Robert C. Mazur, VA3ROM | www.va3rom.com | va3rom@gmail.com

First published in the November-December 2024 issue of The Canadian Amateur

The Road to Radio—Part 1

The Journey Begins

Around 600 BCE, the ancient Greek philosopher Thales of Miletus wrote about a strange phenomenon that occurred whenever "ēlektron" (amber) was rubbed with fur. It became magically able to attract small, lightweight objects such as feathers, hair or papyrus (Figure 1). He also described the peculiar properties of the "magnētis lithos"— the Magnesian stone (magnetite/lodestone)—to attract small iron objects. In Thales' time, this would have been seen as a supernatural or mystical occurrence that required no further explanation or investigation by mere mortals—the gods have spoken. In the centuries that followed, there was no further investigation of or practical use found for either phenomena.

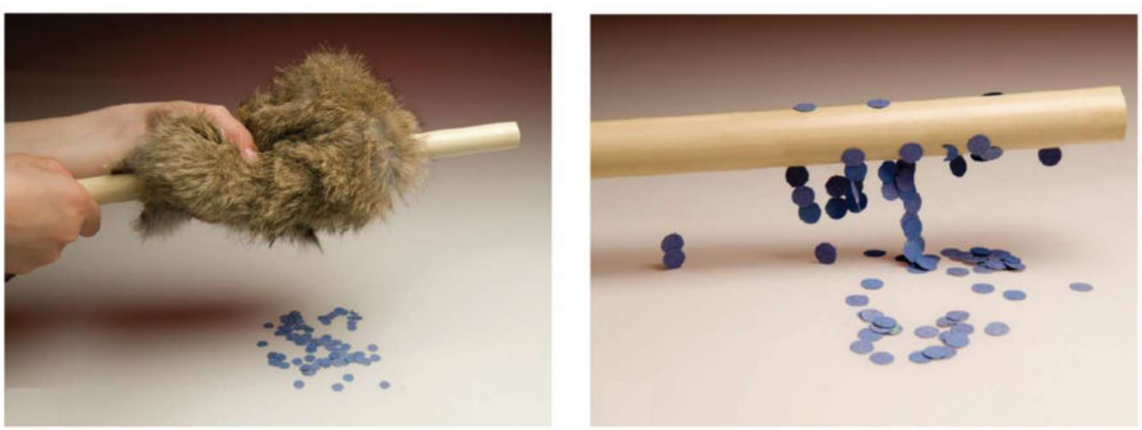


Figure 1: Static Electric Charge

A plastic rod is rubbed with fur and acquires a static electric charge and can then attract small bits of paper. Credit: Nelson Education, Physics 12 textbook.

Note: Prior to the invention of the electrochemical cell in 1800, “electricity” only meant static electricity generated by friction and lightning. Instead of electrostatic charge the term electric charge was used.

In the early 11th century, Chinese nautical navigators modified the much older “south-seeking spoon” (Figure 2) used for divination and geomancy (Feng Shui), by magnetizing steel needles and floating them in water bowls to minimize the rocking and rolling action of ships in rough seas. They called it the “south-seeking needle” because it was marked and aligned to point south based on their cultural preference for that direction.

Figure 2: Chinese South-pointing Spoon
This replica was made in the 20th century. The precursor to the compass, it goes back two millennia to the Han dynasty. Credit: Wikipedia.

By the late 12th century, European mariners learned about it from Arab mariners via the “Maritime Silk Road” trading route that connected Arab and Chinese traders who conducted business at ports in India (the midway point), which facilitated the exchange of goods along with cultural and technological exchanges long before the European Age of Exploration. It quickly evolved into the north-seeking “compassus” (compass) because all maps and charts in the West were (and still are) drawn north-up, originally to align them with the North Pole Star (Polaris).

De Magnete

At the dawn of the 17th century—2200 years after Thales—"electricus" (electricity) and "magnetica" (magnetism) were still as mysterious and puzzling, believed to be two separate, unrelated, distinct forces of nature. In 1600, William Gilbert published his famous *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* (On the Magnet, Magnetic Bodies, and the Great Magnet of the Earth). In it were carefully crafted experiments that conclusively proved:

- The Earth is a giant bar magnet with two poles (Figure 3).
- The magnetic compass needle points to the North Magnetic Pole not Polaris.
- Like magnetic poles repel, unlike magnetic poles attract (Figure 4, next page).
- No matter how many times you divide a bar magnet, the pieces always create north and south pole pairs. There are no north or south monopole magnets.

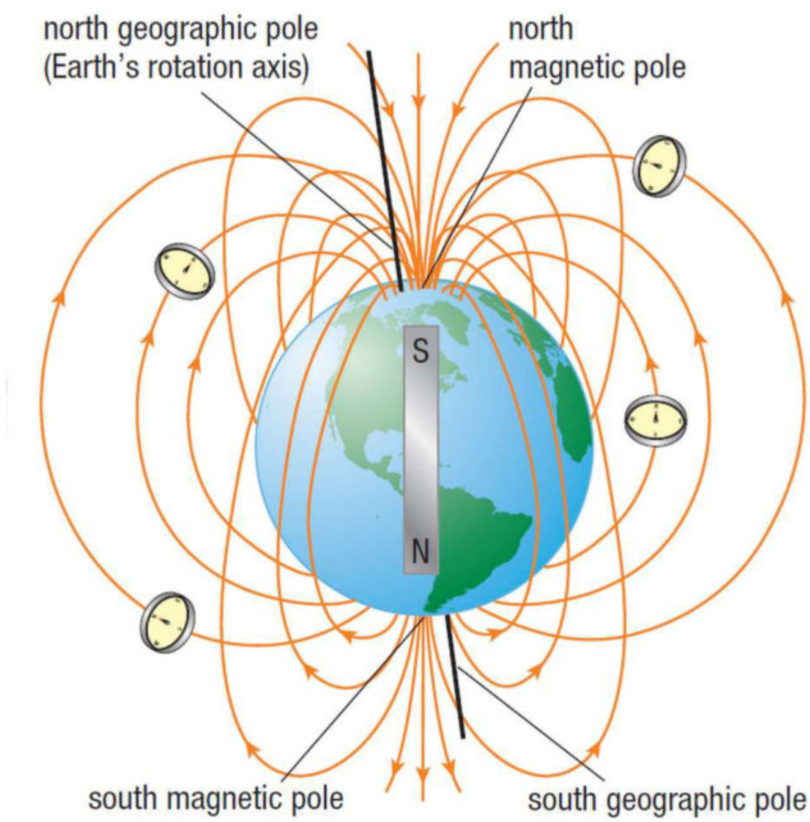


Figure 3: Earth's Magnetic (Geomagnetic) Field

The north poles of compass needles align parallel to the geomagnetic field and point to the North Magnetic Pole. A misnomer because it is actually a bar magnet's south pole that happens to be, for now, located geographically to the north. Credit: Nelson Education, Physics 12 textbook.

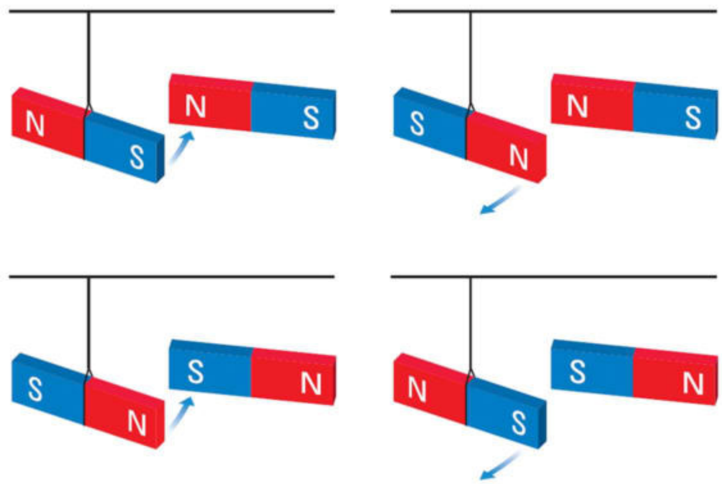


Figure 4: The Law of Magnetic Poles
Credit: Nelson Education, Physics 12 textbook.

These revolutionary revelations influenced Johannes Kepler and Galileo Galilei, who both cited *De Magnete* as part of their own investigations into the natural world. Gilbert's systematic study and interpretation of magnetism, observations and terminology remain largely in use today. He was that good, but was unable to extend any equivalent principles to electricity. He invented a primitive electric charge detector, called a "vesorium" (Latin for "turn around") to try and do so (Figure 5), inspired by his study of the magnetic compass. Just as the compass needle moves in response to a magnetic field, the vesorium moved in response to what he called "effluvium" or attraction through friction.

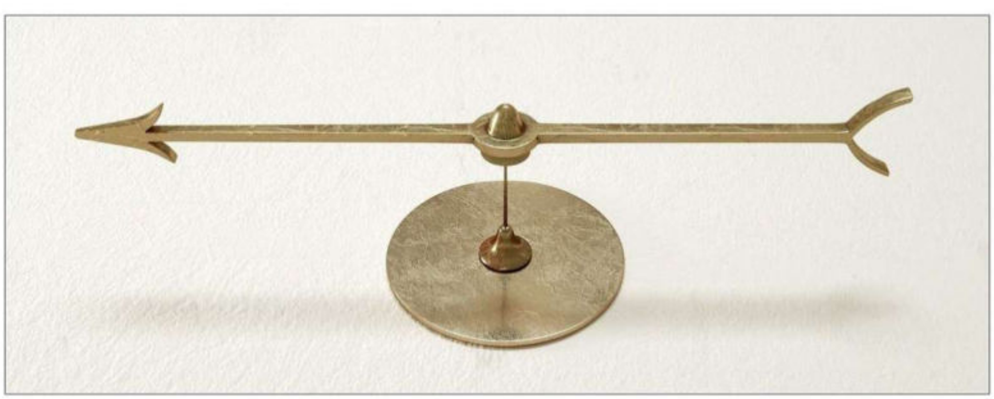


Figure 5: The Vesorium Electric Charge Detector
The vesorium uses a metal needle balanced on a delicate pivot, but unlike a compass needle it was not magnetized and reacted only to nearby static electric charges. Credit: Vesorium Capital.

Gilbert rubbed various materials (fur, cloth and silk) against other substances—glass, sulphur, wax and various resins (amber, rosin, etc.) and they all acquired various strengths of effluvium, which the vesorium would react to, however, it could not determine electric charge polarity. He probably suspected that complementary electric charge pairs must exist analogous to magnetic pole pairs, but skilfully avoided the "logic trap" whereby a deceptive argument or faulty reasoning often leads to incorrect conclusions that seem perfectly logical and valid yet are actually flawed. Instead, he realized that while magnetism and electricity seemed similar, he refused to jump to any conclusions or draw speculative parallels between the two. Gilbert required empirical proof based only on careful experimentation and observation that others could easily reproduce, obtain the same result(s) and reach the same conclusion(s). His methodology would later become a cornerstone of the "scientific method".

The "Electricians"

The fluid theory of electricity emerged in the early 18th century, stating that electricity was an invisible fluid that flowed from one object to another. In 1733, Charles François du Fay proposed a two-fluid theory of electricity with two types of electric charges: "vitreous" (associated with glass) and "resinous" (associated with resins like amber). He came to this logic trap conclusion by observing that whenever materials with vitreous electricity interacted with those with resinous electricity, they attracted each other, and whenever materials of the same type of electricity interacted, they repelled each other.

If electricity was actually a fluid, then logically, it should be possible to condense and store it in a non-conductive glass container or "phial", meaning a bottle, flask, jar or test tube. In 1745, using an enhanced version of Otto von Guericke's electric charge friction generator invented in 1672, Pieter van Musschenbroek—a professor and renowned experimentalist at Leiden University in the Netherlands—along with his student Andreas Cunaeus, conducted experiments that led to the invention of what became known as the Leiden (Leyden) jar, the first "condenser" of electric fluid (Figure 6, next page).

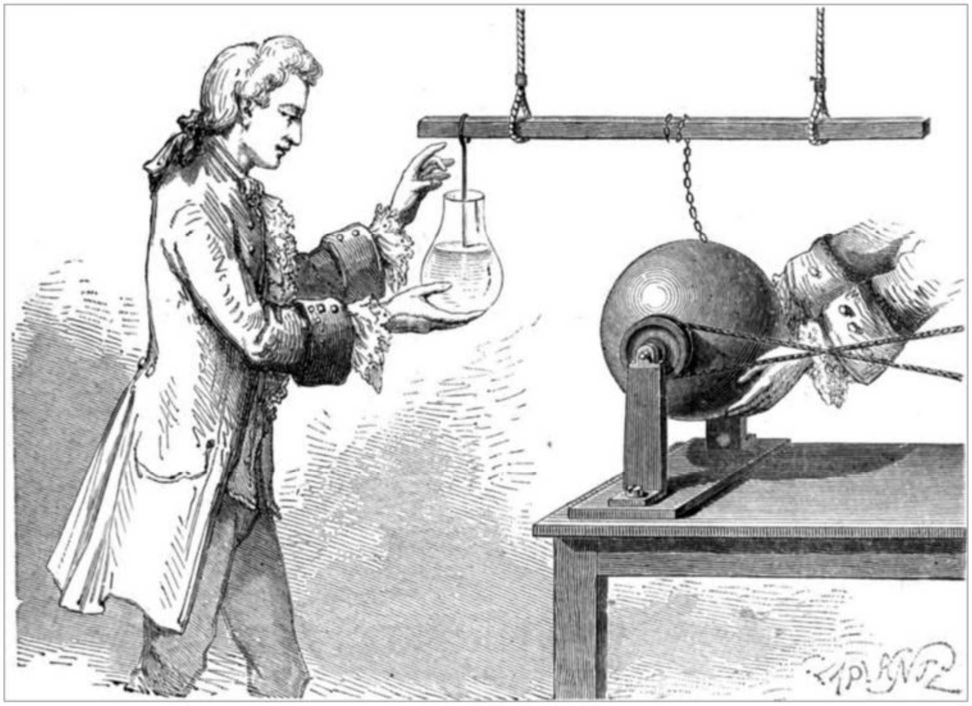
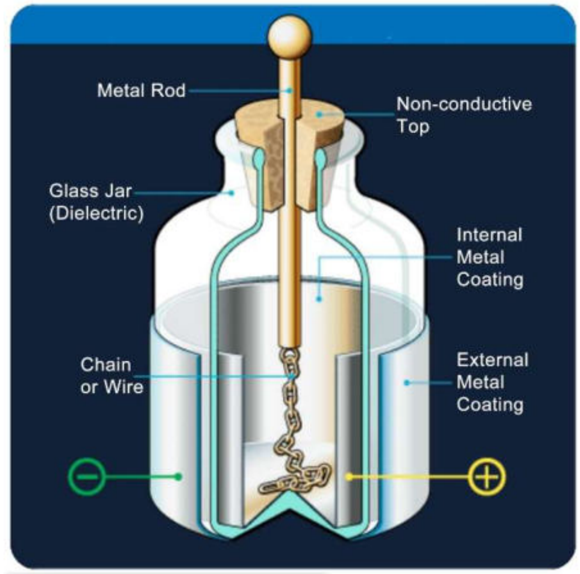


Figure 6: "Discovery of the Leyden jar in van Musschenbroek's Lab"
High-voltage electricity produced by a glass sphere electric charge friction generator is "condensed" in a saltwater-filled glass jar held by Andreas Cunaeus. Credit: *Elementary Treatise on Natural Philosophy, Part 3: Electricity and Magnetism* by Augustin Privat-Deschanel, 1876.

In an early test, van Musschenbroek accidentally discharged a Leyden jar through his body. The shock was so powerful that he was nearly knocked to the floor, stunned and shaken by the totally unexpected force. Writing to a colleague: "I would not take a second shock for the crown of France!" Huzzah, du Fay was right! But something was not right, actually. So much so that van Musschenbroek later wrote, half-jokingly or perhaps not: "I have found out so much about electricity that I have reached the point where I understand nothing and can explain nothing."

News of the invention spread like lightning. In England, William Watson improved the design by coating the inside and outside of phials with metal foil, increasing their "capacity" to hold electric fluid (Figure 7, next page). He then observed reoccurring, predictable patterns of behaviours and proposed an alternative single-fluid model whereby electric fluid flowed between objects with a surplus going to those having a deficit without being created or destroyed in the process.

Figure 7: Improved Leyden jar
Essentially it is a parallel plate condenser (capacitor) using a glass "dielectric", an insulating material (air, glass, plastics, ceramics, etc.) that does not readily conduct electric charge. When placed within an electric field, dielectrics become strongly polarized, preventing electric fluid from flowing between the conductive plates. Dielectrics increase the capacitance to hold more electric fluid. Credit: HowStuffWorks.com.



When properly handled, the Leyden jar could produce a spark or even a flame with a loud retort, like a cannon shot, by an "electrician"—a term used for one engaged in scientific study or speculative use of electrical phenomena. In fashionable parlours and salons across America, Britain and Europe, well-paid electricians amazed their audiences with indoor Leyden jar created "lightning" and "thunder". They performed amazing magic tricks demonstrating attraction, repulsion and transference of static electric charges, and sometimes used their electric charge friction generators for "naughty" forms of adult entertainment (Figure 8).

Figure 8: "The Electrified"
A young lady on an insulated platform is electrically charged by an electrician using a glass sphere friction generator. Touching her literally made the sparks and her clothes fly! The ribald text says, "I know where this almost magical virtue, cleverly called electric, is best found; Young beauties, it is in your eyes." Credit: *Die Elektrisierte* by Hubert-François Gravelot, 1750.

Meanwhile, in the American colonies, one of the greatest scientific minds of the 18th century, the self-taught polymath genius Benjamin Franklin, conducted his own electrical experiments. In the late 1740s, he embraced Watson's single-fluid theory and introduced the terms "positive" (excess of fluid) and "negative" (deficiency of fluid), boldly stating that electric fluid flowed from positive to negative or ground (conventional current flow to us). He borrowed the military term "battery"—referring to a grouping of cannons to increase their effective firepower—to describe the series connection of Leyden jars to increase their effective electric firepower. Franklin and Watson also co-discovered and defined the first two fundamental principles of electric charge central to the modern conservation of charge law:

- Electric charge cannot be created or destroyed, only transferred.
- Like electric charges repel, unlike electric charges attract (Figure 9).

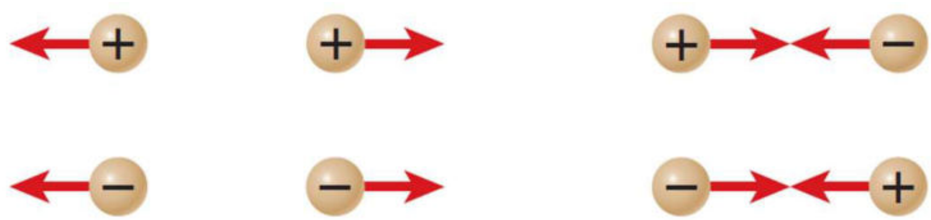


Figure 9: The Law of Electric Charges
Credit: Nelson Education, Physics 12 textbook.

One result of this was Franklin's invention of the lightning rod or "attractor". By the early 1750s, he had installed lightning rods to protect several important buildings in Philadelphia, Pennsylvania, by redirecting "electric fire" (his term) to ground. But the reason why this worked was thought by most people to be based more on faith than fact. So, sometime in June 1752, Franklin, assisted by his adult son William, risked life and limb to prove that lightning was a form of electricity, not divine retribution punishing sin and immorality. The irony, not lost on Franklin, was that church steeples were frequently struck and many churches burned to the ground!

In a letter dated October 19, 1752, he explained the kite experiment to British colleague Peter Collinson:

> Make a small cross of two light strips of cedar, the arms so long as to reach the four corners of a large thin silk handkerchief when extended; tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite; which being properly accommodated with a tail, loop, and string, will rise in the air, like those made of paper; but this being of silk is fitter to bear the wind and wet of a thunder gust without tearing.
>
> To the top of the upright stick of the cross is to be fixed a very sharp pointed wire, rising a foot or more above the wood. To the end of the twine, next to the hand, is to be ty'd a silk ribbon, and where the silk and twine join, a key may be fastened. This kite is to be raised when a thunder gust appears to be coming on, and the person who holds the string must stand within a door, or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window.
>
> As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the loose filaments of the twine will stand out every way, and be attracted by an approaching finger. And when the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle.
>
> At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the help of a rubbed glass globe or tube; and thereby the sameness of the electric matter with that of lightning completely demonstrated.

Franklin had captured “lightning in a bottle” (the origin of the phrase). Peter Collinson spread the news to the Royal Society of London and the larger European scientific community. Franklin became a world-famous “shock star” and hailed as the “American Prometheus”. His work and personal letters were collectively published as *Experiments and Observations on Electricity, Made at Philadelphia in America (1751; revised 1753)*.

Galvani v. Volta

In a modest late 18th-century laboratory, Luigi Galvani was dissecting a frog when his assistant accidentally touched its exposed nerves with a metal scalpel (or so the story goes). To Galvani’s shock then amazement the frog’s leg twitched as though being brought back to life (Figure 10)!

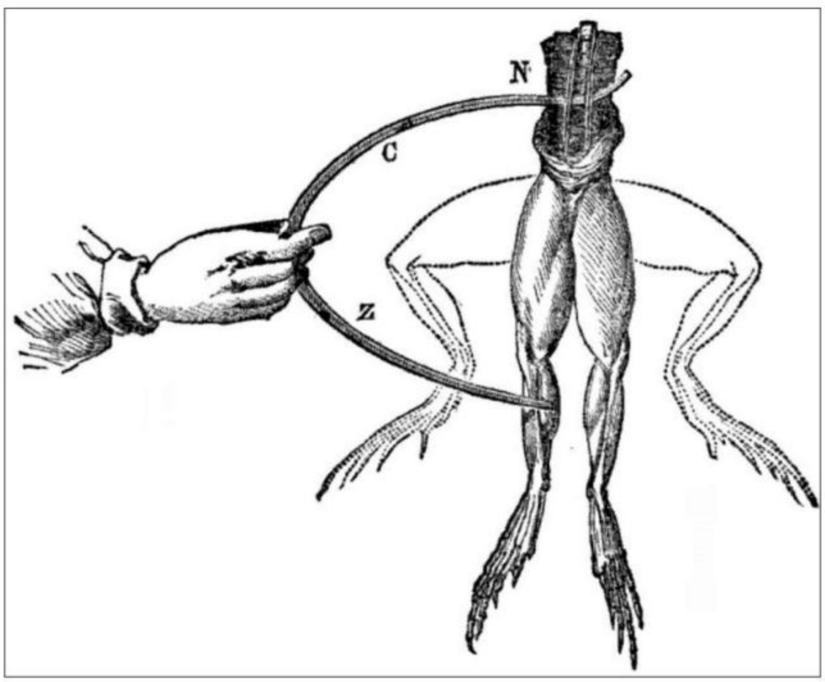
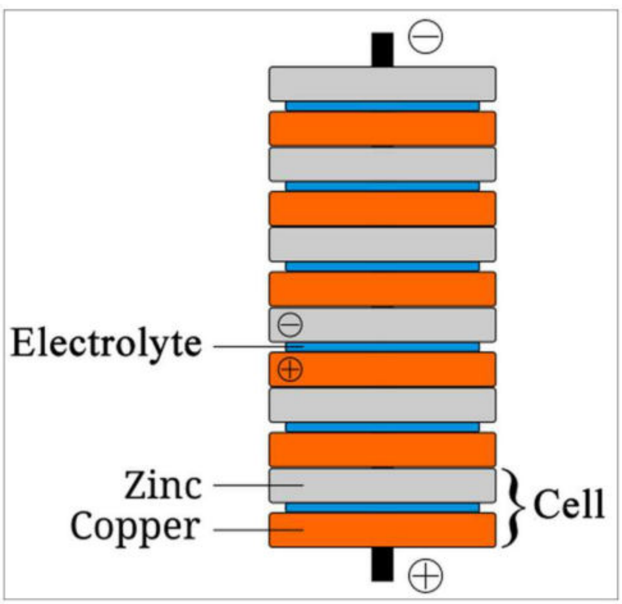


Figure 10: Animal Electricity
The frog’s legs twitched supposedly because animal electricity within it was released whenever the nerves to its muscles were touched by a metal object. Credit: *The Science of Common Things* by David Ames Wells, 1859.

He repeated the experiment and observed that the frog’s muscles contracted with varying intensities depending on the type of metal that touched its nerves. Galvani excitedly assumed (logic trap) that he had discovered a new form of electricity—“animal electricity”. He published his findings in a series of papers beginning in 1791, introducing animal electricity to the world, but it became more popularly known as “galvanism”.

His nephew, Giovanni Aldini, a medical doctor, took it to the extreme by conducting demonstrations “galvanizing” various body parts of dissected cadavers—usually freshly executed criminals—before other doctors, medical students, at public gatherings—even in private homes! Galvanism quickly became the macabre rage of the age, however, not everyone was convinced.

Alessandro Volta was extremely sceptical of Galvani’s conclusion. He believed that electricity was generated not internally by the frog but by the metals touching its moist tissues. To test his theory, Volta constructed a mechanical model by stacking alternating discs of copper and zinc—two dissimilar metals—separated by cloth soaked in brine (Figure 11). He connected wires to the top and bottom discs then touched them to his tongue (no handy voltmeter), and reported feeling a slight shock, peculiar sensation and taste in his mouth. Unlike the sudden release of electric fluid by a Leyden jar in one shot, a continuous and steady “dynamic” electric fluid was flowing from Volta’s pile through his tongue! Triumphant, he sent a smug note to Galvani:



“I do not need your frog; give me two metals and a moist rag, and I will produce your animal electricity. Your frog is nothing but a moist conductor, and in this respect, it is inferior to my wet rag!”

Figure 11: Volta’s Pile or Battery
Credit: Wellcome Images, Wikimedia Commons.

Volta's pile was empirical proof that dissimilar metals could generate dynamic electricity, although he downplayed the role of any chemical reactions, considering them non-essential, believing that it was the contact between dissimilar metals (contact potential theory) that did the deed. How Volta's (voltaic) pile actually worked was left for others down the road to discover.

Note: In English, Volta's pile, with its series connected cells to increase their effective electric firepower, became Franklin's "battery", while the Romance languages still use "pile" or variations thereof today.

As an aside, Dr. Aldini's demonstrations continued until the early 1830s (his death), and are believed to have been the young Mary Shelley's inspiration for Dr. Victor Frankenstein, and the concept of the "spark of life" used to reanimate "the creature" made from fresh cadaver parts. By the mid-19th century, Aldini's medical students, who perhaps also read *Frankenstein*, discovered that all living organisms generate dynamic electricity internally (bioelectricity).

All this because of one dead frog!

My Final

Okay. Time to pull over, take a break and recharge our Humvee's quantum time-jump drive and stealth cloak. Along the way, we have picked up three very important "hitchhikers": the Leyden jar, voltaic cell and compass. But there are many more years and kilometres to go, with speed bumps, cul-de-sacs, round-abouts and detours along the way.—73