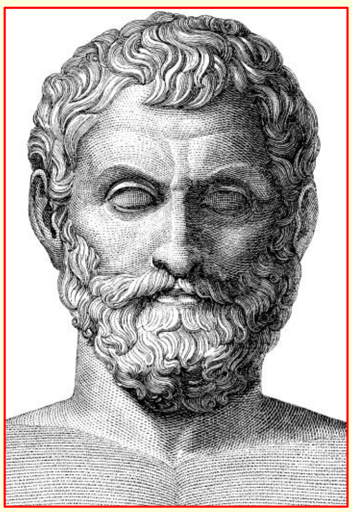
Electricity

Staccato Lightning
New Boston, Texas
September 1, 2013

Photograph from
https://commons.wikimedia.org/wiki/File:Staccoto_Lightning.jpg



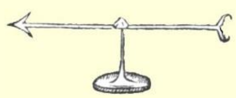
Thales of Miletus (624-546 BCE)

A pre-Socratic philosopher whose work is known only through secondary sources such as Aristotle, Thales believed in the primacy of water. He described static electricity such as can be obtained by rubbing amber with wool (triboelecticity from *tribo* rub). He also considered the nature of the stones that came from Magnesia (*magnetis lithos*), an ancient city in present day Turkey where magnetic stones (lodestone, magnetite) could be found.

Lodestone comes from *lode,* a Middle English word for guide. Lodestone is composed of magnetite – Fe_3O_4 – that has been magnetized, probably by the strong magnetic fields surrounding lightning discharges.
Lodestone was first used for a compass by the Chinese around 200 BCE. Later compasses were made from iron needles that had been magnetized by a lodestone. These came to be used in Europe around 1300.

William Gilbert (1544-1603)

A physicist and physician, Gilbert published *De Magnete* in 1600. This described the magnetic field of the earth and distinguished between magnetism and electricity. He proposed that the Earth was itself a magnet. Gilbert was the first to use the term electricity, deriving it from the Greek *elektron* for amber. He used a non-magnetized needle (*versorium*) to detect charged objects:

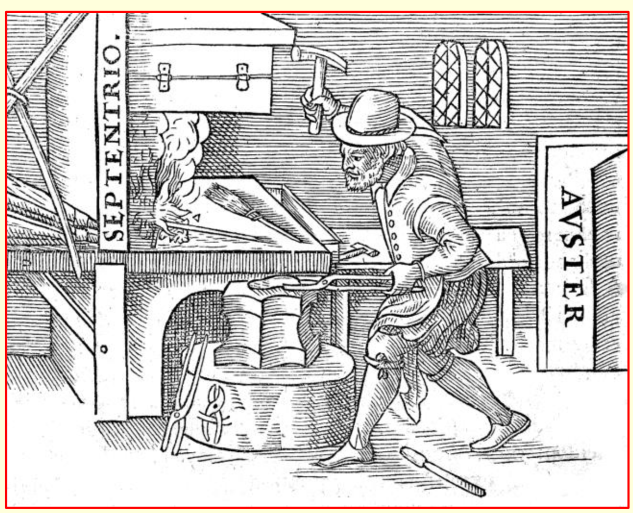


Gilbert was appointed personal physician to Elizabeth I and (briefly) to James I.
Gilbert supported the Copernican heliocentric theory of planetary motions.
Proposing that the earth was itself a magnet contradicted the mythical idea of a northern island named Polaris that magnetically attracted compass needles.

The *versorium* works because a charged object causes changes in the metal needle – electrostatic induction. For example if it approaches a positively charged object, the electrons in the metal are drawn toward the end of the needle closest to the object. This end becomes negative and is attracted to the object.

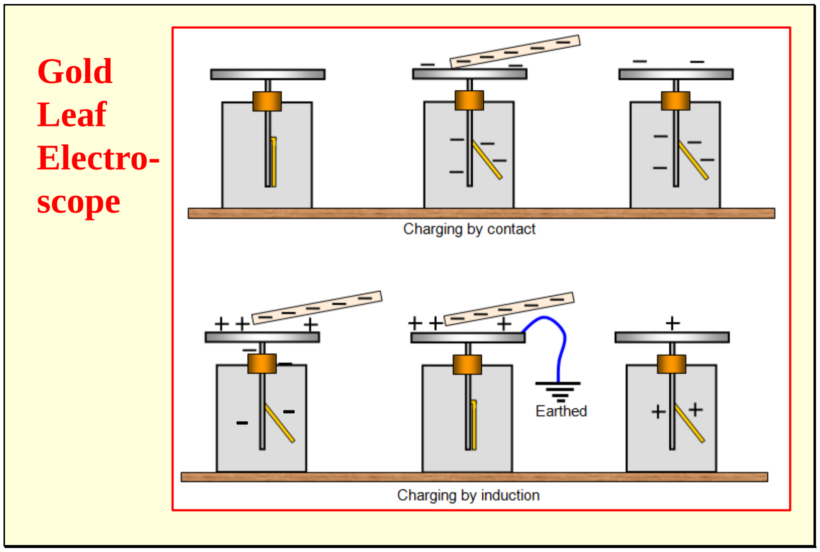
Illustration from Gilbert's *De Magnete*

Blacksmith hammering iron bar to make it magnetic.



The idea is that hammering the bar when it is oriented from north (septentrio) to south (auster) will render it magnetic. However, the effect is very slight. A recent paper about Gilbert's claim is at http://rsnr.royalsocietypublishing.org/content/65/4/411

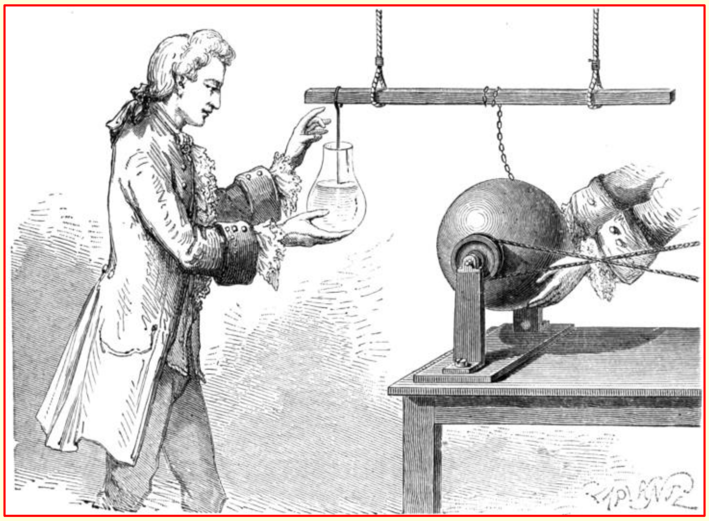
The term *septentrio* refers to the seven stars of the Great Bear constellation in the northern sky, and *auster* refers to the southern winds.



This electroscope was invented by a British Clergyman Abraham Bennet in 1787. It was more sensitive and reliable than previous electroscopes using tiny needles (Gilbert's *versorium*) or pith balls that were attracted to charged objects.

The electroscope works because like charges repel each other. If the very light gold leaf becomes charged it is repelled away from the other metal which is similarly charged.

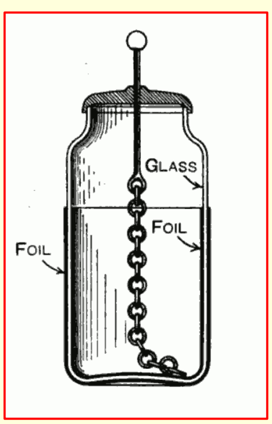
In these example, a rod is negatively charged by rubbing with cloth. This is the "triboelectricity" of Thales. The electroscope can be activated by direct contact, whereby charge flows into the electroscope. It can also be activated by "induction." In the lower example the negatively charged rod attracts positive charge to the top of the electroscope – leaving the lower part of the electroscope with the gold leaf negatively charged. If the contact region of the electroscope is grounded the negative charge is drained to ground. When the charged wand is removed the electroscope is positively charged



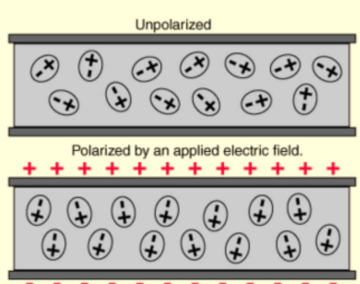
The Leyden Jar provided a way to store electric charge. Its discovery is usually attributed to work in the laboratory of Pieter van Musschenbroek (and his assistant Andreas Cuneus) in 1745 in Leyden. They used an electrostatic generator – a rotating glass sphere. This was derived from the earlier generators designed by Otto Von Guericke in the 17^{th} Century.

The glass sphere at the right is rotated by a belt moved by a crank (not shown) rotated by an assistant. Friction between the glass and the hands builds up change on the glass. This is transferred via the chain and the metal bar suspended with nonconductive silk cords to the wire going into the water in the jar. The conductive water in the bottle and Cuneus's hand supporting the jar, separated by the thin insulating glass, form a capacitor able to store charge. A large charge builds up in the water, and an opposite charge builds up in Cuneus's hand, attracted through his body from the ground. When Cuneus touches the wire going into the jar he provides a conducting path between the two opposite charges held in the jar and gets a significant shock.

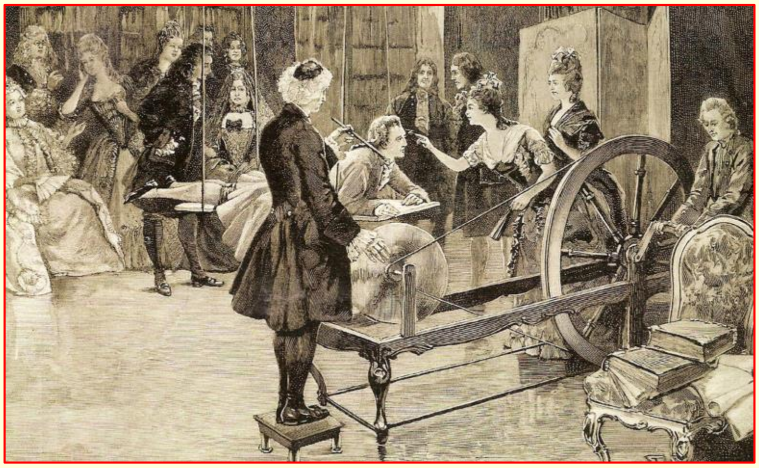
Leyden Jar



The Leyden Jar was the first "capacitor" storing opposite charges on either side of the glass. The glass is a "dielectric" – a type of material that does not conduct electricity but can be electrically polarized to balance out an accumulated charge.

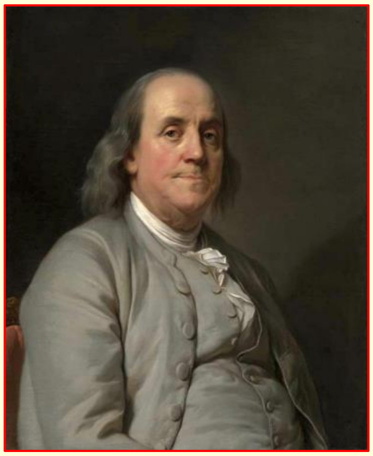


Leyden jars were used to store charge for electric experiments. However once the two sides of the jar were connected the accumulated charge dissipated. There was no sustained current. This would have to await the discovery of the bimetallic battery by Alessandro Volta



Abbé Nollet and the electric boy, 1746

The Abbé Nollet (1700-1770) was a French priest and physicist. He demonstrated electrical phenomena at various salons in Paris. The electric boy was a demonstration wherein a young man was suspended from the ceiling using insulating silk cords, and electrified using an electrostatic generator. Light objects were attracted to him. It another person came close to him they could initiate sparks as the charge in the boy dissipated to ground.



Portrait by Joseph Duplessis, 1785

Benjamin Franklin (1706-1790)

Born in Boston, Franklin attended school only until he was 10 years old. He taught himself everything he knew. At the age of 17 years he went to Philadelphia and worked in the printing business, publishing the *Pennsylvania Gazette* and *Poor Richard's Almanack.* His interest in science led to his experiments with atmospheric electricity and the invention of the lightning rod. He later contributed to the Declaration of Independence and the US Constitution.

Kites and Keys and Lightning Rods

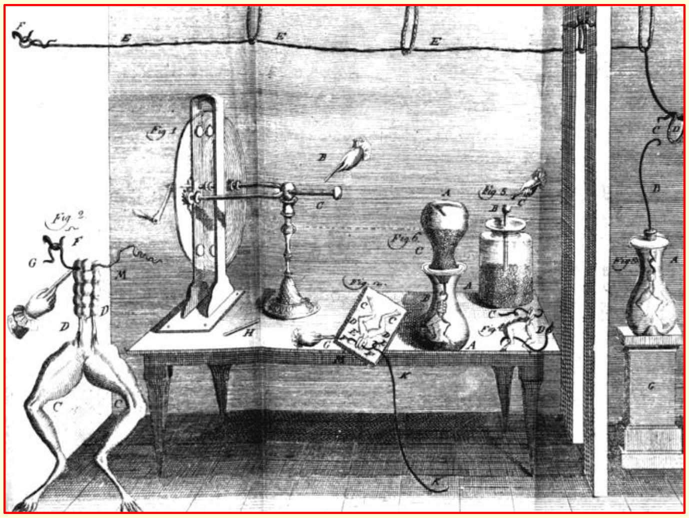
Benjamin Franklin's experiments on atmospheric electricity (1747-50) showed that the lightning discharge was electrical in nature. This led him to recommend the use of lightning rods on tall buildings. The idea was to provide a low-resistance pathway for excess atmospheric electricity to be drained to ground, or for an actual lightning strike to reach ground.

Benjamin Franklin Drawing Electricity from the Sky
Benjamin West, 1816

The painting shows one of Franklin's experiments. It falsely suggests that the scientist tapped a lightning strike. Actually he flew his kite when there was no actual lightning. Furthermore he kept himself dry under a roof. The advice to those who wish to replicate his results is "Do not do this!"

Luigi Galvani (1737-1798)

Galvani studied medicine at the University of Bologna and became interested in the possibility of "animal electricity." He published *De viribus electricitatis in motu musculari commentarius* (Commentary on the Effect of Electricity on Muscular Motion) in 1791. This described experiments using a preparation of isolated frog legs. He found that the legs twitched when touched by a metallic probe. They also twitched when an electrostatic generator gave off sparks or when there was thunder in the air.



This illustration from Galvani's book shows some of his experiments. At the left the frog-legs twitch when the nerves are touched by a metallic probe and there is a spark from the electrostatic generator. This is not an easy experiment to explain or to duplicate. What is probably happening is that the spark gives off electromagnetic radiation which is picked up by the human being and probe acting as an antenna. A similar effect is noted (in the center) when the frog-legs are connected to a wire (which more effectively acts as an antenna). The illustrations on the right show that the frog-leg preparation is a very sensitive electroscope, for charged objects or for atmospheric electricity.

Almost all of Galvani's experiments demonstrate that the neuromuscular system is "sensitive" to electrical stimulation but they do not really demonstrate that the nerves and muscles work by means of electricity.

Alessandro Volta (1745–1827)

Intrigued by Galvani's experiments, Volta, a professor in physics in Como, began to study electricity. He decided that the frog legs were activated by the electricity generated between the different metals in the probes. Galvani had used a probe of iron and the frog-legs were affixed on a brass hook. This idea led Volta to develop the voltaic pile, the first battery. Napoleon was impressed by Volta's experiments and bestowed several honors on the physicist, making him a count and a senator.

What Volta is actually demonstrating to Napoleon is the ignition of methane by an electric spark. His voltaic pile is on the table.

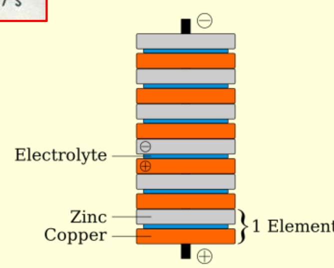
Napoleon had invaded northern Italy in 1796 and over the next two years defeated the Austrian forces who controlled Northern Italy. In 1802 he was named the king of the newly formed Kingdom of Italy.
Unlike Volta, Galvani was unable to swear allegiance to Napoleon's government because he considered it atheistic. He therefore lost his university position and retired from science.

The great difference between the Voltaic pile and the Leyden jar is that the pile gives a sustained current.

The unit of electromotive force – the volt – is named after Volta

Bimetallic Electricity

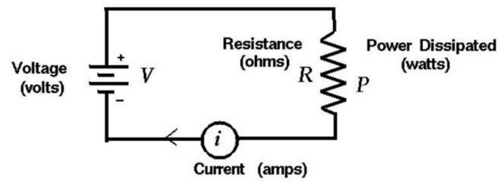
Volta's electrical pile consisted of alternating discs of zinc and copper separated by a piece of cloth or cardboard soaked in brine or vinegar. The two metals differ in their ability to dissolve into the electrolyte and release electrons. In this particular pairing the zinc dissolves and becomes negative relative to the copper



The equation for the battery is
$Zn \rightarrow Zn^{+2} + 2e^-$
This loss of electrons is called oxidation. The gain of electrons by the copper electrode is reduction. The zinc is negative relative to the copper. The difference in potential of this battery is about 1.4 volts.
The most common battery for a car is uses lead and lead oxide. However there battery connects several sheets of zinc in series to give a total voltage greater than 12 volts.

Electric Circuits

Volta's batteries allowed a constant current to flow in an electrical circuit. This differed completely from the transient current that flowed from a Leyden jar.



$$V = i\ R$$

$$P = i\ V = i^2 R$$

The French physicist André-Marie Ampère (1775-1836) studied the currents that occurred in these electric circuits.

The German mathematician Georg Simon Ohm (1789-1854) found in 1827 that the voltage in a circuit depended on the resistance over with it was measured. This relationship became known as Ohm's law (illustrated)

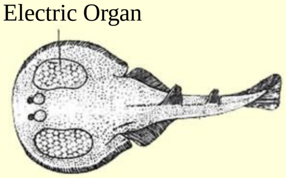
The power generated in the resistor could in part do work or could be dissipated in the form of heat or light.
The unit of power is named after James Watt who invented the steam engine.

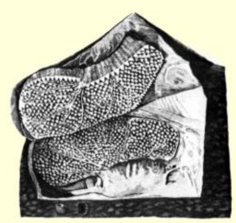
Animal Electricity

Galvani and Aldini, 1794

Alexander von Humboldt, 1797

Electric Organ

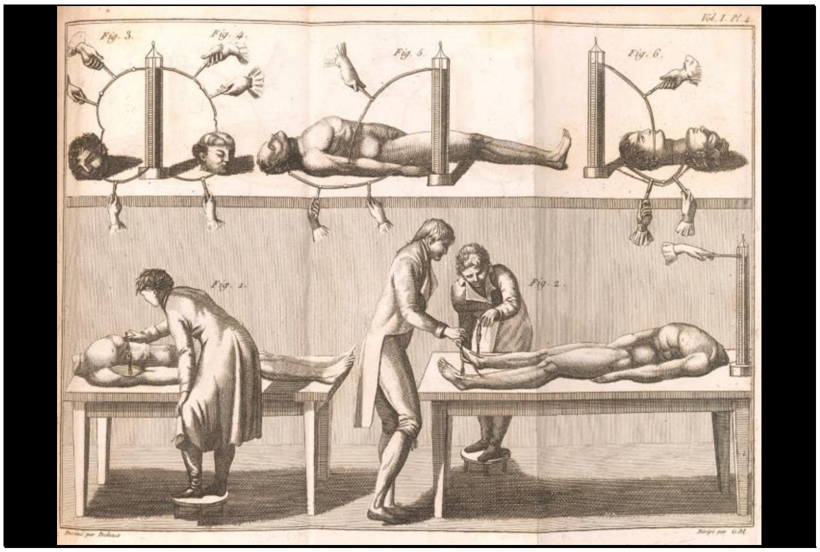




John Hunter, 1773

Although most of Galvani's experiments could be explained by the sensitivity of the neuromuscular system to electrical stimulation, one experiment seemed to indicate that the nervous system actually generated its own electricity. In 1794 an anonymous pamphlet, probably written by Galvani and his nephew Giovanni Aldini (1762-1834), demonstrated that the frog leg would twitch when it came in contact with the cut end of the frog's spine (upper center). And in 1797 Alexander von Humboldt (1769-1859) demonstrated that the frog's muscle would twitch when it came in contact the cut end of a nerve (upper right). These findings are likely caused by what is now called the "cut-end" or injury potential. Damaged nerves are negative relative to the surrounding tissue.

The anatomical studies of the electric fish *Torpedo* by John Hunter had shown that its electric organ was extensively innervated with nerves. Clearly the nervous system was generating the large shock.



Galvani's nephew, Giovanni Aldini (1762-1834), continued his uncle's research on animal electricity. His main goal was to see whether he could use electrical stimulation to restore function to paralyzed limbs or even to revive the dead. He travelled around Europe and was allowed to test his techniques on convicts who had been beheaded or hung. This illustration descries some experiments performed on beheaded criminals in Bologna.

Another subject of Aldini's esperiemtns was George Forster, a murderer who was hanged at Newgate prison in London in 1803. The reports of Aldini's experiments on the body were sensational:

> On the first application of the process to the face, the jaws of the deceased criminal began to quiver, and the adjoining muscles were horribly contorted, and one eye was actually opened. In the subsequent part of the process the right hand was raised and clenched, and the legs and thighs were set in motion.

https://en.wikipedia.org/wiki/George_Forster_(murderer)

It is likely that these and other reports of Aldini's experiments triggered in Mary Shelley the idea of Frankenstein's monster.

Boris Karloff as Frankenstein's monster, *The Bride of Frankenstein*, 1935

Frankenstein's Monster

With an anxiety that almost amounted to agony, I collected the instruments of life around me, that I might infuse the spark of being into the lifeless thing that lay at my feet. It was already one in the morning; the rain pattered dismally against the panes, and my candle was nearly burnt out, when, by the glimmer of the half-extinguished light, I saw the dull yellow eye of the creature open; it breathed hard, and a convulsive motion agitated its limbs.

Mary Shelley, *Frankenstein's Monster; or, The Modern Prometheus*, 1818

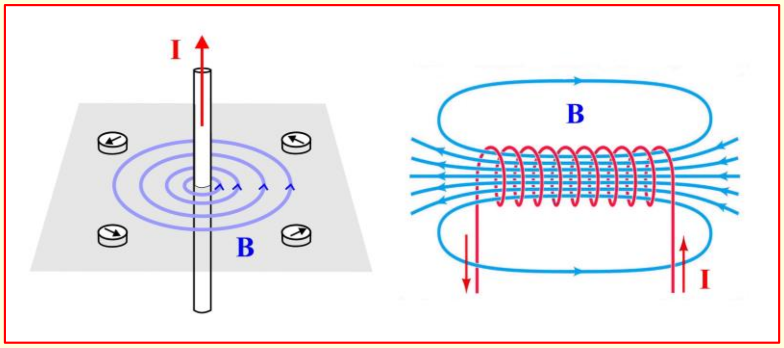
This passage describes the awakening of Frankenstein's monster.

Hans Christian Oersted (1777-1851)

Oersted became a professor of physics are the University of Copenhagen in 1806. In 1820 during a lecture and demonstration at the university Oersted noted that when current passed through a wire a compass needle near the wire was deflected from the magnetic north. This was the first demonstration that electric current produces a magnetic field that circles around the current-carrying wire. Within months, André-Marie Ampère (1775-1836), a professor of Physics in Paris, had replicated and extended Oersted's findings, and provided some mathematical laws for electromagnetism.

Oersted was a mentor for Hans Christian Andersen, who described himself as the "little Hans Christian"

Oersted's Wire and Ampère's Solenoid

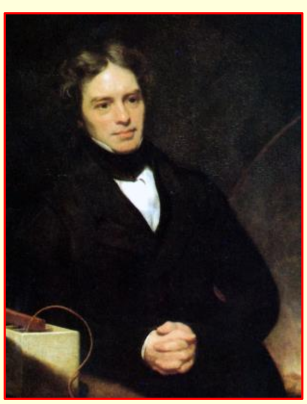


There are two right hand rules:
1. When holding a wire with the right hand and the thumb pointing in the direction of current flow, the fingers coil in the direction of the magnetic field.
2. When wrapping the right hand around the solenoid with the fingers in the direction of the conventional current, the thumb points in the direction of the magnetic north pole.

The word "solenoid" comes from the Greek *solen* ("pipe, channel") and *eidos* ("form, shape").

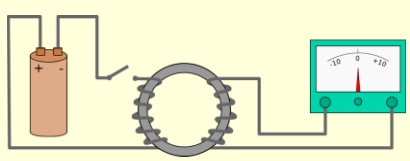
The field within the coil depends upon the number of turns of wire. The field was soon increased by using multiple turns of fine insulated wire. If a ferromagnetic material is within the coil of a solenoid it becomes an electromagnet and can be used to attract and lift metals.

Michael Faraday (1791-1867)



1842 Portrait, Thomas Phillips

Largely self-taught, Faraday became an assistant to the chemist Humphrey Davy. In the 1830s he discovered that a magnetic field could induce current in a conductor. His ideas led to the electric generator – which creates current by moving coils in a magnetic field – and the electric motor – which causes movement by means of current-induced magnetic fields.

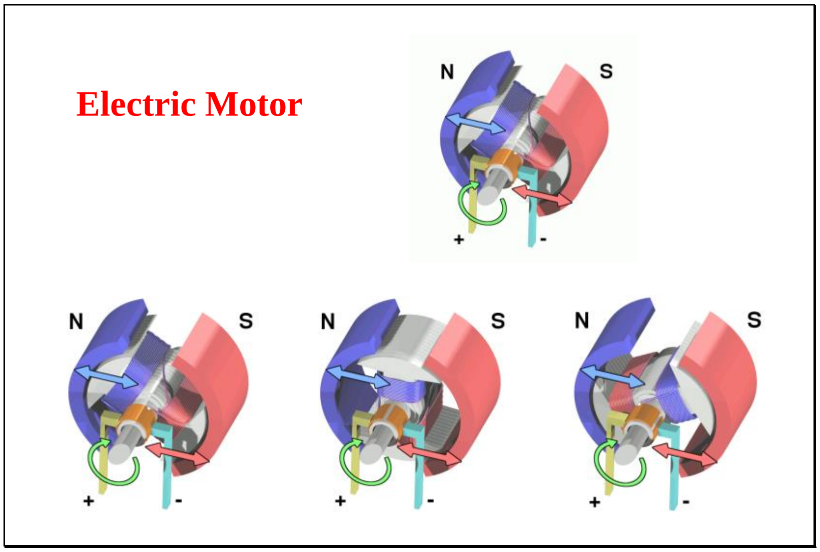


Faraday was not considered a "gentleman" and when he served as Davy's assistant he was treated as a household servant. Nevertheless, he was able to learn from all the people he met through his position.

The diagram shows Faraday's iron-ring demonstration of "mutual induction." Passing current in the left circuit induces a magnetic field in the iron ring. This in turn induces current in the circuit on the right.

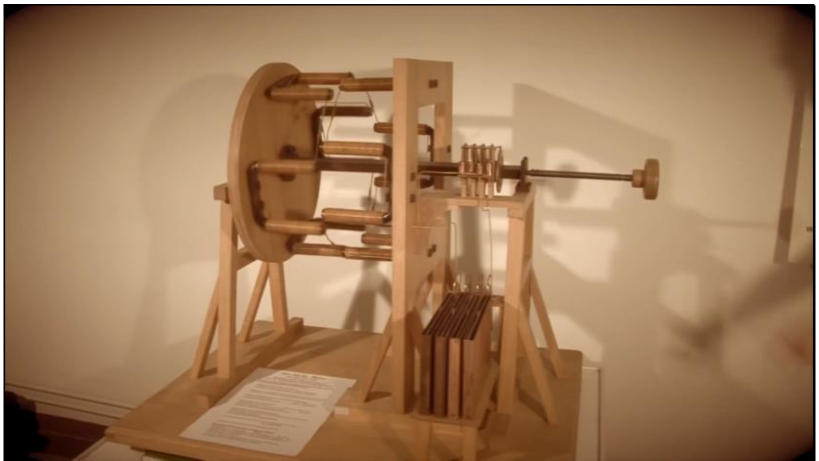
This type of circuit is the basis of the induction coil transformer which can change the voltage of alternating current. By Faraday's Law of Induction the voltage is relative to the number of coils in each coil.

Currents induced by magnetic fields were also discovered at about the same time as Faraday by the American scientist Joseph Henry. He invented many different applications from electromagnets to doorbells and from electric relays to electrical motors.



At the bottom left the current flowing into the coils on the rotating armature (grey) causes a magnetic field to be set up with the north at the left and the south at the right. This field is the opposite to that of the stationary magnet and causes the armature to rotate to align its field with the stationary field. As it rotates the commutator (a rotatory electric switch) (yellow) causes the current to the coils to reverse. This then sets up a magnetic field which is once again opposite to that in the stationary magnet. This maintains the rotation.

An electric generator is basically a motor in reverse. The armature is rotated, e.g. by a water driven turbine, and the currents induced in the armatures coils are transferred to the outgoing electrical circuit.



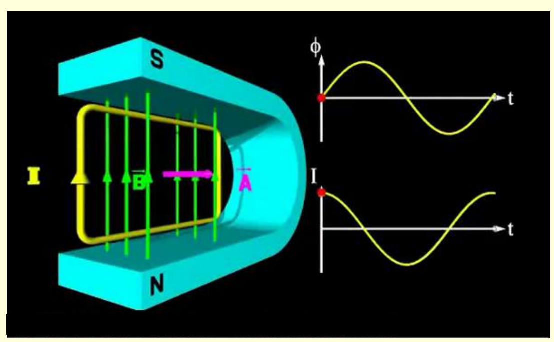
Model of the Jacobi Motor

One of the first functioning electric motors was built by Moritz von Jacobi (1801-1874) in 1934. It used an electromagnet as the stationary magnet (stator) and initiated movement in a set of oriented coils. The current for both the electromagnets and the coils was derived from a battery made of cooper-zinc plates in sulfuric acid.

video of the operation of the Jacobi motor by Martin Doppelbauer:
https://www.youtube.com/watch?v=kIPyyGyBZ60

Jacobi was born in Potsdam. He invented his first motors in Königsberg, and then moved from Prussia to St Petersburg, Russia, in 1838. There he was able to build a paddle-wheel boat driven by a battery.

Generation of Electricity



The electric motor converts electric energy to mechanical energy. This process can be inverted if a conducting coil (with area A) is mechanically moved in a stable magnetic field (B). As the magnetic flux (Φ) passing through the coil changes an electric current (I) occurs in the coil. If the coil is rotated an alternating current is produced.

Video by Yves Pelletier
https://www.youtube.com/watch?v=wchiNm1CgC4

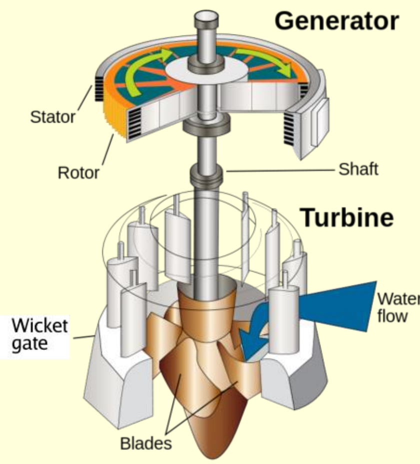
The first electric generators produced direct current by using a set of rotating switches (commutator). These were call "dynamos" (from the Greek *dynamis*, power).

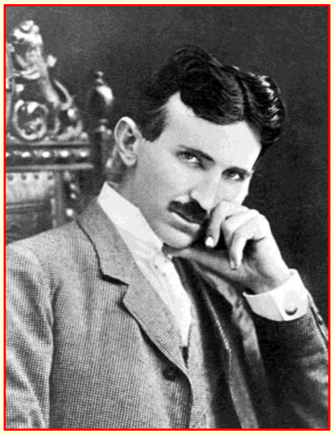
However, it soon became apparent that the alternating current was every bit as effective in performing work as direct current. As well as being simpler to generate, its voltage could be adjusted using a transformer.

Electric Power

An efficient way to convert mechanical energy into electric energy uses water to drive a turbine. This rotates a set of coils in a static magnetic field and produces current in those coils. The voltage level of this alternating current can then be altered in a transformer.

Coal- or oil-fired generating systems use the same principles but turn the turbine using steam.

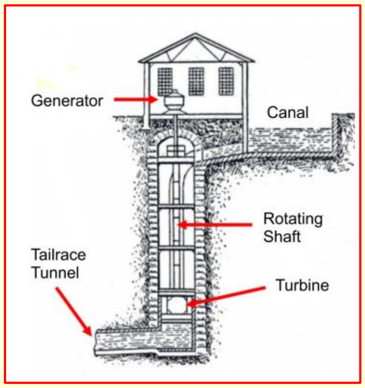


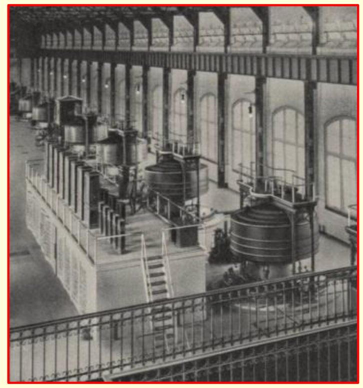


Anonymous Photograph, 1896

Nikola Tesla (1856-1943)

Born in what is now Croatia in the Austrian Empire, Tesla worked initially for the telephone exchange in Budapest before joining the Continental Edison Company in Paris. In 1884 he came to New York, and took out patents for an alternating current induction motor. At this time there was a "war of the currents" with Edison promoting DC power and Westinghouse AC power. In 1893 the Niagara Falls Cataract Construction Company asked Tesla to advise them on whether to provide AC or DC power. Tesla proposed AC power because it is more easily transmitted over long distances.



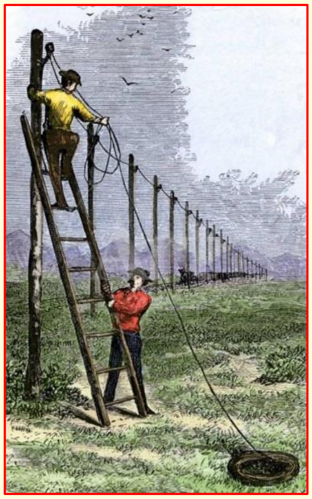


The Edward Dean Adams Power Plant was opened in 1895 to generate alternating current power. The photograph on the right was taken in 1903.

This is the Adam Beck Generating Station on the Canadian side of Niagara. The section on the right was built in 1922 and that on the left in 1952.

Telegraph

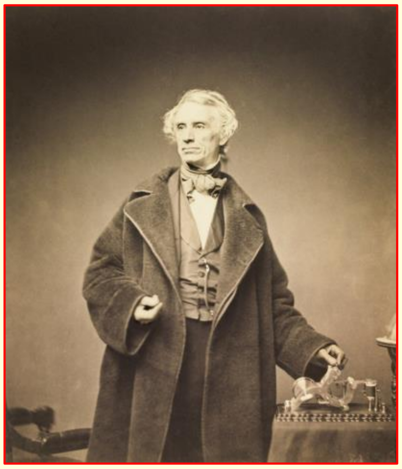
Electric current can flow through a conductor over great distances. Using the principles of electro-magnetism, scientists could have this current cause movement far away from where it was initiated. The first commercially successful telegraph was designed by William Fothergill Cooke and Charles Wheatstone. The current ran along wires strung beside railway lines. The current moved a needle at the destination to indicate a particular letter in a code. Telegraph systems began to be installed along the railways in England and the United States in the 1830s.The illustration shows workers installing telegraph lines along the US transcontinental railway in 1860.



The first telegraph lines were underground. However the insulation did not last. Thereafter uninsulated wires were hung in the air using telegraph poles.

Samuel Morse (1791-1872)

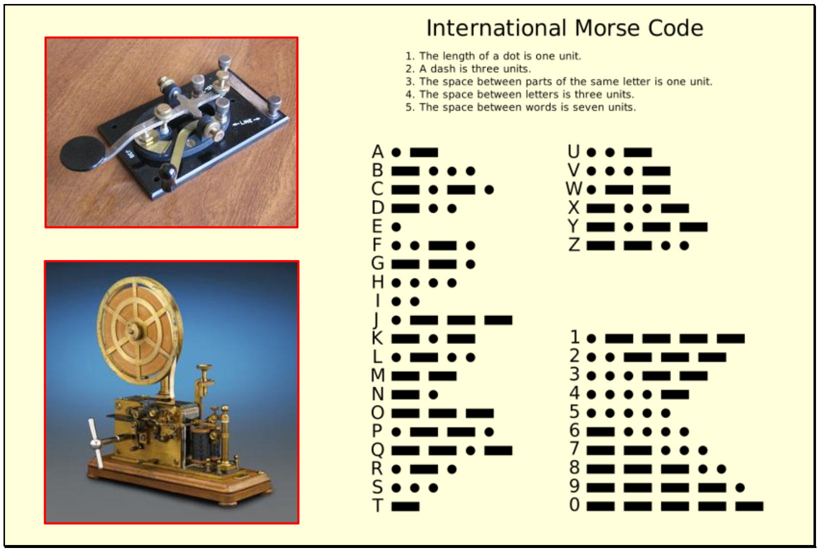
A successful portrait painter, Morse turned to electromagnetism in his middle age. He invented a telegraph system that used brief pulses of current. The signal was recorded by a stylus that made marks on a moving paper tape that was operated by clockwork. He also invented a coding system to enable the rapid transmission of messages. In 1844 he demonstrated his telegraph by transmitting the message "What God hath wrought" from Washington to Baltimore.



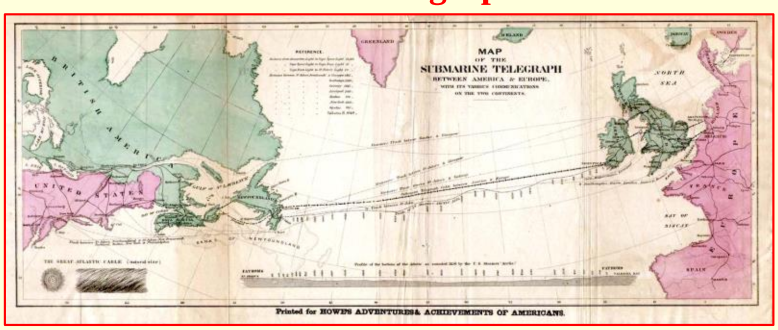
Photograph of Samuel Morse with his Recorder by Matthew Brady, 1857

The advantages of the Morse system over the Cooke-Wheatstone system

- the permanent record of the message
- the faster transmission of information



Transatlantic Telegraph Cable

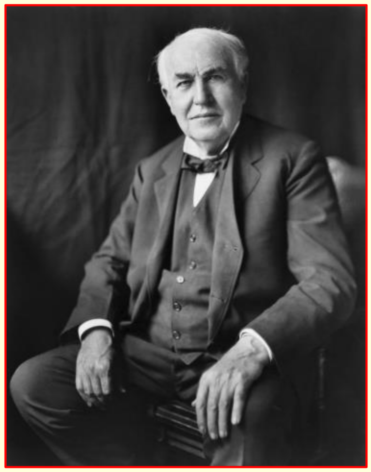


In 1866, after several failures in the preceding years, the first transatlantic telegraph cable was laid between County Kerry in Ireland and Heart's Content Newfoundland using Isambard Kingdom Brunel's *SS Great Eastern.* The cable consisted of seven intertwined copper wires insulated with gutta percha and tarred hemp with iron wires on the outside to give it strength..

Two engineers supervised the laying of the cable – Lord Kelvin and Wildman Whitehouse. They had opposite ideas for how the cable should work, Kelvin favoring low voltage and Whitehouse high voltage. Kelvin used his own very sensitive galvanometers to record the low voltage currents. Ultimately Kelvin's ideas prevailed since the very high voltages used by Whitehouse compromised the insulation.

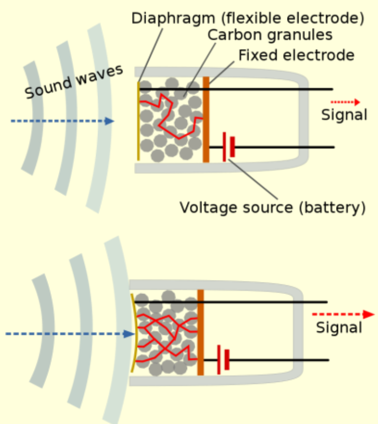
Thomas Alva Edison (1847-1931)

Largely self taught, Edison worked as a telegraph operator for Western Union. In 1876, he invented the quadriplex telegraph and sold the rights to Western Union. With the proceeds of this sale he set up a research laboratory in Menlo Park, New Jersey. Here he was able to improve the electric light bulb, invent an early phonograph machine, manufacture microphones, and produce a motion picture camera.



Portrait by Louis Bachrach, 1922

In 1997 Life magazine considered him the most important person of the last 1000 years for his invention of the light bulb.



Microphone

In 1877 Edison patented the idea of a using loosely packed carbon granules to modulate the passage of current in an electric circuit. When a sound wave exerted pressure on the carbon granules, they made more contact with each other and thus allowed more current to pass. A similar microphone was invented at the same time by David Hughes in England but this was not patented.

Phonograph

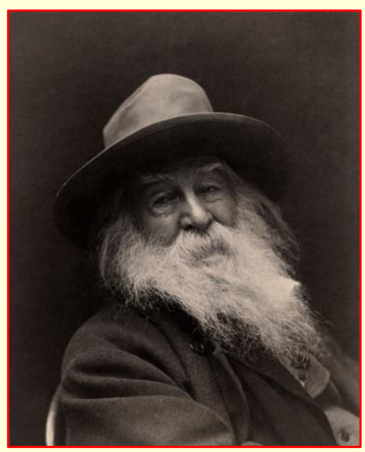
Edison invented the phonograph in 1877. While others had produced devices that could record sounds, Edison's phonograph was the first to be able to reproduce the recorded sound. His phonograph originally recorded sound onto a tinfoil sheet wrapped around a rotating cylinder. Alexander Graham Bell made improvements and introduced the wax cylinder as the recording medium. Wax cylinder recordings were first marketed in 1885. In 1894 Emile Berliner initiated the flat disk with a spiral groove, which he called the gramophone. This became the dominant recording method after about 1910.

The figure shows an Edison phonograph from about 1899.

America

Centre of equal daughters, equal sons,
All, all alike endear'd, grown,
ungrown, young or old,
Strong, ample, fair, enduring, capable,
rich,
Perennial with the Earth, with
Freedom, Law and Love,
A grand, sane, towering, seated Mother,
Chair'd in the adamant of Time.

Recorded on an Edison wax cylinder, 1890



Walt Whitman (1819-1892)
Photographed by George Cox, 1887

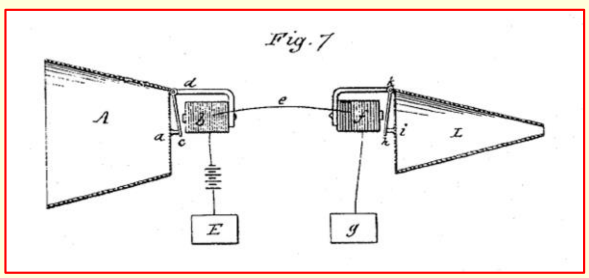
Only the first 4 lines of the poem were recorded.
Available on YouTube:
https://www.youtube.com/watch?v=cnMoUm87QII

Alexander Graham Bell (1847-1922)

In 1870, Bell came to Canada and lived on a homestead near Brantford. He was interested in hearing since his mother and wife were hearing-impaired. In 1876 he patented the “telephone,” a device wherein sound waves varied the resistance in an electric circuit and the resultant electrical changes could move a speaker to reproduce the sounds. The first long-distance call was made between Brantford and Paris, Ontario in 1876. In 1885 Bell founded that American Telegraph and Telegraph Company (AT&T).

The opening of the long-distance line from New York to Chicago in 1892

The armature **c** is fastened loosely by one extremity to the uncovered leg **d** of the electromagnet **b**, and its other extremity is attached to the



center of a stretched Membrane, **a**. A cone, **A**, is used to converge sound-vibrations upon the membrane. When a sound is uttered in the cone the membrane **a** is set in vibration, the armature **c** is forced to partake of the motion, and thus electrical undulations are created upon the circuit **E b e f g**. …The undulatory current passing through the electro-magnet **f** influences its armature **h** to copy the motion of the armature **c**. A similar sound to that uttered into A is then heard to proceed from **L**.

The figure and text are from Bell’s patent. In this design the electromagnets were simple bar magnets placed within the coils.

There has been much dispute about the patent. Several other inventors had similar ideas to Bell’s. In particular Elisha Gray had a patent for a device that varied the current through water and transmitted the sounds via vibrating reeds.

Electric Lighting

During the middle of the 19th Century, several people invented incandescent light bulbs based upon passing current through a filament. In 1878 Thomas Edison took out a patent for an improved light bulb using a carbon filament in a vacuum contained by a glass bulb. This led to the Edison and Swan United Electric Company. Later improvements were to use a tungsten filament and an inert gas in the bulb. The efficiency of incandescent lighting is low with only 5% of the energy converted into light. Fluorescent lighting is more efficient with 22% conversion. Light-emitting diodes are even more efficient.

Electric lighting quickly replaced gas lighting. The first public street lighting using gas was in London in 1812. Electric lighting began to replace gas lighting in 1880 in New York. Electric lighting was much more easily set up for indoors than gaslighting which had been limited to the rich.

Luminous efficiency – approximate amount of visible light from the energy used (lumens/watt):

candles	0.3
incandescent	15
halogen incandescent	20
fluorescent	90
light-emitting diode	150

Electricity

Lighting of the world, 1994-1995

Illustration from
https://en.wikipedia.org/wiki/Electric_light#/media/File:Earth%27s_City_Lights_by_DMSP,_1994-1995_(large).jpg

Data: Marc Imhoff/NASA GSFC, Christopher Elvidge/NOAA NGDC; Image: Craig Mayhew and Robert Simmon/NASA GSFC

From the notes on the Wikipedia website:

The brightest areas of the Earth are the most urbanized, but not necessarily the most populated. (Compare Western Europe with China and India.) Cities tend to grow along coastlines and transportation networks. Even without the underlying map, the outlines of many continents would still be visible. The United States interstate highway system appears as a lattice connecting the brighter dots of city centers. In Russia, the Trans-Siberian railroad is a thin line stretching from Moscow through the center of Asia to Vladivostok. The Nile River, from the Aswan Dam to the Mediterranean Sea, is another bright thread through an otherwise dark region. Even more than 100 years after the invention of the electric light, some regions remain thinly populated and unlit. Antarctica is entirely dark. The interior jungles of Africa and South America are mostly dark, but lights are beginning to appear there. Deserts in Africa, Arabia, Australia, Mongolia, and the United States are poorly lit as well (except along the coast), along with the boreal forests of Canada and Russia, and the great mountains of the Himalaya.