism: galvanism being only introduced for the purpose of changing the poles."

Note 4: In 1832, William Sturgeon invented the first practical direct current electric motor, expanding on Faraday's 1821 simple homopolar motor, the first device to convert electrical energy into continuous mechanical motion. Part 5 refers.

The Discovery of Electromagnetic Induction—Twice!

On a quiet evening in early 1832, Joseph Henry is startled when he reads a brief announcement in the *Proceedings of the Royal Institution, Annals of Philosophy* wherein Michael Faraday reports his discovery of what he calls *electromagnetic induction* (now *mutual induction*), the phenomenon whereby a changing magnetic field in one wire coil induces an electric current in a nearby but electrically isolated second coil. In discovering induction, he also discovered how to generate an electric current from magnetism or *magnetolectricity*, as it was called then.

Henry notes that,

“No detail is given of the experiments, and it is somewhat surprising that results so interesting, and which certainly form a new era in the history of electricity and magnetism, should not have been more fully described.”

As he sits quietly and thinks, it suddenly dawns on him that induction explains how the sparks in the long-wire telegraph circuit and reciprocating motor are generated. The following month, Henry published his discovery of “*the action of the current upon itself*” (now *self-induction*), emphasizing that his work was conducted independently and before Faraday's announcement. The paper describes how sudden changes in the magnetic field of a wire coil induce a counter-current in it, which quickly surges back through the electric circuit!

About Philip Ten Eyck

During his time at Albany Academy, Joseph Henry closely collaborated with fellow scientist, mathematician and medical doctor Philip Ten Eyck, who was five years younger and also taught at the Academy. Together, they conducted their groundbreaking electromagnet experiments and reported them in *Stillman's Journal* beginning in early 1831 under both their names (Henry's first).

Shorter versions of the same articles were published in the *Journal of the Royal Institution of Great Britain* in late 1831. What I find really interesting is that in Utrecht, the Netherlands, Dutch physicist Gerald Moll, also experimenting with electromagnets, was closely monitoring their work and sending updates on their progress to Faraday in London. Why? And did the Dutch Moll have a Dutch mole in Albany? Now free of Davy, Faraday worked alone in his basement laboratory at the Royal Institution and never published intermediary reports because he knew they could benefit his "competition". When later asked what the secret of his success was, Faraday famously replied—ala Julius Caesar—“Work. Finish. Publish.”

Henry and Ten Eyck’s work drew heavily from Georg Simon Ohm's 1827 treatise, *Die galvanische Kette mathematisch bearbeitet* (The Galvanic Circuit Mathematically Treated). As a fluent Dutch speaker, Ten Eyck could read and understand enough German to grasp the basic concepts behind the still not yet widely accepted Ohm's Law and used it to optimize the designs of electromagnets and batteries best suited for their intended purposes. When Henry left Albany for Princeton in 1832, Ten Eyck became the lead instructor and experimentalist in science and mathematics.

Note 5: For more about Ohm’s Law, see my article *Tinker Tailor Circuit CAD* published in the May-June 2021 issue of *TCA*. Also hosted on my website.

Philip Ten Eyck never married or had children, but he did have four younger siblings. Sadly, the whereabouts and/or disposition of all his personal correspondence, laboratory notes, travel journal, diary, etc., are unknown. We do know that he and Henry visited England in 1837 (from Henry's travel journal), where they met with Michael Faraday and clarified the still lingering priority dispute surrounding electromagnetic induction and who actually discovered what and when, along with Charles Wheatstone (who helped Ten Eyck to better understand the mathematical proofs behind Ohm’s Law) and several other prominent scientists of the day.

Philip Ten Eyck's quiet, low-profile life makes it difficult to find information about the man. I accidentally stumbled on the Moll letters written to Faraday that mentioned Joseph Henry and him. Not knowing about their collaboration, and being curious, I started to dig and was able to find the Henry-Ten Eyck coauthored articles, a Dutch Wikipedia page's short but concise paragraph about him, which provided links to his family tree and New York Times obituary; selected portions of which read,

"Dr. Philip Ten Eyck, the associate of the famous Joseph Henry died yesterday (July 15, 1893) at Albany, N.Y. He was 91 years old...In his early life he was the daily companion of Joseph Henry... Suggestions that led to experiments in electromagnetism were of the united minds of Ten Eyck and Henry. The former got the instruments in order in the academy building and made the first experiments by which a current was passed through the wire that sounded the alarm bell that electrified the world..."

My Final

Well, time to take a break and recharge the quantum jump drive before we make another transatlantic hop to see what Mr. Faraday has been doing in our absence.—

Additional References and Resources

Joseph Henry: The Inventor of the Telegraph? <https://tinyurl.com/3spy5fme>

Joseph Henry: A Life in Science <https://tinyurl.com/c4frbhkr>

Joseph Henry Project <https://tinyurl.com/5edc6ncn>

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The Papers of Joseph Henry, Volume 1: 1797-1832, The Albany Years, Nathan Reingold et al, Smithsonian Institution Press, 1972.

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