History of Electricity

Based on book ”Sähkön pitkä historia” and additional history sources

February 2025
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Sähkön pitkä historia

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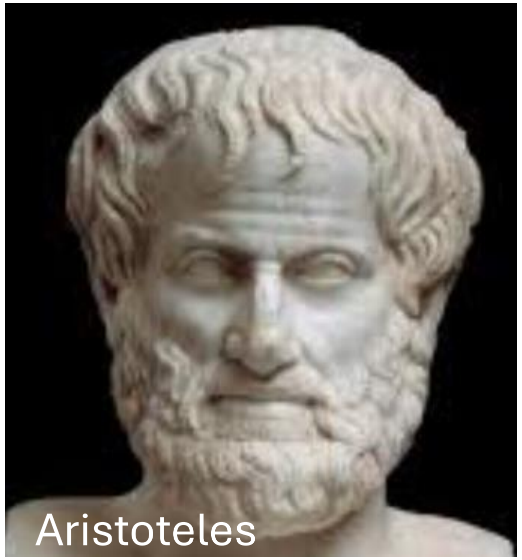
Electric Phenomena in Nature ~2750 bce … 40 ce.

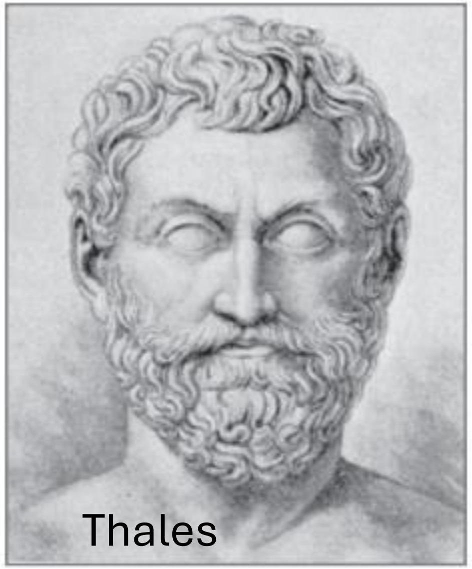
- Most natural electrical phenomenas we know already during antiquity, but those were not connected to each other (lightning, electric eels, snt. Elmo, attraction,…)
- Egyptians knew how to stun a person by using an electric ray (torpedo mamorata) already 2750 bce.
  - Based on ”*Naturalis Historia*” electric ray can stun your legs when touched
- Scribonius Largus (a doctor of Roman Empire), wrote circa 46 in a book of ”*Compositiones Medicae”* that an electric ray can be used to treat your headache and gout:
  - *At the onset of gout-related pain, a black live electric ray must be placed under the feet. The patient must stand on a damp beach washed by the sea and must remain there until the legs are numb up to the knees. This removes existing and prevents future pain. In this way Anteros, the freed slave of Tiberius, was cured*.

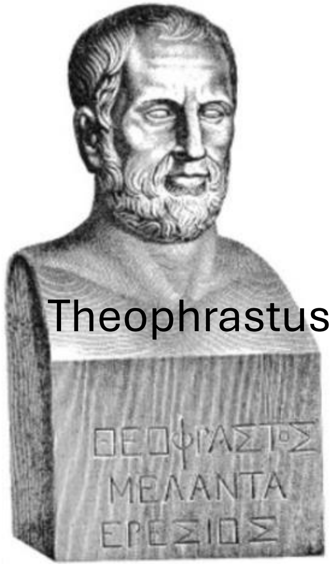
Thales, Aristotle and Theofrastos ~620…280 BCE.

- Thales of Miletus (c. 624–620 bce—c. 548–545 bce) found that wool fibres were sticking on surface of spindle (spindle had amber pieces for decoration)
- Aristoteles (384–322 bce.) mentioned in *Physics* Thales amber and magnetism trials
- Theofrastokselta/Theophrastus (372–287 bce.) amber and magnetite both have the power of attraction of wool (part of stone research he made)

  → magnetic objects possess souls by virtue of their capacity to move iron,”psykhe”





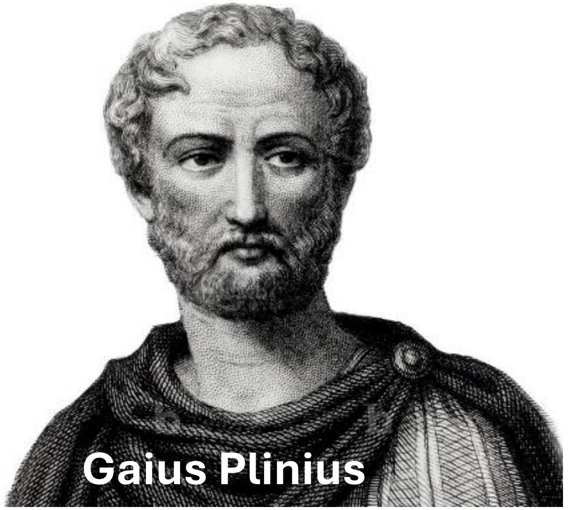


Pilinius – Collecting Information ~70 AD.

- Roman admiral Gaius Plinius Secundus (Pliny the elder) (23–79 bce.) collected the encyclopedia ”*Naturalis Historia*” – containing 20000 subjects, 37 books
  - → Amber attracts straw, dry leafs and dry pieces of bark when rubbed with hand, just like magmetic stone attracts iron
  - → Tourmaline and Rubin attracts straw and dry perchament pieces when rubbed with hand
  - → ” *Saint Elmo's Fire /Corposant/virvatuli/…*” can be seen around masts, poles, and spires causing fire of the surrounding air

Pilinius wrote ”Caesar said that there was a fire on the tip of legion spears prior a thunder storm”

Snt. Elmo was a bishop of Formia and a marthyr, - This name was associated with the discharge phenomena around middle age



Ether – ~2000 bce – 1881 ce

- *Ether as a concept probably came to Europe from the East*
    - An infinitely thin liquid substance that filled the entire universe and acted as a mediator – “all is made of water <-> Greek philosophy”
    - According to the Greek *Anaxagoras* (500–428 bce), the ether is finely structured and clear fiery air
    - The word "ether" comes from the Greek word for burning “*έγκαυμα*”
    - In Descartes' synthesis of the world, ether was a finely divided substance that filled all space and was the basis for later concepts of ether in physics
    - The heyday of ether was in the 19th century, all authorities relied on it
    - Christiaan Huygens used the concept of ether when interpreting the wave motion of light. Newton utilized the "gravitational ether“. Thomas Young, Augustin-Jean Fresnel and Huygens' Wave Theory, etc.
- In Maxwell's theory, ether was not needed and *Lodge* stated that ether was not needed until **1881**

Lightning Rods ~1000 bce

- Egyptian temples had tall wooden poles covered with metal as "lightning conductors“
- Masts made of iron were similarly used in Indian Hindu culture

  → They probably act as lightning conductors by accident and the original purpose was to make the masts of the temples showy & shiny

  → The Romans discovered that large bronze statues protected Jupiter from lightning strikes

- It is said that the Etruscans knew how to "turn" lightning aside by shooting metal arrows into threatening thunderclouds in 600 bce

Olmecs – Magical Magnets ~1000 bce

- The Olmecs were the predecessors of the Mayan and Aztec cultures in what is now Mexico's Veracruz province
- More than 3000 years ago, they already had a 356-day calendar in use, writing based on hieroglyphs and counting based on the 20s system
- Some of the statues were made of volcanic basalt containing magnetized magnetite and it is precisely placed in the right place
- In the head at the right temple, in the body again at the navel – magneettinen napa =)
- The 2.5 cm long and half a centimeter thick magnetic bar discovered in 1967 may have been a compass - or not…

Ancient Greece – Magnets ~1000 bce

- The ancient Greeks, Chinese, Mesopotamians (3000 BC) and Egyptians knew the ore stones that attract them (shadânu sabitu = sticky stones))
- Pliny describes Ethiopian magnetic ore as the best, which was worth its weight in silver
- The word magnet is generally explained by a city called Magnesia in Asia Minor. There was a large deposit of magnetite ore (Fe_3O_4) nearby

- The Greeks called the ore the Hercules stone because of its power
- Thales (550 BC) mentions in his poem that "the soul is a kind of mover, because he said that a stone has a soul when it moves an iron object"

Middle age Europe – Magnetism ~1300

- In the Middle Ages (~1300), magnetism was associated with all kinds of magic, such as the ability to unite estranged married couples, which is why magnetite was ground into potions
- Rubbing with garlic was thought to cause the magnetic force to disappear, but it could be restored with goat's blood
- Diamonds were believed to be able to magnetize and demagnetize iron nails. The magnetic islands could pull nails off the ship. A piece of magnetic ore kept gout away and thunder harmless

- These beliefs remained largely constant 300 years until the late 1600s
  - As writter by church bishop you'll not object the truth

China and the Invention of the Magnet ~X00 bce…100 ce

- The magnetic compass was invented in China and is thought to have developed through magical spending (magic ~ magnet)
- The soothsayers studied state matters by throwing various objects on the table and made decisions based on their mutual position. When there was a spoon made of magnetic ore, at some point it was discovered that the handle of the spoon most often pointed south

- In 80 AD, *Wang Chung* described a spoon pointing south, called *Sinan*, and a stone relief depicting it is known from 114 bc
- Used only for geometry, religious spending and temple design
- Not used for navigation (at least on waterways)

Compass and Expeditions

- In the Middle Ages, it was known that the Earth was spherical because in Pliny's "*Natural History*" it was said that the Earth is a sphere in which the countries around the Mediterranean formed a continent and the rest of the sphere is covered by water.
  - However, before the compass, you didn't dare go very far into the ocean
  - In the states of Genoa and Venice, products from the Far East were found to be in demand and the sea route was attractive instead of the expensive and uncertain caravan route via Muslim region

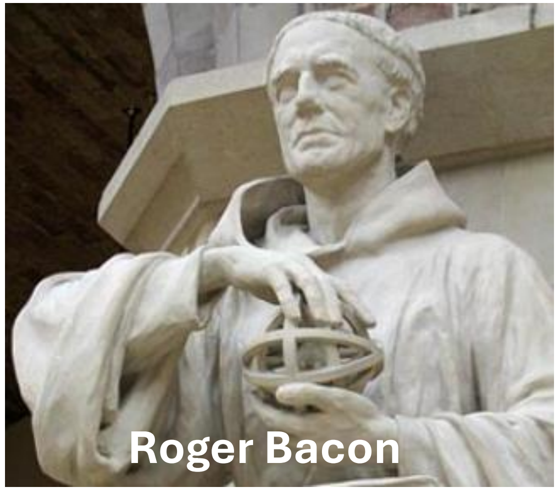
- Expeditions became possible in the 16th century, when trust in the compass grew. Christopher Columbus, however, discovered during his journey across the Atlantic on 17th of September 1492, close to the Caribbean Sea, that the compass deviated from north by about 5.5 degrees to the west;

"the pilots steered north and noted that the magnetic needles pointed a large quarter to the northwest. The helmsmen were afraid..."

Europa and Compass ~1300

- Roger Bacon (1214–1294) taught at the universities of Oxford and Paris and in the work *Opus minus* discussed the magnetic stone → spent >10 years in prison for heresy
- Bacon's student ***Petrus Peregrinus*** continued the experimental research method
  - During 1269 to the siege of the city of Lucera in Apulia (Italy), Petrus killed his time by studying the properties of magnetic stone
- Sent a letter about magnetic studies and it was copied in monasteries, but remained unknown until the 1560s when a book was printed about it

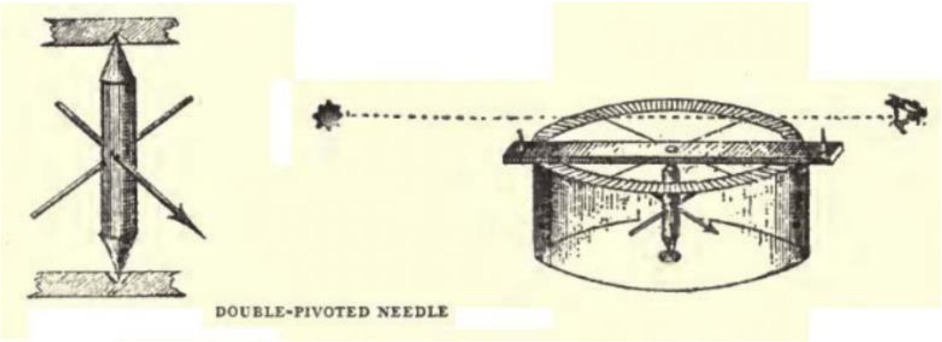
” so also this stone, as you must understand, has two points, one north and one south. You can find these points in different ways. One way is to grind the stone into a ball shape with a machine used to grind crystals and other stones, and place a needle or oblong piece of iron, as thin as a needle, on the stone and draw a line around the stone parallel to the needle,..., you can repeat this in many places and without a doubt all the lines will be on the stone on the surface pass through two opposite points like the earth's meridians meet at the poles”



Petrus - Magnets ~1269

- Observations of *Petrus Peregrinus*
  - the differently named poles (*Polus*) of two magnetic stones attract each other and the poles of the same name repel each other - the first mention of "*poles*"
  - an iron needle touched by a magnet turns towards the poles of the world
  - the end of the needle touched by the south pole of the magnet turns north
  - magnetized iron and a magnet behave in the same way
  - the magnetic stone wants to merge into a larger stone and the detached stone pieces are just as magnetic as the larger piece
  - The <u>North Star does not attract the needle</u>
  - A plate divided into 360 degrees can be placed under the suspended magnetic needle, which can be used to navigate

<u>Didn't connect magnetism to earth, but to heaven</u>



DOUBLE-PIVOTED NEEDLE

Gilbert and Magnetism ~1580

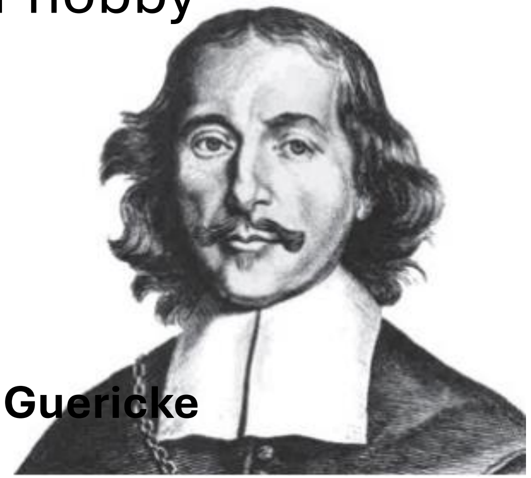
- **William Gilbert** (1544 – 1603) was one of the first researchers of magnetism and electricity (mathematician, court physician and philosopher), died of the plague
  - Did chemistry and magnetism experiments at home during 18 years
  - Published his research in the work "*De Magnete*" where he continued Peregrius' work done 300 years earlier
  - Showed that experiments can separate knowledge from belief/imagination
  - Galileo Galilei got to know Gilbert's work and was influenced by it
  - Gilbert showed that rubbing with garlic does not remove magnetism
  - This is how Ptolemy's 2,000-year-old ban could be removed and ship's compass attendants could start eating garlic
  - He also proved that iron cannot be made magnetic with a diamond
- In part II-2 of the publication, he also discussed "electric force" - which he said was **not** related to magnetism

Gilbert and Magnetism ~1580

- Permanent magnets were needed in Gilbert's time and after, mainly for the manufacture of compass needles
- Gilbert described three methods of magnetizing iron and steel:
    1. brushing with a magnetic stone
    2. forging a piece of iron in the north-south direction
    3. heating and cooling the iron body in the north-south direction
- A magnetic stone cost its weight in silver, but the price of the best stones was added to the weight of the iron that the stone could lift
- The quality of a magnet was measured by how many times it could lift its own weight, the manufacture of permanent magnets was a well-hidden skill

Guericke – Rubbing Electricity ~1670

- ***Otto von Guericke*** (1602–1686) was a German natural philosopher and statesman best known for developing the first proper vacuum pump
  - Wrote a book “*Experimenta Nova Magdeburgica de Vacuo Spacio*”, which did not appear until 1672
  - A small part also included the results of electrical tests
- Gilbert's work gave the initial impetus to the study of frictional electricity.
- After experiments by enthusiasts, the phenomena became more noticeable and people started to be interested
- Electrical experiments became famous and became a direct popular hobby

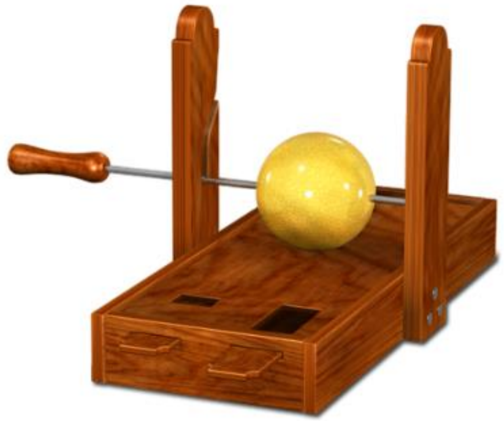


Guericke

Guericke – Rubbing Electricity ~1670

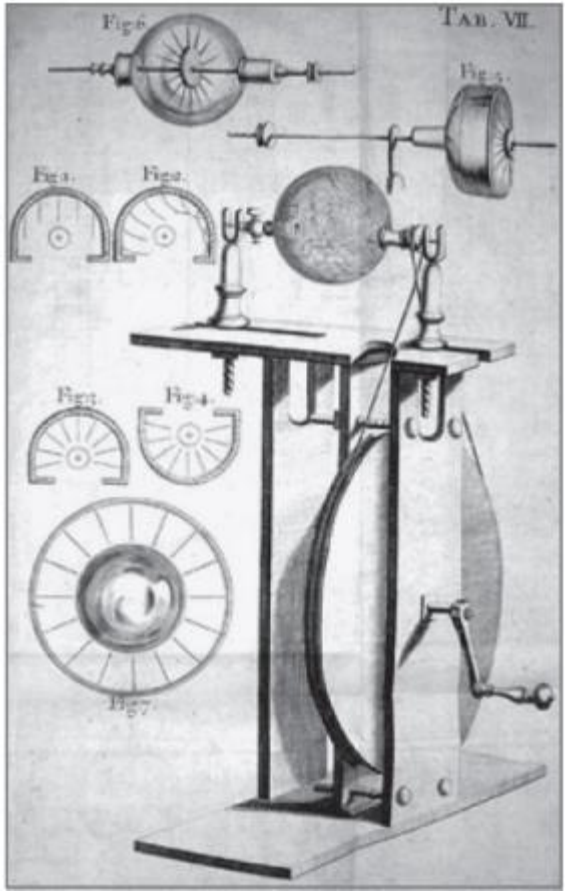
- Guericke was looking for planetary souls, or world forces, which could be magnetic according to Gilbert
  - Gilbert had done with a spherical magnetite, but Guericke tried to represent the Earth more realistically by adding other minerals to the sphere, such as sulfur
    - The ball attracted light objects and produced small sparks in the dark
    - Sulfur strengthened the electrical force effect, and he made a new ball by pouring a glass ball full of only sulfur and breaking the glass. After adding an iron shaft and a wooden frame, the first electrostatic generator was born
- By spinning the ball vigorously on the axis and simultaneously holding a dry hand on its surface, the ball became more electric than any other before
  - Ball attracted pieces or rejected them "randomly"

Unfortunately, he broke a glass bottle that would have been a better generator than a ball of sulfur



Hauksby – Electrical Tests ~1710

- The nine-inch glass ball provided so much light that you could read a book next to it
- Light is created in the same way as in Saint Elmo's fire, when electrons combine back into ions
- Hauksbee was the first to use a glass tube, from which, by rubbing with silk, the small amount of electricity needed for the experiments was obtained
  - The glass tube became the most important generator around Europe for over 100 years
- In 1710, Hauksbee discovered that electricity accumulates on the outer surface of the object. A solid and a hollow wooden cube behave exactly the same in electrical experiments
- The electricity could be felt as a weak "wind" when it was brought close to the cheek and Gilbert's concept of effluvium was supported



Gray – Electric Conduction ~1730

- Royal Society member ***Stephen Gray*** (1670–1736) was inspired by Hauksbee's experiments and also acquired a glass tube generator
- Gray closed the ends of the glass tube with a cap (so that no dust would get in there)
    - To his surprise, the feathers stuck to the caps rather than the glass tube itself

      → the electricity had somehow stuck to the cap without friction
- He started testing how far he could make the electricity transfer
    - first with a wooden stick, then a fishing rod, metal wire and finally a thick parcel string, everything conducted electricity
    - Published the results of the experiments in 1731 in the *Philosophical Transactions of the Royal Society*

Gray → Dufay – Electric Conduction ~1730

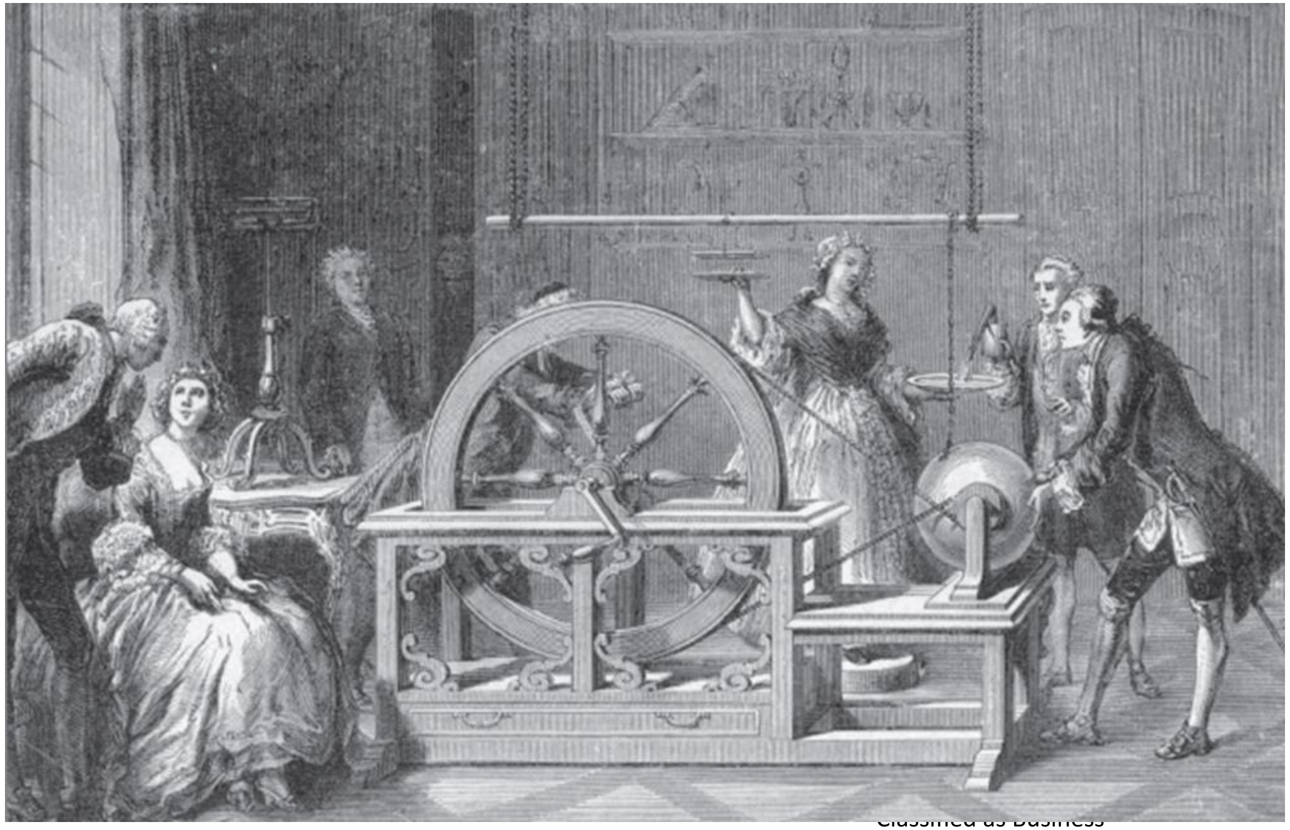
- According to Gray:
  - The effluvium transmitting the electric force was absorbed from the glass tube into the conductive substance and could thus be moved further away from the electrified body
  - The jumps of electricity, on the other hand, were based on the transfer of the effluvium to the conducting body through the air
  - Effluvium does not pass through the insulation
- Word *conductor* (johde) ja *insulator* (eriste) invented *John Desaguliérs* (1683–1744) who followed Hauksbee as the demo maker in Royal Society
  - *”Insula”* meand island (latin)
- ***Charles François de Cisternay Dufay*** (1698–1739), an officer of the French king *Louis XV* and superintendent of the gardens of Versailles, was inspired by Gray's experiments and started systematic tests at the *French Academy of Sciences*

Dufay – First Electric Rules ~1730

- Was all electricity the same? Dufay assumed this was the case, but still wanted to make sure by experimenting
  - To his surprise, he noticed that there were two types of electricity - some attract and some repel each other
- 1734 came up with a bold hypothesis about the existence of two types of electricity, in which case the direction of the force depends on the substance from which the electricity was obtained by rubbing
  - One he called glass electricity and the other lacquer electricity
  - Different types of electricity strived together and similar to separate (this was invented **135** years after Gilbert's experiments)

Bose ja Nollet – Fun Electricity ~1740

- No other use was invented for scrubbing electricity other than amusement
  - A spark could be used to set off a miniature cannon or explode spirits
  - Bose and abbot Nollet competed for the most spectacular demos - these often used humans as guinea pigs for interest

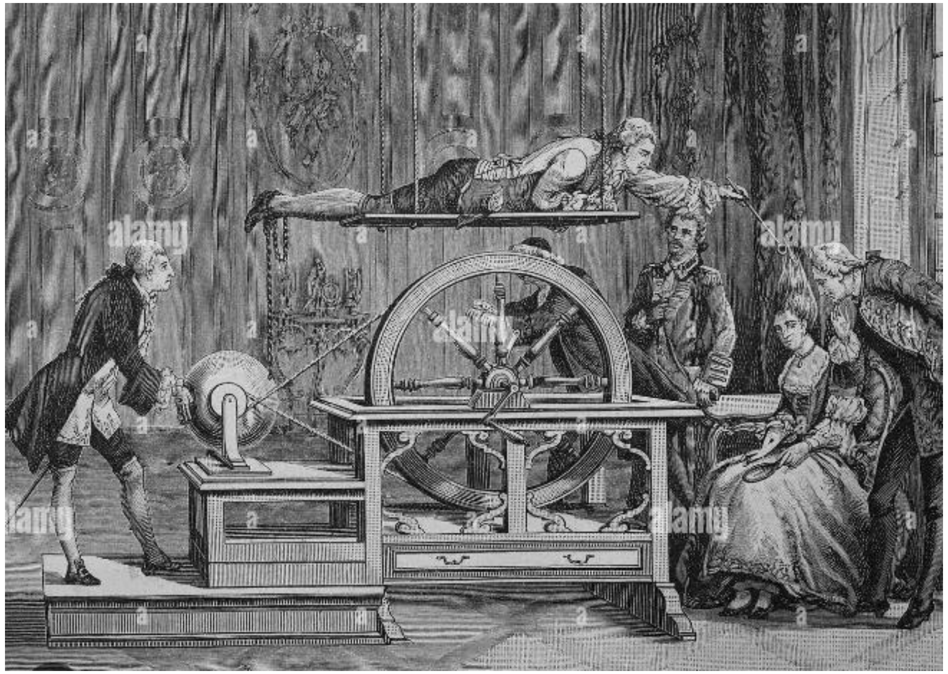


Bose

Bose ja Nollet – Fun Electricity ~1740

- In the 1750s, electrical experiments became a real popular hobby
  - A person charged with electricity had to be isolated from the ground, in which case he had to stand on an insulated platform or hang from silk ropes
  - Funny effects: hair and skin hairs stood up, St. Elmo's corona discharges from fingertips and other tips could be seen in the dark, and a handshake with an unsuspecting person gave an electric shock

- The bigger the electronic "storage", the more fun
  - Ordinary experiments used rifle barrels or swords hanging from silk threads, larger ones used hanging cannon barrels
  - Metal chains served as conductors



Kleist – Playing with Layden’s Jar ~1745

- Storing electricity was difficult, it usually only lasted for hours
- The first electricity storage device (capacitor) was invented in October 1745 by the German jurist *Ewald Georg von Kleist* (1700–1748) in Cammin, Pomerania
  - He tried to ignite the alcohol in another glass bottle with an electric spark using the charged mercury
  - The bottle seemed to work strangely as it gave off sparks when held in the hand, but when placed on the table it did not, the nail in the bottle acted as a conductor
  - When Kleist grabbed the nail with one hand to remove it, he received an electric shock that was strong for the size of the bottle

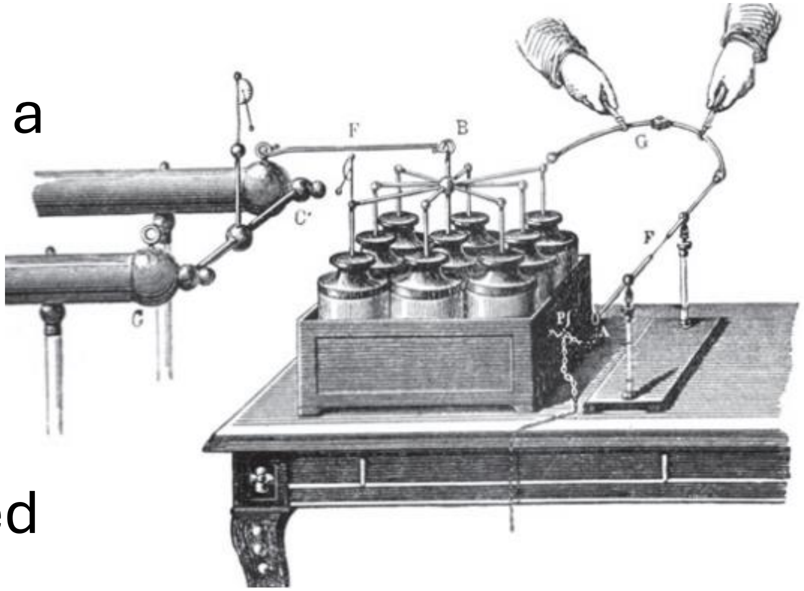
    ” I'm sure Bose won't dare to do his usual kissing game with such an electric shock”
- Information about the invention spread through an experiment by Professor *Pieter van Musschenbroek* (1692–1761) conducted at the University of Leyden in 1/1746

Musschenbroek – Playing with Layden’s Jar ~1745

- Swedish doctor *Andreas Cunaeus* (1716–1788), who was visiting the laboratory, held a water bottle in his hand like Kleist and received a strong electric shock from it
    - Next, Musschenbroek's assistant tried and was stunned for a few minutes
    - A couple of days later, Musschenbroek tried it himself with a larger glass container and got such a painful shock that he was still shaking hours later
- Musschenbroek wrote about the experiment to his friend *René de Réaumur* in France, who in turn passed the information on to Nollet at the French Academy of Sciences
    - ” I'm going to tell you about a new but terrible experiment that I advise you not to try on yourself…”
- *Jean Antoine Nollet* (1700–1770) was in extensive correspondence with the scholars of the world
    - Soon experiments with the bottle were carried out everywhere - Nollet killed a swallow with an electric shock

Le Monnier – Electic Circuit ~1750

- Watson showed that the more electricity can be stored in the Leyden flask, the larger the area covered by the hand holding the flask.
- *John Bevis* (1693–1771), English astronomer, invented replacing the hand with tin foil on the outside and Watson replacing the liquid inside with another tin foil with an electrode lead attached – the eventual Leyden flask
- Watson assumed that electricity travels the shortest way from one point to another, but found that this was not the case, and that the quality of the materials also affected
- Le Monnier was also the first to discover that the earth is a conductor – this was evident when shoes conducted electricity
- To test the "eunuch theory", some castrates were borrowed from the king's choir and subjected to electric tests - the effect was the same as the others, they jumped from the electric shock



Lightning Rod ~1750

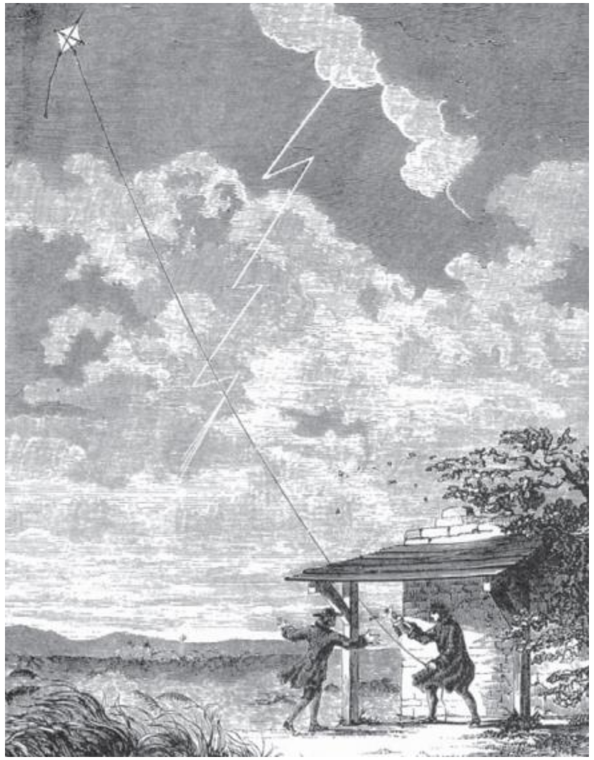
- Benjamin Franklin (1706–1790) tested static electricity phenomena seven years
  - Franklin became interested in electricity after hearing a public lecture by Adam Spencer from England in Philadelphia in 1744 and the related bang of an electric discharge, which made him wonder if lightning was an electrical phenomenon(?)
  - The idea was not new (proposed in 1708), but it had been difficult to prove it right
  - Franklin bought Spencer's equipment and began conducting electrical experiments
- From the beginning, Franklin's interest was focused on the ability of sharp conductors to absorb electricity from a nearby charged object without a visible spark
- Franklin said he could draw electricity from a charged piece with a sock stick from a distance of one foot. This was based on the idea of discharging electricity in the atmosphere to the ground with a sharp metal tip before lightning strikes

Lightning Rod ~1750

- Franklin proposed that a 20…30 foot long sharp metal rod insulated from the ground should be installed at the end of a tall tower and see if it would become electrified

  ” It is probable that these sharp rods would steadily draw the electric fire out of the cloud before it got near enough to send forth the lightning, and thus protect us against this swift and terrible calamity…”

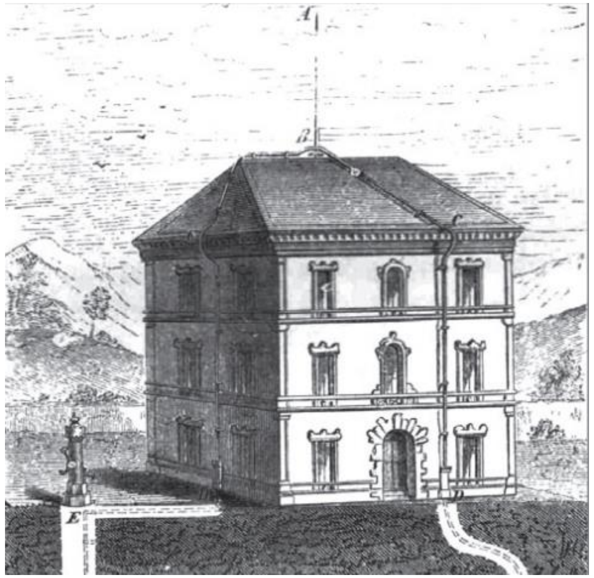
- Franklin's idea was to collect dangerous electricity from the sky before the start of lightning
- The English were not enthusiastic about testing, but in France Louis XV got excited about the subject and ordered long iron bars to be installed on high lonely hills
  - In May 1752, *Thomas d'Alibard* observed sparks between the lower end of a 13 m high iron rod and the ground
  - In June 1752, Franklin did his kite experiment and got a key attached to a string to charge a Leyden flask



Lightning Rod ~1750

- In Germany at the beginning of the 18th century, 170 church bell ringers died in 33 years due to lightning strikes because the bells were rung at the beginning of a thunderstorm to keep evil spirits away
- People generally went to churches for protection from thunder, but it was high churches that were most often struck by lightning - this had to be a punishment for sinners
- Franklin had already described the first lightning rod in 1750, installed the first one in his house in Philadelphia in 1752

- At the same time, two-meter-high sharp iron bars were also installed on the roofs of the Parliament building and the Academy.
- An account of the structure of the lightning rod appeared in 1753 in the yearbook "Poor Richard's Almanach"



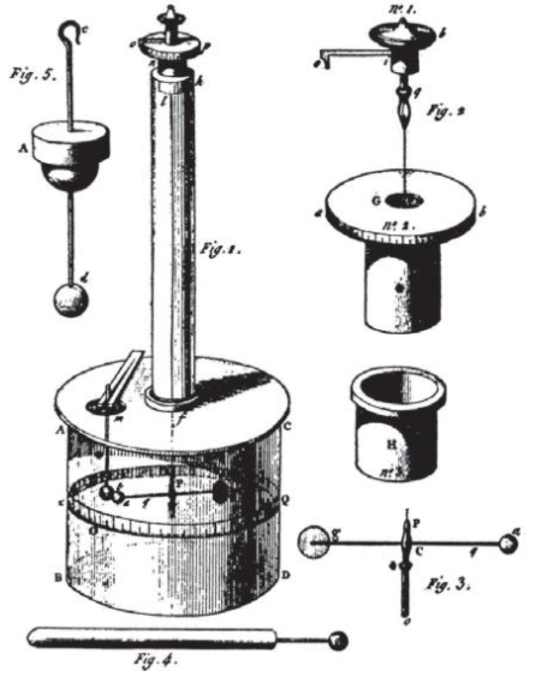
Lightning Rod ~1780

- In Europe, few churchmen accepted lightning rods, in their opinion it was an act of opposing God's will, and the electricity, after hitting the ground, would in any case “cause earthquakes”
- In France, this kind of thinking resonated
  - Lightning conductors were torn out in France due to Catholic church opinion
  - In Philadelphia, in 1782, all except the French embassy were equipped with lightning conductors → Lightning struck this very embassy building and killed one officer, resistance quickly ended in France as well
- In England, *King George III*, annoyed by the American rebellion, installed round-headed lightning conductors instead of sharp ones
- Some of the ancient temples had a gilded roof and sharp metal spikes – a natural lightning protection

Coulomb - Measurement of Electrical Force ~1784

- *Charles Coulomb* (1736–1806) worked as a researcher after his career as a civil engineer
  - His interest focused on the strength of materials, and the first scientific work (1773) dealt with friction and cohesive force

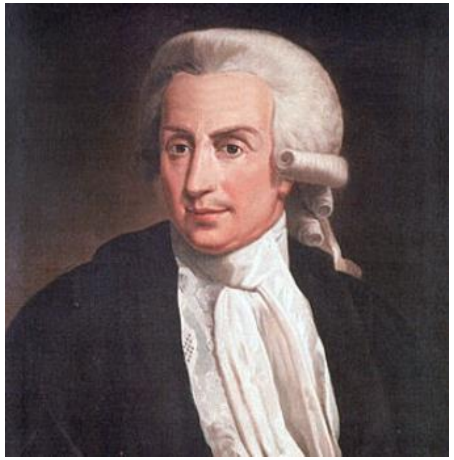
- Coulomb studied the torsional elasticity of various fibers and found that with small forces the angle of rotation was proportional to the rotational force → developed a rotational balance that could measure weak forces
- Mastered scientific research methods, both theoretical thinking and experimental testing
- 1784 he published a paper on the torsional elasticity of metal wires and developed his final sensitive rotary balance, which he used to measure electric and magnetic forces - the aim was to improve the sensitivity of the compass
- 1785–1791 published a series of seven treatises on the measurement of electric and magnetic forces



Galvani - Electrochemistry ~1784

- *Aloisio Luigi Galvani* (1737–1798) started a series of experiments that led to the invention of the electrocoupling
  - Studied medicine at the University of Bologna and, after graduating, worked there initially as a lecturer, from 1782 as a professor of anatomy
  - He began to conduct electrical experiments 1790 as the fashion of the time
    - Acquired for this purpose, he prepared special dissected frogs, in which only the hind limbs, part of the spinal cord and the nerve fibers of the legs remained
    - The frog's leg on the metal platform now twitched when the wire attached to the electrostatic generator touched the nerve bundle of the spinal cord - as was already common knowledge
    - To my surprise, the frog's leg was now also moving, even though the wire of the electric machine did not touch the nerve and the leg was far from the machine

” placed the leg on the table, which also had an electric machine at a considerable distance. When one accidentally touched the frog's spinal nerve with a scalpel, all the muscles of the leg seemed to contract”



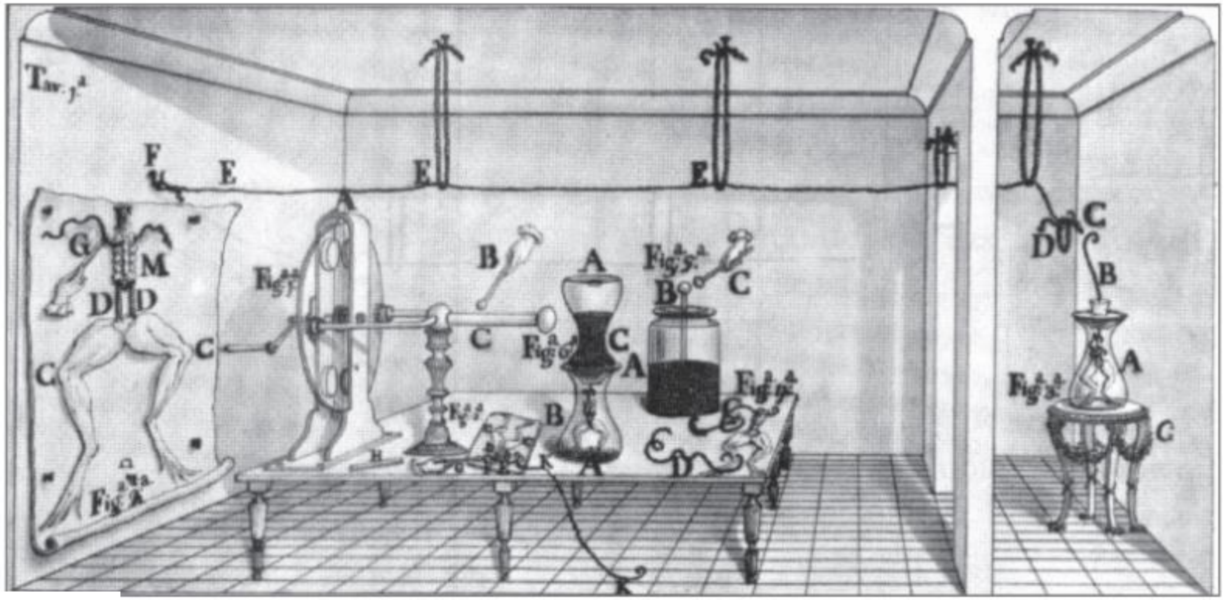
Galvani - Animal Electricity ~1784

- He discovered that whenever the nerve of the leg was touched with a scalpel and when an electric spark was produced at the same time, the muscle contracted even though there was no direct contact from the machine

  ” It was affected by how the knife was held in the hand. The knife had a bony handle and if you just held the handle, there were no muscle contractions at all, but if you touched the blade of the knife or the metal rivet in the handle with your finger, the spark caused contractions”

- The friction generator acted as a spark-telephone, the human as the antenna and the frog's thigh muscle as the detector - <u>The first wireless data transmission</u>

- Proposed that there is "animal electricity" - electricity stored in the leg



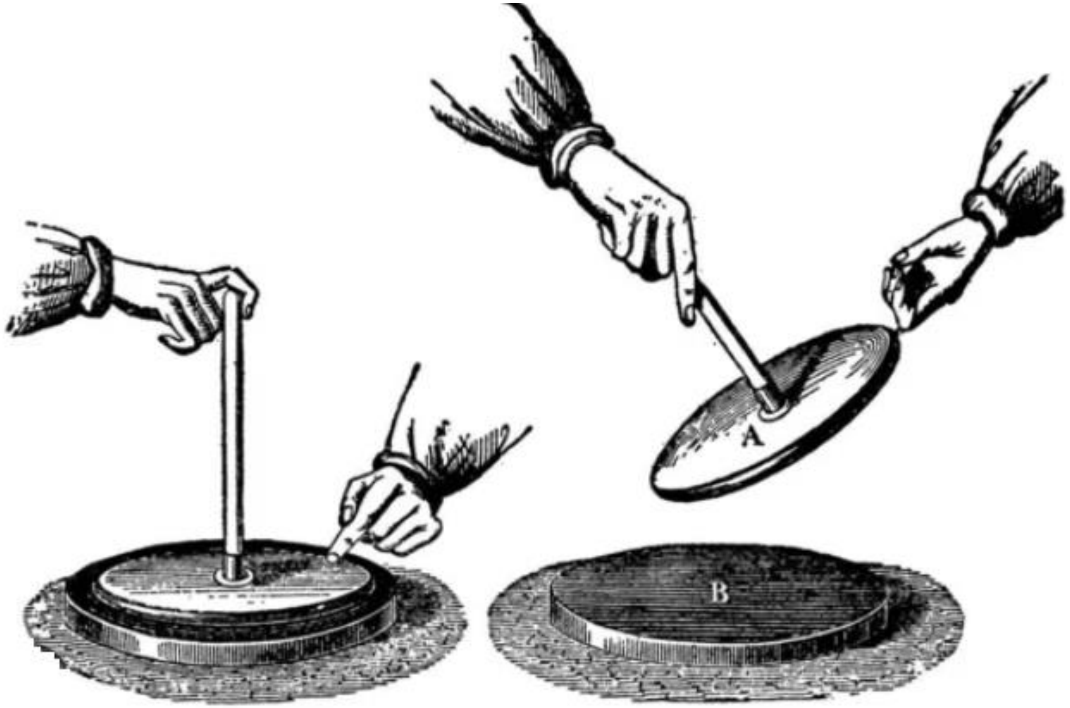
Volta - Metallic versus Animal Electricity ~1800

- *Alessandro Giuseppe Antonio Anastasio Volta* (1745–1827) was born in Como to a noble family. In 1774 he became a physics teacher at the high school in Como and in 1779 a professor at the University of Pavia
- Volta was interested in electrical experiments, and he developed the instruments for the experiments, such as the electrophorus and the condenser electroscope
- In 1791, Galvani sent a different edition of his publication to Volta, who immediately stopped his work on marsh gases and started doing similar experiments to Galvani.
- With a capacitor electroscope, Volta was able to show that a voltage was generated at the junction of two metals

- Two competing schools were born: Supporters of animal and metallic electricity
  - Galvani and Volta were friends, but when Volta abandoned animal electricity they became bitter rivals
  - Inspired by Galvin, *Mary Shelley* wrote the "*Frankenstein*" story in 1818

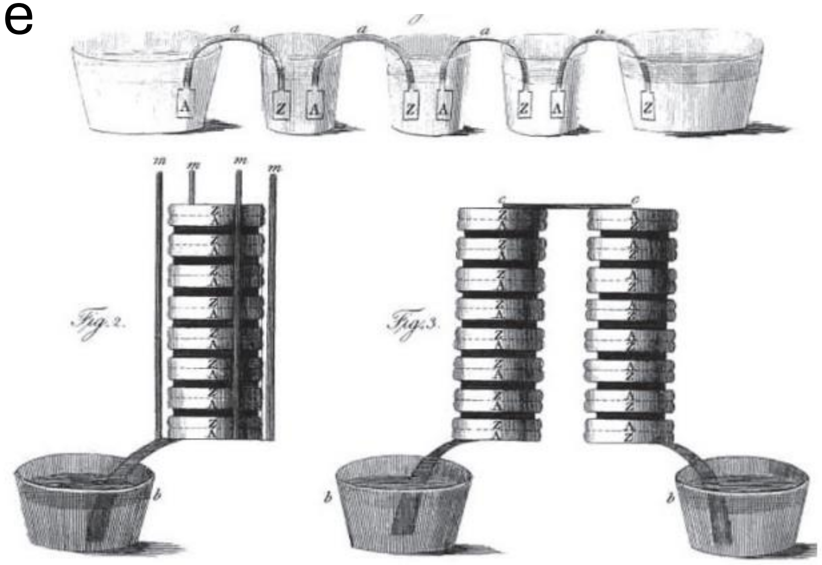
Measuring the Quantity and Strength of Electricity ~1770

- In 1775, Alessandro Volta invented a device to generate static electricity
  - The device called an electrophore ("carrier of electricity") is based on electrostatic induction
  - Electricity was collected in portions of a certain size. It was an induction generator where mechanical energy could be changed into electrical form
- The electrophore became popular in the world and replaced glass tubes in the generation of electricity
- The condenser electroscope was another Volta invention – it allowed to measure much smaller charges than with other methods



Volta - Volta's statue ~1800

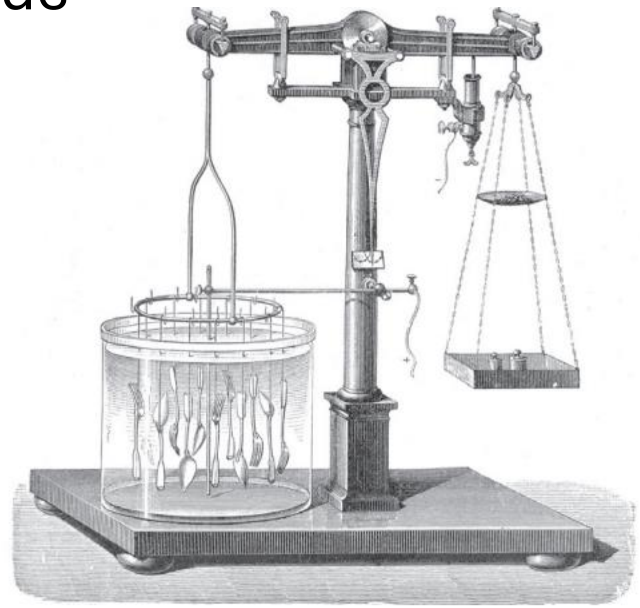
- Volta wanted to increase the voltage obtained from metal contact by placing several pairs of metals in series to form a battery
  - However, connecting metal pairs in series did not increase the voltage
  - As a solution, Volta included non-metallic conductors, which were pieces of fabric moistened with salt solution
- The idea of an electric battery was a surprise → Volta sent a letter about it to Sir *Joseph Banks*, president of the Royal Society in London, on 20 March 1800
- The letter did not arrive until the summer of 1800 because of the war between France and England
- The electric battery was called Volta's statue (pila in Italian, pile in English)
- The statue had copper and zinc plates alternately on top of each other, and moistened cardboard between every other pair of plates



Galvanizing ~1801

- 1801 *William Hyde Wollaston* (1766–1828) discovered that copper began to accumulate on the surface of a silver object immersed in a copper sulfate solution when it was connected to an electrode of some other metal
- The Italian chemist *Luigi Brugnatelli* (1761–1818) had already gilded a silver coin in 1805, was forgotten, and was reinvented not until in 1840

- The large-scale electroplating industry began in 1841 in Birmingham when *John Wright* discovered that potassium cyanide acts as an electrolyte in gilding
- Elkington & Co. claimed the patent and started manufacturing jewelry and silverware
  - The silverware on the *Titanic* was made by Elkington

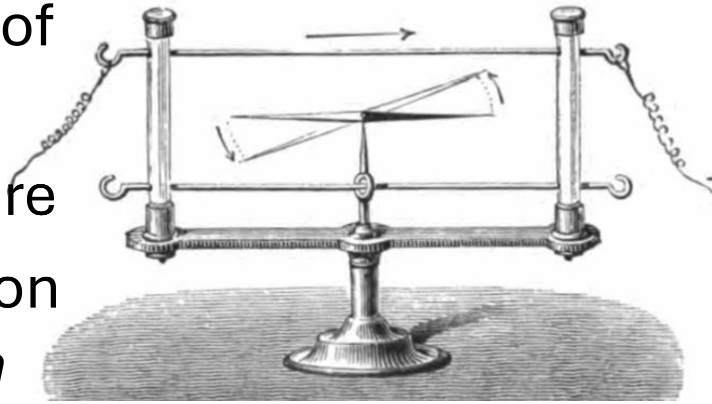


Örsted ~1820

- Early 1800s, magnetism and electricity were considered independent of each other
  - It was well known that magnetizations caused by lightning strikes and ships' compasses were confused by thunder
  - Sir Davy observed that an arc, which was known to be electricity, shifted laterally when a magnet was brought near it
  - Nobody thought of putting a compass near the wires of a shorted battery
- Danish *Hans Christian Örsted* (1777–1851) worked as a researcher at the university and became interested in Kant's theories according to which all forces are related to each other - light, heat, electricity and magnetism must also be related to each other
- In the winter of 1819–1820, he gave a series of lectures on "electricity, galvanism and magnetism" in Copenhagen. At that time, static and galvanic electricity were not considered the same thing

Örsted – Electromagnetism ~1820

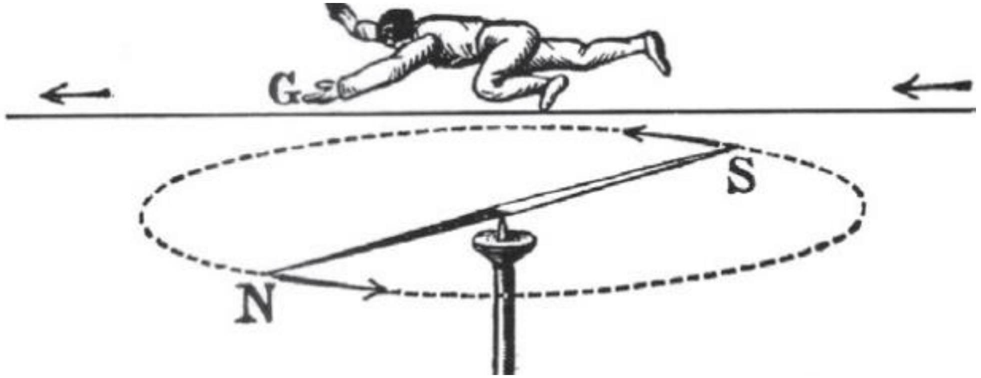
- Davy had previously shown that a thin metal wire was heated by electricity. Since the even thinner wire emitted light, Örsted surmised that it might also emit magnetism
- According to his own account, Örsted had not come to try the matter before the lecture, so on a sudden impulse he did the first test directly in front of the audience
  - When the circuit was closed, the compass needle vibrated, but the phenomenon was quite weak and vague - Örsted forgot about it for three months
- Made another set of experiments with a more powerful battery
- Örsted conducted more than 60 experiments in the presence of Danish professors and wrote:
  - The magnetic needle turns perpendicular to the current wire
  - The publication was only four pages long and was printed on 21 June 1820 as self-published in Latin "*Experimenta circa effectum electrici in acum magneticam*“ →The publication became a sensation in academic circles



Ampere – Electric Current and Voltage ~1820 - 1827

- *André Marie Ampère* (1775–1836), a member of the French Academy, was the first to define the concepts of voltage and current
  - Ampere got hold of Örsted's publication and switched from researching chemistry to electricity
  - By September 18, 1820, Ampère had already developed the basic mathematical theory of modern electromagnetism
  - The basic theory of electrodynamics was born in 1820–1827
    - He was the epitome of the distracted professor; looked at his watch, picked up a stone from the ground, threw his watch into the water and put the stone in his pocket
    - Ampère: had enough adversity in his life and chose the words tandem felix, "finally happy" for his gravestone in advance

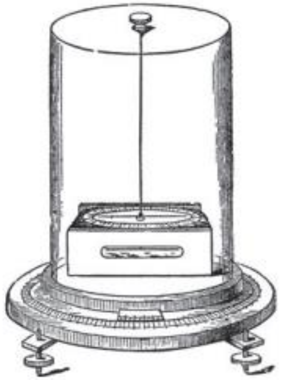
- He introduced the new words electrodynamics, electromagnetism, and as a counterbalance to these, the earlier theory of electricity began to be called electrostatics

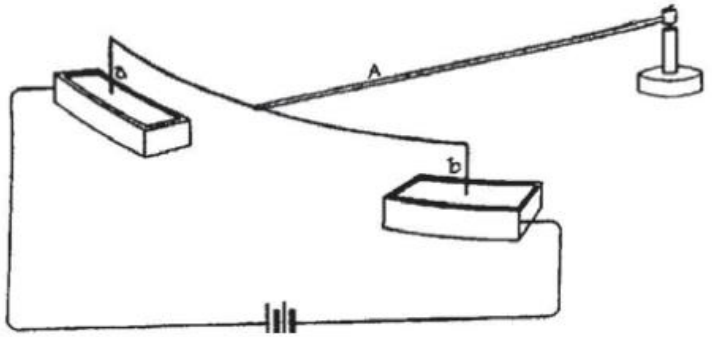


Ampere – Electric Current and Voltage ~1820 - 1827

- Ampere's goal was to base the theory on the smallest possible number of experiments and derive all the laws of electromagnetism from them
  - Publication”*Mémoire sur la théorie mathématique des phénomènes électrodynamiques, uniquement déduite de l’expérience* (1827)”, which has been called the *Principia of Electrodynamics*
  - In 1845, Hermann Grassmann published the laws in the form in which the fundamental force law of electric current is presented today
  - ***Clerk Maxwell*** completed the final laws of electromagnetism **50 years later**
  - Intensity and quantity remained vague concepts as long as the performance of experiments was hampered by the lack of a stable battery and measuring devices
- The concept of electrical resistance was also not clear before Ohm's law was born in 1826
- A more accurate current meter was invented in 1820

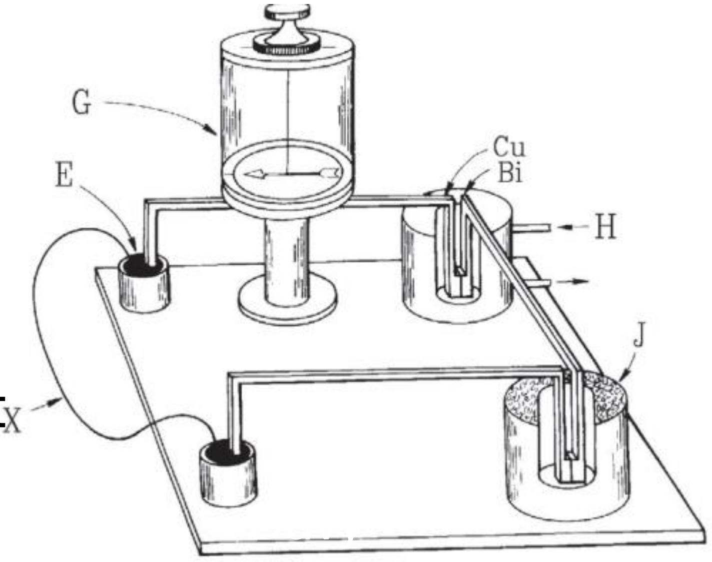
  → Galvanometer





Ohm ~1826

- The researches of the Bavarian *Georg Simon Ohm* (1789–1854) were not valued in his own time and especially in his own country
  - Örsted's and Ampère's writings inspired him to do electrical experiments, but the intensive teaching work gave him little time for them
  - The first paper from 1825 dealt with the effect of the length of the current conductor on the strength of the magnetic field
  - Decided in 1826 to find out the conductivity of different metals, but the first publication had errors → took away credibility from the following publications
  - Made more precise measurements and presented a table of the relative conductivities of different metals
  - Published in the best-known Schweigger and Poggendorff scientific publication series - The publication was difficult for physicists to understand with its differential equations



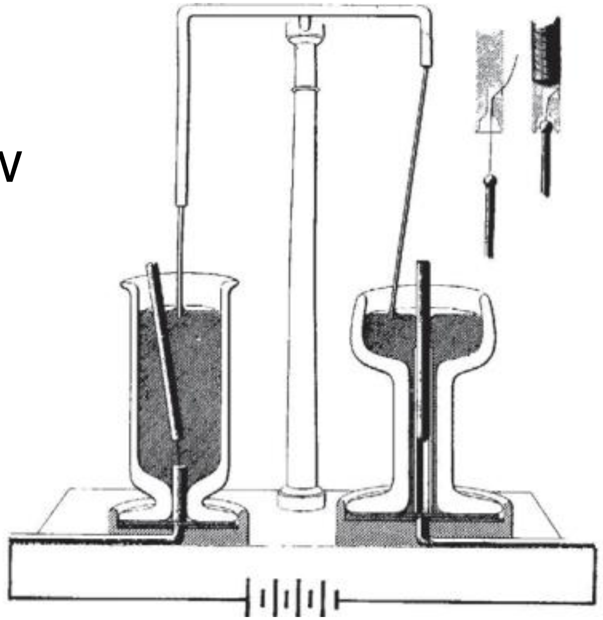
Faraday ~1820

- Michael Faraday (1791–1867) knew how to document and observe various tests clearly and accurately
  - Faraday did not go to school much and did not know mathematics
  - At the age of 13, he got to work binding books and read a lot at the same time
  - Faraday read J. Tytler's article on electricity from the Encyclopaedia Britannica and Jane Marcet's common sense work Conversations on Chemistry

  - Faraday tried different tests in the back room of the bookstore with friction electricity and a Leyden flask, for which he made the necessary equipment himself or bought it with his little money
  - He also acquired supplies for chemistry tests
  - Joined the association of young men interested in science "*The City Philosophical Society*"

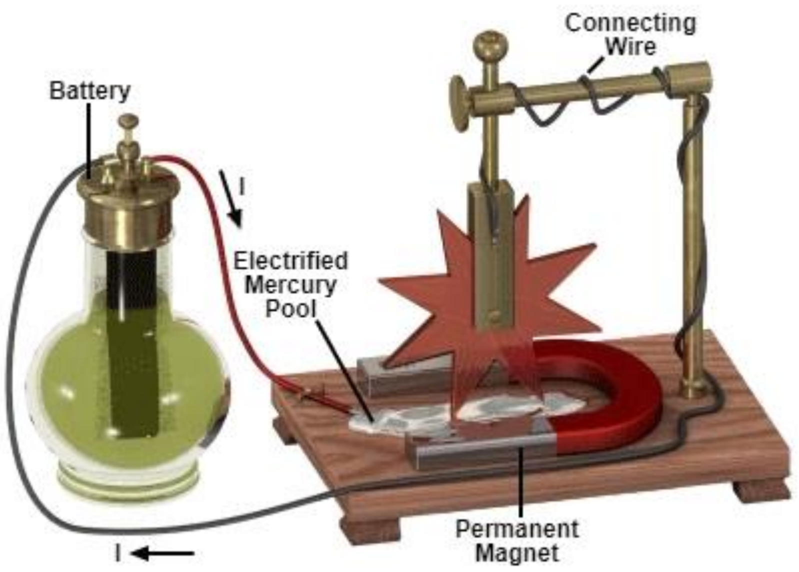
Faraday ~1821

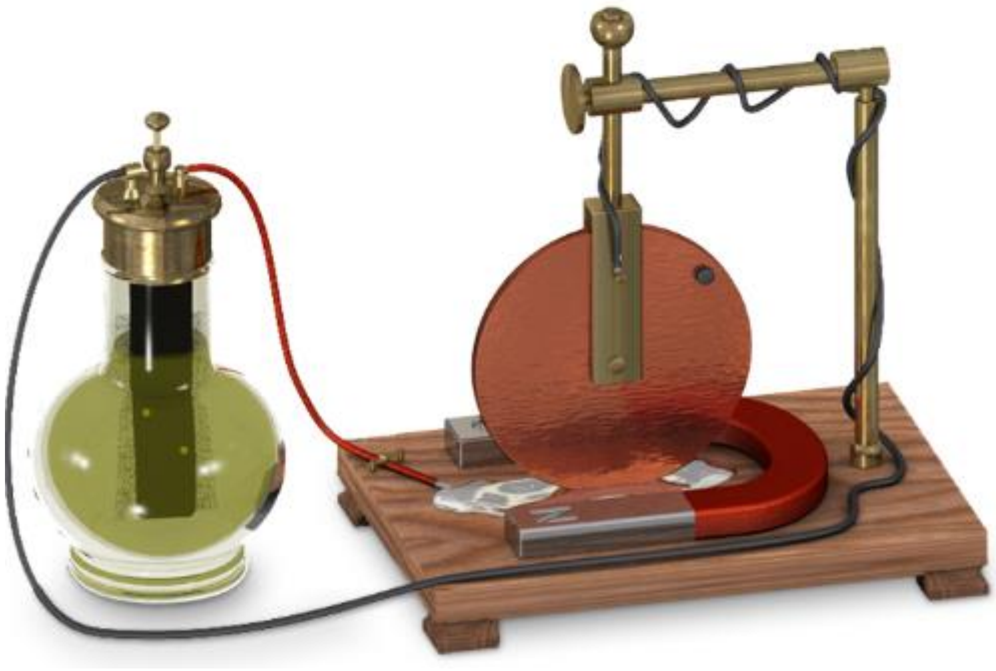
- Davy and Wollaston tried to use a magnet to make the current conductor rotate around its axis, but without success - Faraday followed the tests
- How to get the magnet to go around the current conductor? Faraday solved this in 1821 by burying one end of a long bar magnet in the current by immersing it in mercury
  - The force caused by the current applied only to one end of the magnet and made it rotate around the current wire. This is how the first electric motor, the "rotator" was born
  - He immediately built another device where a moving current wire revolved around a fixed bar magnet
- The first time that a rotating movement was achieved with a magnet and a power source
  - Published the explanation in "*On Some New ElectroMechanical Motions and a Theory of Magnetism*", which made him famous



Peter Barlow – The First Electric Motor ~1823

- Barlow was appointed assistant mathematics master at the Royal Military Academy, Woolwich – Studied e.g. deviation of compass due to iron hull of ships
- Inspired by Faraday's rotator, in 1823 the English physicist Peter Barlow led an electric current through a copper plate between the magnetic poles and a pool of mercury, causing the plate to spin - an electric motor

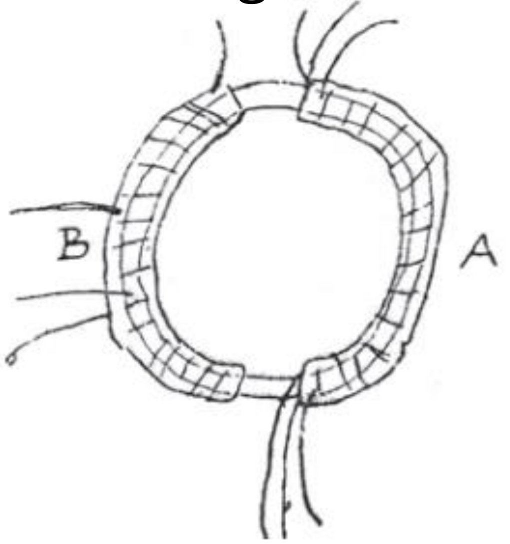




Source: Barlow's Wheel - 1822 - Magnet Academy

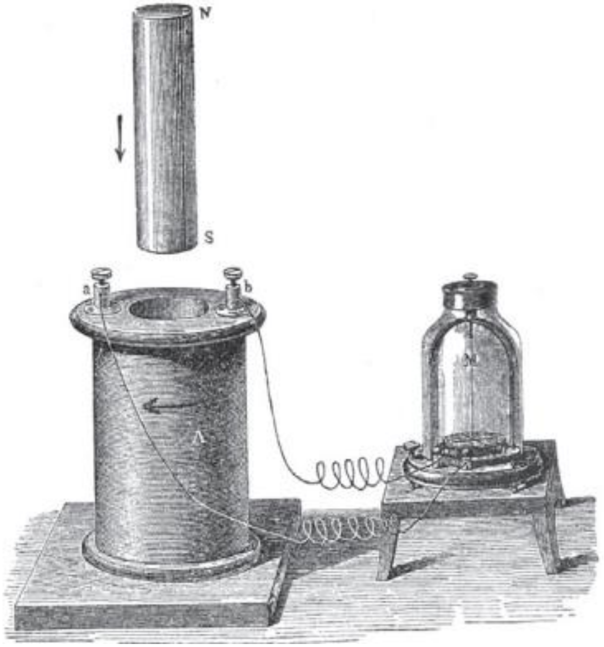
Faraday – Invention of Induction ~1831

- After multiple trials he wrote:
  - *”When the contact was made, a very slight oscillation was seen in the galvanometer, and a similar effect was observed when the battery contact was removed. But when Volta's current passed continuously through the coil, no indication of the galvanometer or phenomenon of induction was observed in the other coil"..." the current when passing through one wire produced a similar current in the other wire, but that it lasted only for a moment and more resembled the electric wave produced by the discharge of a Leyden flask...”*
  - It was already known from Gilbert's tests that the iron core strengthens magnetism
    - Did another experiment where two coils were wrapped around an iron ring with a diameter of 15 cm
      - The needle of the galvanometer rotated several times, which was proof of the induction phenomenon
      - On October 17, he observed an induced electric current when a bar magnet was moved inside a solenoid



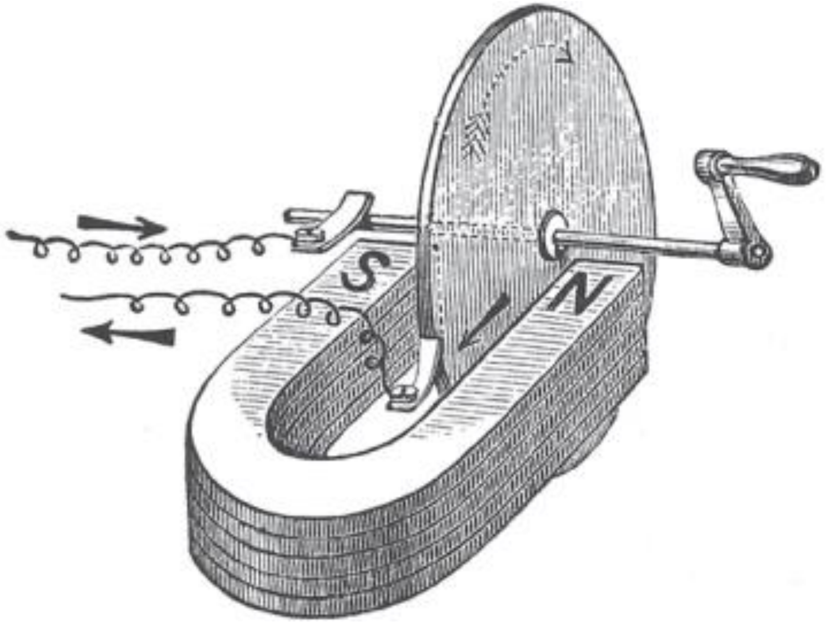
Faraday – Inventing the Generator ~1831

- On October 28, he let a copper disk rotate between the poles of a magnet and in this way produced a continuous electric current by touching the ends of the wire to different points on the surface of the rotating disk
- On November 4, he discovered that the greatest current is obtained when one end of the wire is on the axis of the disk and the other on its edge
    - Selected experiments had invented a new way of generating electricity: an electromagnetic generator
    - The experiments were reported in the Royal Society on 24 Nov
- The results were reported in 1831 and printed in Philosophical Transactions in 1832
- Faraday called the phenomenon “Volta-electrical induction”



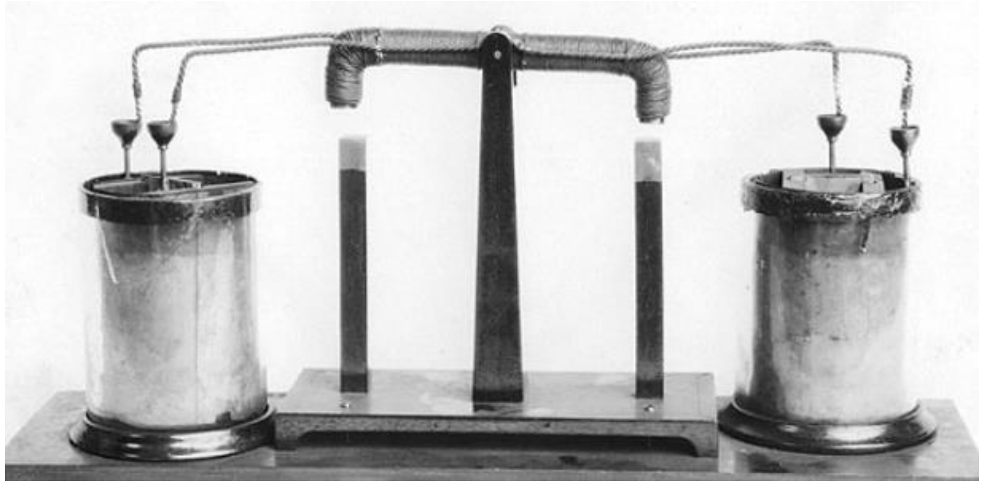
Faraday – Inventing the Generator ~1831

- Faraday wrote from his observation that an induction current is created when a wire moves through a magnet's line of force
  - The current is momentary, but Faraday realized that with the help of the phenomenon, a continuous electric current can be obtained if a loop of wire is made to rotate in the field of a magnet
- Faraday had discovered three ways of generating an electric current in a conductor by means of induction:
  - by changing the current in a nearby coil
  - by moving the magnet while the wire is in place
  - by moving the conductor while the magnet or other current conductor is in place.



Henry – Self Induction ~1832

- *Joseph Henry* conducted induction experiments in Albany, New York
  - Henry invented his own electric motor in 1831. It had a swing-like winding powered by two batteries and either attracted or repelled by magnets near the ends of the windings
  - Henry did not continue the development of the engine because it was expensive to use with a battery as a power source
    - The efficiency of the steam engine was much better than that of the battery-electric motor
- Discovered in 1832 that by cutting off the power supply sparks can be created if the connected wire is long enough - self-induction
- It was not until 1845 that Professor Franz Ernst Neumann (1798–1895) derived the law of induction mathematically from Ampère and Lenz's law



Maxwell – The Birth of Electromagnetism ~1846

- James Clerk Maxwell (1831–1879) enrolled at Edinburgh University aged 16 in 1847 to study mathematics, philosophy, humanities and physics
  - Belonged to a rich family born from the union of the well-known Scottish Clerk and Maxwell families
- 1856 started as the professor of Marischal Collegein Scotland, Aberdeen
  - Maxwell's lectures were beyond the reach of ordinary students, but very rewarding for the few who were able to follow
- Maxwell studied electromagnetic theory between 1854 and 1879, that is, from the time he graduated until the end of his life. At Trinity College he began by reading Faraday's collection Experimental Researches in Electricity, whose field concepts impressed him
- Maxwell continued Thomson's work by elucidating the behavior and interdependence of electric and magnetic quantities

Maxwell – Electromagnetism ~1864 - 1881

- Maxwell's article "*A dynamical theory of the electromagnetic field*" came out in 1864
  - Presented his electromagnetic theory in its final form without a mechanical model
  - Maxwell was not familiar of vector calculus, he presented the equations in a cumbersome component form with 20 equations needed to describe the theory
  - The work was very difficult for physicists to understand, but it was understood by Heinrich Hertz and Oliver Heaviside, who continued to develop the theory

- A novelty in Maxwell's theory was the displacement current term, which made an electromagnetic wave possible
- According to Faraday's law, a change in the magnetic field causes an electromotive force around it, i.e. an electric field. According to Maxwell's additional term, a changing electric field causes a magnetic field around it
- Oliver Heaviside simplified the formulas to the current four ~1878

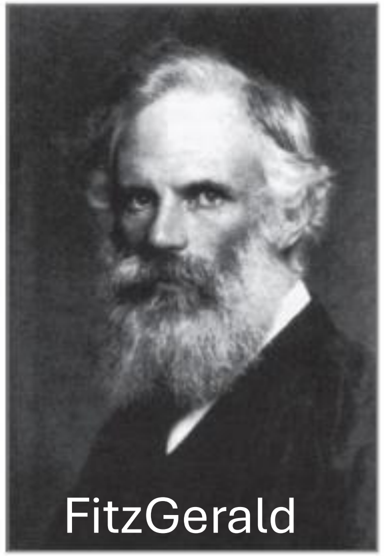
$$a = \frac{dH}{dy} - \frac{dG}{dz}$$
$$b = \frac{dF}{dz} - \frac{dH}{dx}$$
$$c = \frac{dG}{dx} - \frac{dF}{dy}$$
$$P = c\frac{dy}{dt} - b\frac{dz}{dt} - \frac{dF}{dt} - \frac{d\psi}{dx}$$
$$Q = a\frac{dz}{dt} - c\frac{dx}{dt} - \frac{dG}{dt} - \frac{d\psi}{dy}$$
$$R = b\frac{dx}{dt} - a\frac{dy}{dt} - \frac{dH}{dt} - \frac{d\psi}{dz}$$
$$X = vc - wb$$
$$Y = wa - uc$$
$$Z = ub - va$$
$$a = \alpha + 4\pi A$$

FitzGerald – Electromagnetism ~1883

- *George Francis FitzGerald* (1851–1901), a professor at Trinity College, Dublin, was one of the few experts on Maxwell's theory
  - Explore the connection between electromagnetic phenomena and electromagnetic radiation predicted by Maxwell - initially opposed Maxwell's theories
  - It is likely that "part of the alternating current energy can be radiated into space
  - By placing numerical values in Thomson's theoretical vibration circuit, he discovered that the radiation power is minimally small unless the frequency of the vibration is high enough

$$P = (4\pi^5 a^4 \eta I^2 / 3\lambda^4)$$

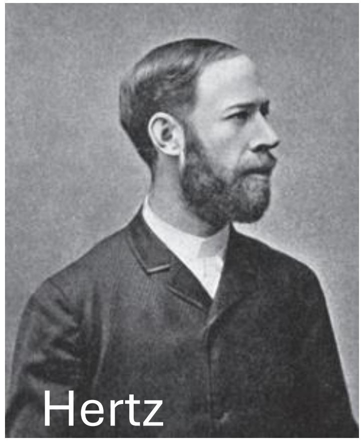
- Alternating current was only available with rotating generators, and the frequencies they provided were far too low
  - FitzGerald suggested: "... let's discharge the capacitor through a small resistance circuit, this way we get sufficiently fast fluctuating currents"



FitzGerald

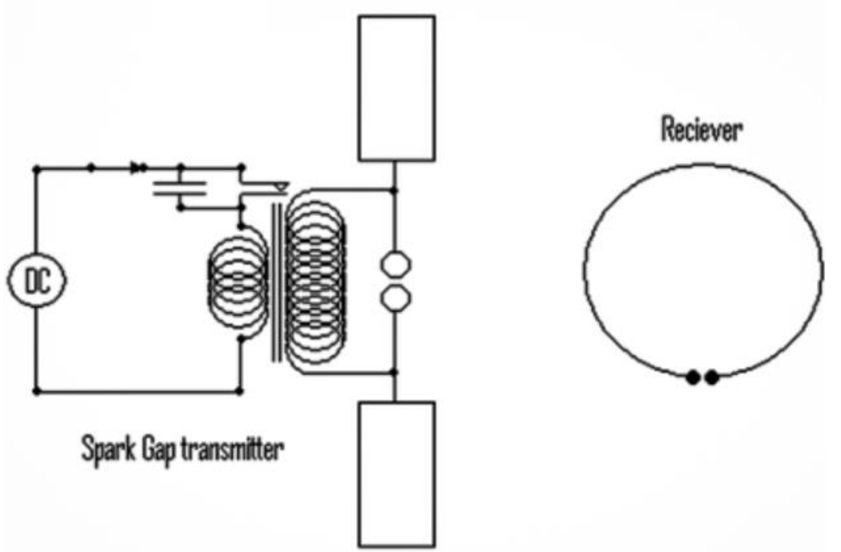
Hertz – Electromagnetism Waves ~1888

- Maxwell's field theory was most opposed in Germany because Weber's theory was considered correct
- The Prussian Academy of Sciences decided to settle the question once and for all by promising a prize in 1879 to whoever would be the first to validly prove Maxwell's theory right or wrong
  - This was first proved by *Heinrich Rudolf Hertz* in 1886–1888
- Heinrich Rudolf Hertz (1857–1894) was born in Hamburg into a wealthy Jewish family
  - In Germany, Jews did not have access to high positions in the army or government positions, so many turned to the academic world
  - Professor Helmholtz of the University of Berlin originally proposed to Hertz as a topic for his dissertation the testing of Maxwell's theory in accordance with the Academy of Sciences award task - Herz did not want such a difficult topic - no one took up the Academy's proposal
  - Died of brain cancer at only 37 years old



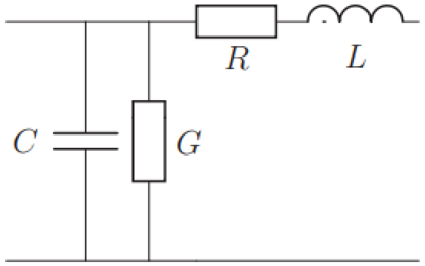
Hertz – Electromagnetism Waves ~1888

- Hertz's goal was to investigate whether electromagnetic waves could be produced as predicted by Maxwell's theory, created 22 years earlier
- An electric spark turned out to be a suitable source of the rapidly oscillating signal
  - Hertz reduced the inductance L of the oscillating circuit by replacing the coil with straight wires and the capacitance C by using small metal balls
    - Invent the dipole antenna
    - He chose a wire loop as the receiving antenna and a spark gap adjustable with a micrometer screw as the detector - tuned to the same frequency
- Discovered that UV radiation strengthened the spark - a photoelectric phenomenon
- Got a signal measured 12 m away
- In his opinion, the results were only academic – not of practical use



Heaviside – Ionosphere and Skin effect ~1901

- Maxwell's theories simplified Oliver Heaviside (1850–1925)
    - He gained his knowledge of electrical engineering through self-study and working as a telegraph operator since 1871 at the Newcastle-upon-Tyne office
    - Lived as a hermit, but published his theories and related thoughts often boldly and annoyingly



$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$$
$$\nabla \cdot \mathbf{D} = \varrho$$

- At the age of 24, he devoted himself to electromagnetic theory and isolated himself from the outside world. Got his finances in order with the help of his parents or friends and occasional writing fees
- His life's work was developing Maxwell's equations, and it was also named after him, but later again Maxwell's equations
    - Used the concept of negative resistance and applied vector calculus
    - Presented the idea of the ionosphere and the phenomenon known as the skin effect
    - Did not benefit financially from his inventions. His uncle *Charles Wheatstone*

Heaviside – Publications ~1906 - 1912

- He went to school only until he was 16, after that he studied mathematics and physics on his own
- 1896 When Heaviside's father died, he had to support himself, however he refused to apply for work anymore, worked as a younger electrician, but deafness prevented him from working
  - He did not accept poor relief, as was also the Royal Society's grants. With his pension, Heaviside moved into a rented house with a housekeeper. Here he completed the second and third parts of his work ~1901
  - The articles were too unclear, and the editor of The Electrician stopped publishing them in 1906 - cutting off all channels to the outside world
  - Predicted that the mass of the charge increases with speed → relativity theory
- Today, the schematic and calculation methods defined by Heaviside are used to study electromagnetics → reduced Maxwell's 20 equations in 20 variables to 4 equations in 2 variables

$e+\frac{df}{dx}+\frac{dg}{dy}+\frac{dh}{dz}=0$	(1)	Gauss' Law
$\mu\alpha=\frac{dH}{dy}-\frac{dG}{dz}$ $\mu\beta=\frac{dF}{dz}-\frac{dH}{dx}$ $\mu\gamma=\frac{dG}{dx}-\frac{dF}{dy}$	(2)	Equivalent to Gauss' Law for magnetism
$P=\mu\left(\gamma\frac{dy}{dt}-\beta\frac{dz}{dt}\right)-\frac{dF}{dt}-\frac{d\Psi}{dx}$ $Q=\mu\left(\alpha\frac{dz}{dt}-\gamma\frac{dx}{dt}\right)-\frac{dG}{dt}-\frac{d\Psi}{dy}$ $R=\mu\left(\beta\frac{dx}{dt}-\alpha\frac{dy}{dt}\right)-\frac{dH}{dt}-\frac{d\Psi}{dz}$	(3)	Faraday's Law (with the Lorentz Force and Poisson's Law)
$\frac{d\gamma}{dy}-\frac{d\beta}{dz}=4\pi p'$ $\quad p'=p+\frac{df}{dt}$ $\frac{d\alpha}{dz}-\frac{d\gamma}{dx}=4\pi q'$ $\quad q'=q+\frac{dg}{dt}$ $\frac{d\beta}{dx}-\frac{d\alpha}{dy}=4\pi r'$ $\quad r'=r+\frac{dh}{dt}$	(4)	Ampère-Maxwell Law
$P=-\xi p \quad Q=-\xi q \quad R=-\xi r$		Ohm's Law
$P=kf \quad Q=kg \quad R=kh$		The electric elasticity equation (**E** = **D**/ε)
$\frac{de}{dt}+\frac{dp}{dx}+\frac{dq}{dy}+\frac{dr}{dz}=0$		Continuity of charge

Maxwell / Heaviside -Equations

$$\nabla\cdot\mathbf{E}=\frac{\rho}{\varepsilon_0}$$
$$\nabla\cdot\mathbf{B}=0$$
$$\nabla\times\mathbf{E}=-\frac{\partial\mathbf{B}}{\partial t}$$
$$\nabla\times\mathbf{B}=\mu_0\left(\mathbf{J}+\varepsilon_0\frac{\partial\mathbf{E}}{\partial t}\right)$$

With $\mathbf{E}$ the electric field, $\mathbf{B}$ the magnetic field, ρ the electric charge density and $\mathbf{J}$ the current density. ε_0 is the vacuum permittivity and μ_0 the vacuum permeability.