The History of Biolectromagnetism

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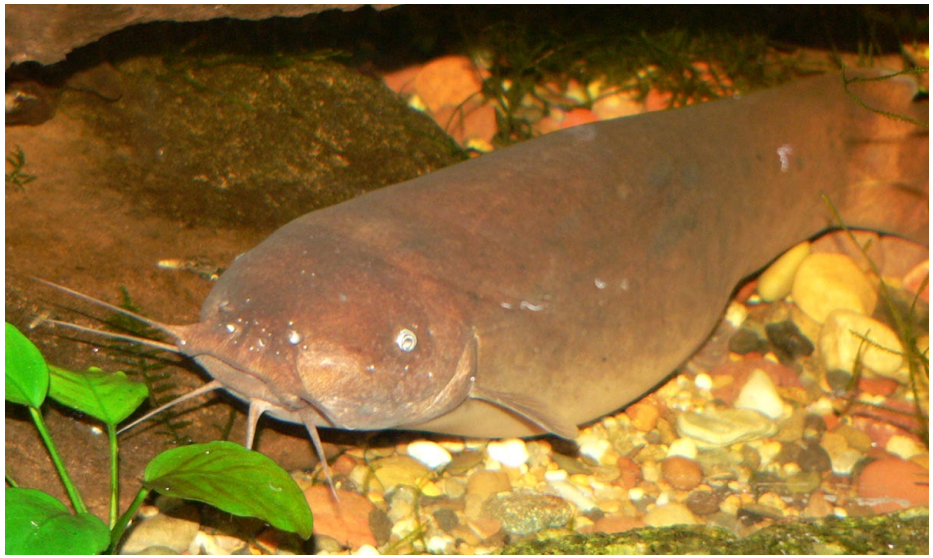
Summary

- Classically the early period of bioelectromagnetism is meant into three phases:
- Pre-Galvanic
- Galvanic
- Instrumental

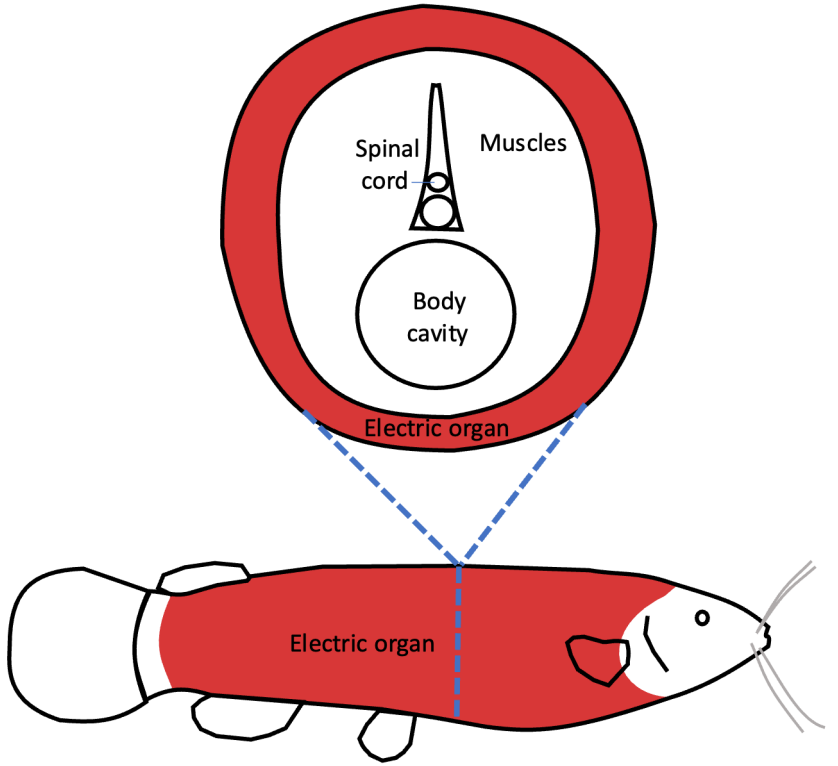
Pre-Galvanic

Malopterurus electricus



- The first bioelectric phenomenon to come to human awareness was the electric discharge of certain fishes: the Nile catfish (Malopterurus electricus), the electric ray (torpedo), the common skate (Mormyrus) and the electric eel (Electrophorus electricus), which are capable of delivering a very painful and paralyzing shock.

Pre-Galvanic



- Electric catfish or Malapteruridae is a family of catfishes, with 21 species.
- Several species of this family have the ability to generate electricity, delivering a shock of up to 350 volts from its electric organ.
- Electric catfish are found in tropical Africa and the Nile River.
- Electric catfish are usually nocturnal and carnivorous.

Pre-Galvanic

The electric catfish of the Nile was well known to the ancient Egyptians.

The Egyptians reputedly used the electric shock from them when treating arthritis pain.

They would use only smaller fish, as a large fish may generate an electric shock from 300 to 400 volts.

The Egyptians depicted the fish in their mural paintings and elsewhere.

The first known depiction of an electric catfish is on a slate palette of the predynastic Egyptian ruler Narmer about 3100 BC.

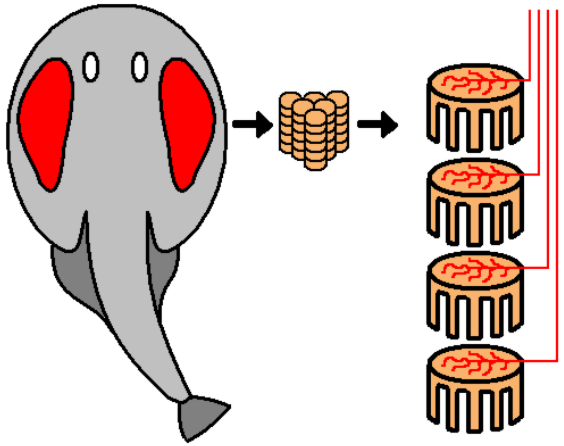
Pre-Galvanic

Marbled electric ray
(Torpedo marmorata)

- The electric rays are a group of rays, flattened cartilaginous fish with enlarged pectoral fins, being capable of producing an electric discharge, ranging from 8 to 220 volts, depending on species, used to stun prey and for defense.

Pre-Galvanic

Diagram of structure of electric organs and stacked electrocytes



- The electrogenic properties of electric rays have been known since antiquity, although their nature was not understood.
- The ancient Greeks used electric rays to numb the pain of childbirth and operations.
- Scribonius Largus, a Roman physician, recorded the use of torpedo fish for treatment of headaches and gout in his Compositiones Medicae of 46 AD.

Pre-Galvanic

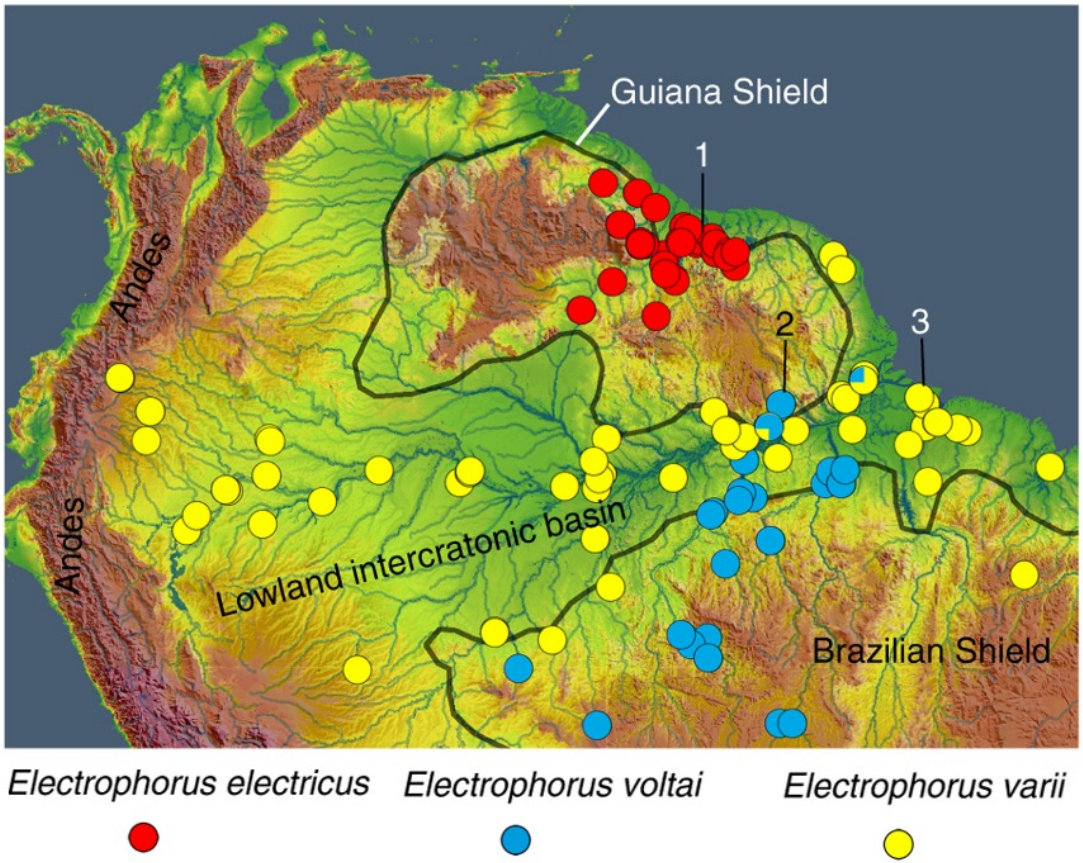
- The electric eels are a genus, Electrophorus, of neotropical **freshwater** fish from South America in the family Gymnotidae.
- They are known for their ability to stun their prey by generating electricity, delivering shocks at up to 860 volts.
- Their electrical capabilities were first studied in 1775, contributing to the invention in 1800 of the electric battery.

Pre-Galvanic

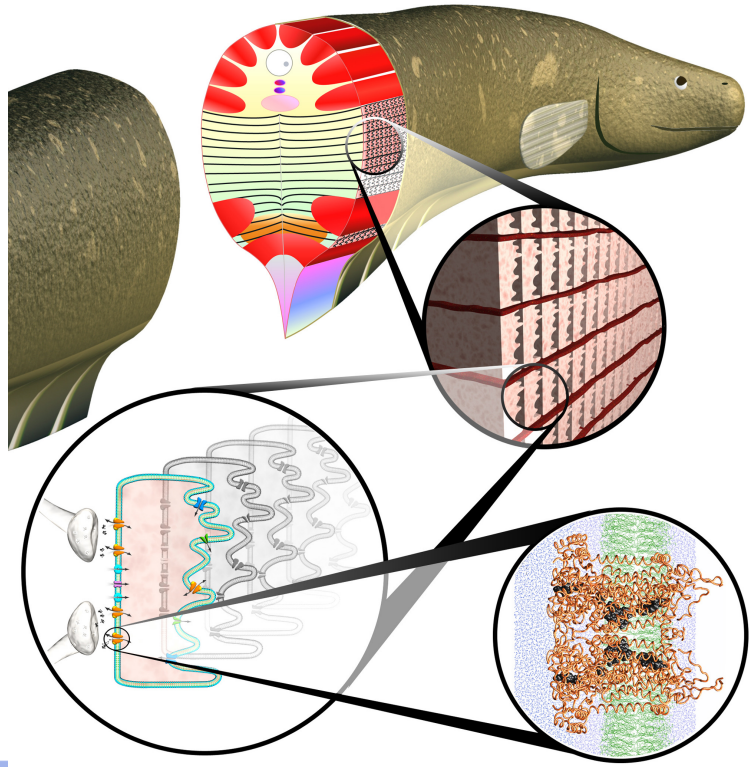
There are three described species in the genus, not differing significantly in body shape or coloration.

The three species have largely non-overlapping distributions in the northern part of South America.

Electric eels are mostly nocturnal.



Pre-Galvanic



- Electric eel anatomy:
  - First detail shows stacks of electrocytes forming electric organs.
  - Second detail shows an individual cell with ion channels and pumps through the cell membrane; A nerve cell's terminal buttons are releasing neurotransmitters to trigger electrical activity.
  - Final detail shows coiled protein chains of an ion channel.

Pre-Galvanic

- Electric eels have three pairs of electric organs, arranged longitudinally: the main organ, Hunter's organ, and Sachs' organ. These organs give electric eels the ability to generate two types of electric organ discharges: low voltage and high voltage.
- The organs are made of electrocytes, modified from muscle cells.
- The maximum discharge from the main organ is at least 600 volts, making electric eels the most powerful of all electric fishes.
- Freshwater fishes like the electric eel require a high voltage to give a strong shock because *freshwater has high resistance*; powerful marine electric fishes like the torpedo ray give a shock at much lower voltage but a far higher current. The electric eel produces its strong discharge extremely rapidly, at a rate of as much as 500 Hertz, meaning that each shock lasts only about two milliseconds.

Pre-Galvanic

- The naturalists Bertrand Bajon, a French military surgeon in French Guiana, and the Jesuit Ramón M. Termeyer in the River Plate basin, conducted early experiments on the numbing discharges of electric eels in the 1760s.
- In 1775, the "torpedo" (the electric ray) was studied by John Walsh, both fish were dissected by the surgeon and anatomist John Hunter. He described the structure of the organs (stacks of electrocytes).
- Also in 1775, the American physician and politician Hugh Williamson, who had studied with Hunter, presented a paper "Experiments and observations on the Gymnotus Electricus, or electric eel" at the Royal Society.

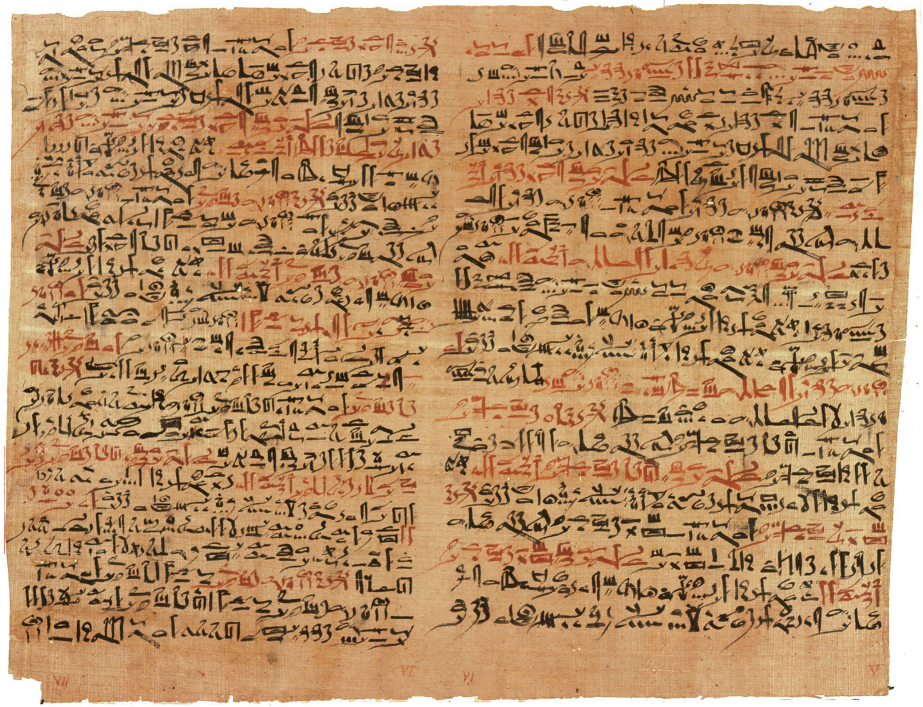
Pre-Galvanic

The studies by Williamson, Walsh, and Hunter appear to have influenced the thinking of Luigi Galvani and Alessandro Volta.

Triboelectricity

- Before 1745, the observations on the effects of the discharge of electric fish seemed unconnected with observations on electric effects of inorganic matter.
- However, *triboelectricity*, generated by rubbing or striking dielectric materials such as amber, agate, rock crystal and horn, has probably been observed and used since at least the Stone Age. The medical use of the special properties of magnetic materials is documented even much earlier than that of electric fish .

Papyrus Ebers



- Already in the Papyrus Ebers (3600 B.C.) there is a recommendation for the use of lodestone, and some museums display Egyptian scarab-amulets made from magnetite and magnetic iron.
- Hippocrates prescribes a preparation with magnetite powder against infertility and gastric problems.

William Gilbert


GVILIELMI GIL-
BERTI COLCESTREN-
SIS, MEDICI LONDI-
NENSIS,

DE MAGNETE, MAGNETI-
CISQVE CORPORIBVS, ET DE MAG-
no magnete tellure; Physiologia noua,
plurimis & argumentis, & expe-
rimentis demonstrata.

LONDINI
EXCVDEBAT PETRVS SHORT ANNO
MDC.

- The scientific era of bioelectromagnetics did not start until 1600, when William Gilbert defined and named electricity.
- William Gilbert (24 May 1544? – 30 November 1603), also known as Gilberd, was an English physician, physicist and natural philosopher. He passionately rejected both the prevailing Aristotelian philosophy and the Scholastic method of university teaching. He is remembered today largely for his book De Magnete (1600).

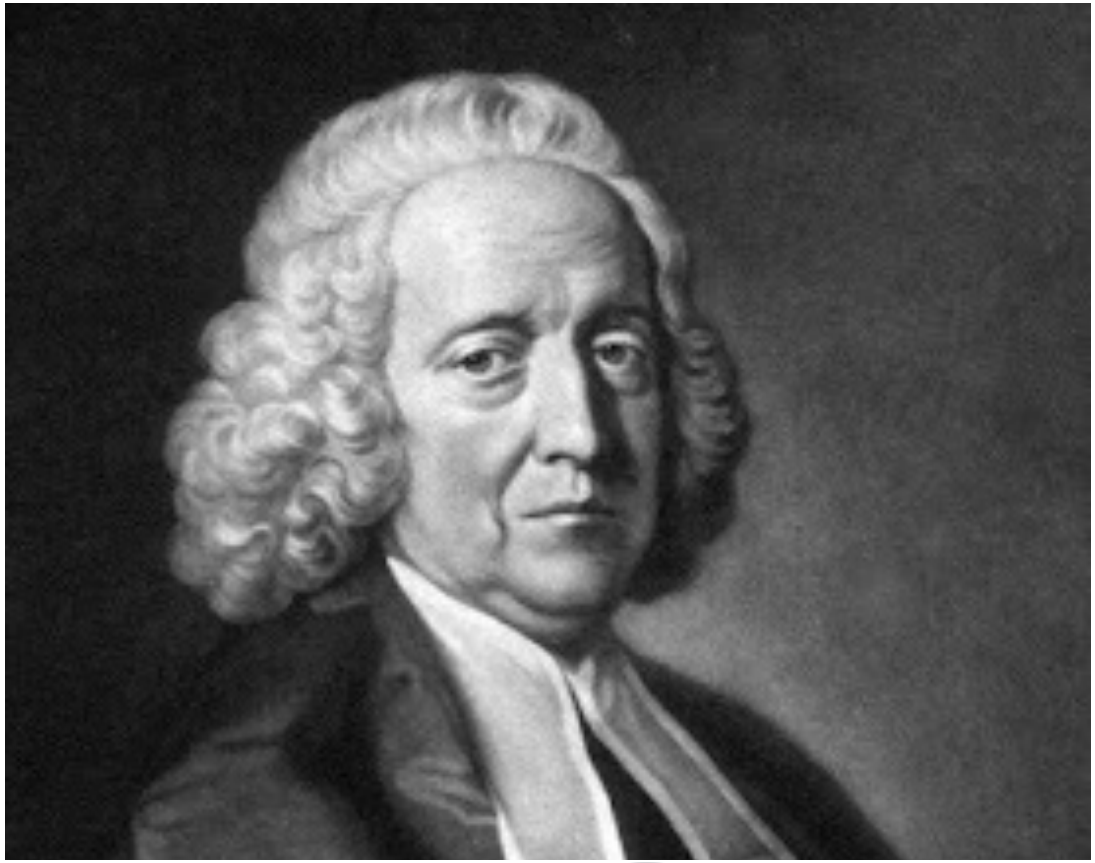
William Gilbert

- His primary scientific work was *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* (On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth) published in 1600.
- In this work, he describes many of his experiments with his model Earth called the terrella.
- From these experiments, he concluded that the Earth was itself magnetic and that this was the reason compasses point north (previously, some believed that it was the pole star (Polaris) or a large magnetic island on the north pole that attracted the compass).
- He was the first to argue, that the centre of the Earth was iron, and he considered an important and related property of magnets was that they can be cut, each forming a new magnet with north and south poles.
- Gilbert argued that electricity and magnetism were not the same thing.

Stephen Gray

Stephen Gray (December 1666 – 7 February 1736) was an English scientist who was the first to systematically experiment with electrical conduction.

He was the first to propose the existence of conducting and non-conducting materials of electricity.



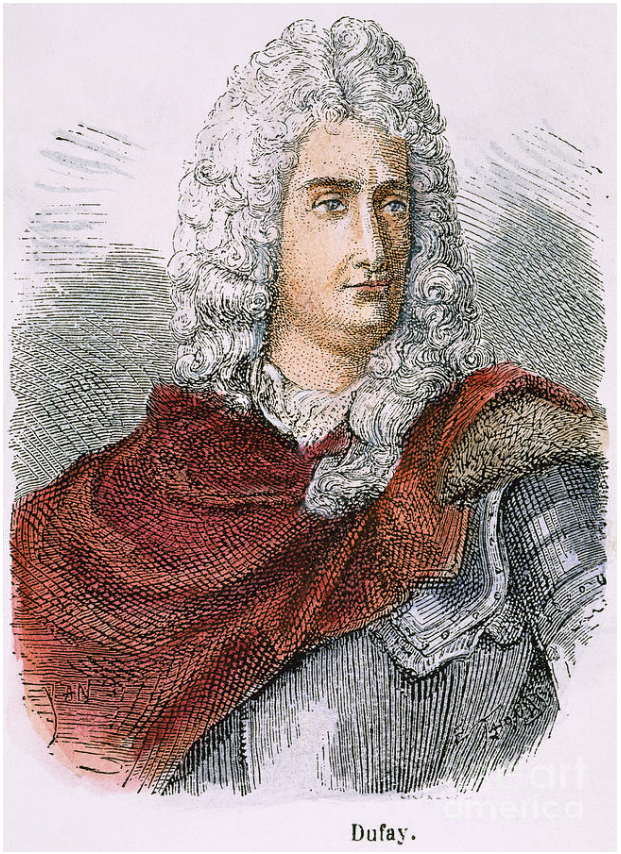
Charles Du Fay

Charles François de Cisternay du Fay (14 September 1698 – 16 July 1739) was a French chemist and superintendent of the Jardin du Roi.

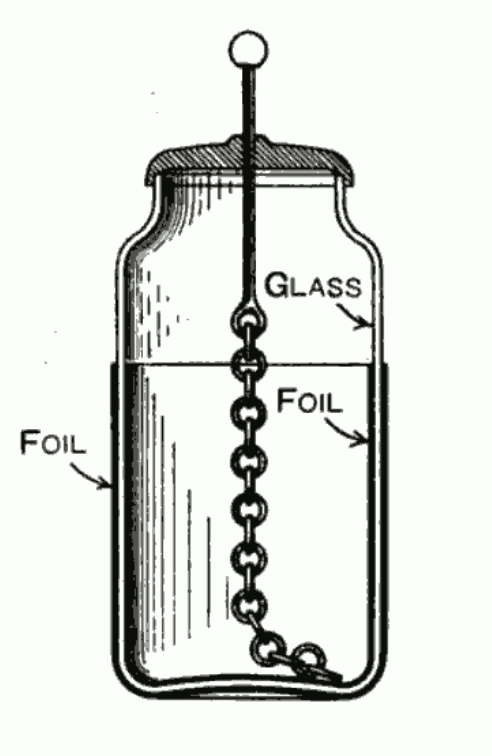
He discovered the existence of two types of electricity and named them "vitreous" and "resinous" (later known as positive and negative charge respectively).

He also discovered that alike-charged objects would repel each other and that unlike-charged objects attract.

He also disproved certain misconceptions regarding electric charge, such as that of Dr. Stephen Gray who believed that electric properties of a body depended on its colour.



The Leiden jar



- Instances of Europeans using electric fish for medical purposes are to be found in the literature up to about 1850.
- When in 1745, the Leiden jar was invented, the similarity between the shock it delivered and the discharge of the electric fish was pointed out, which led to a wave of experiments with electric fish.

Leiden jar

A Leyden jar (or Leiden jar, or archaically, sometimes Kleistian jar) is the first form of an electrical capacitor.

Leiden (archaic name Leyden) is a Dutch city in the south of the Netherlands.

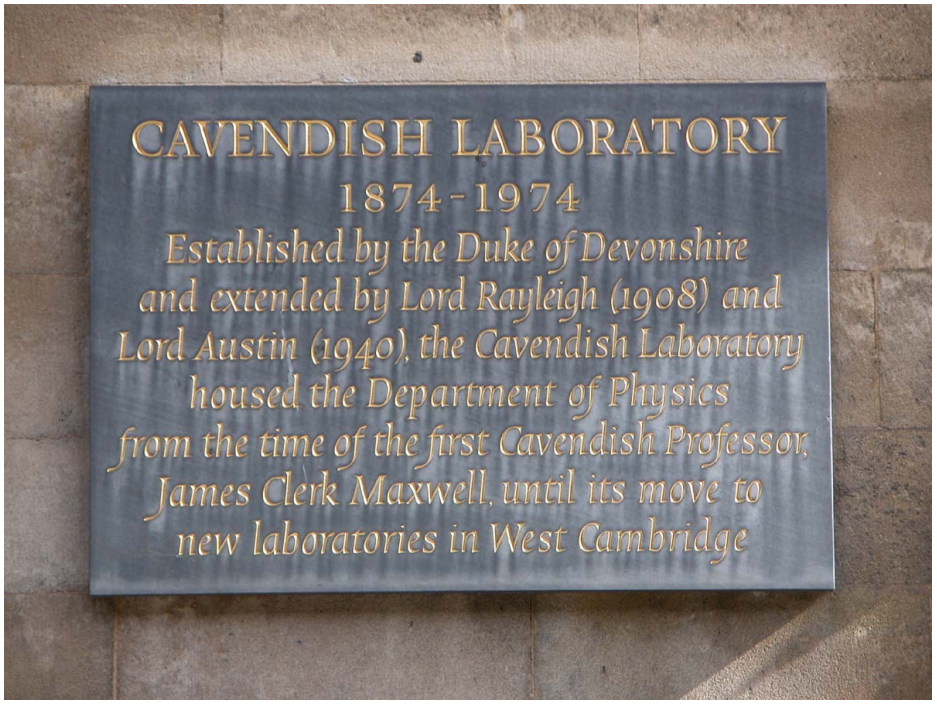
Its invention was a discovery made independently by German cleric Ewald Georg von Kleist on 11 October 1745 and later by Dutch scientist Pieter van Musschenbroek of Leiden (Leyden), Netherlands.

The Leiden jar

- Drawing of an early form of Leyden jar, from an 1898 textbook on physics.
- Unlike the later type of Leyden jar which had coatings of metal foil on the inside and outside, this first form of Leyden jar was filled with salty water. The water formed the inner plate of the capacitor.
- A metal nail driven through the cork stopper made contact with the water, allowing the water to be charged with electricity and discharged.
- The jar was held in the hand, and the (grounded) hand on the outside of the jar formed the other plate of the capacitor. Once charged, the jar could be discharged by approaching the nail with a finger as shown. The charge from the water would jump via a spark to the hand, and flow through the body to the other hand holding the jar, neutralizing the opposite charge there.

Henry Cavendish

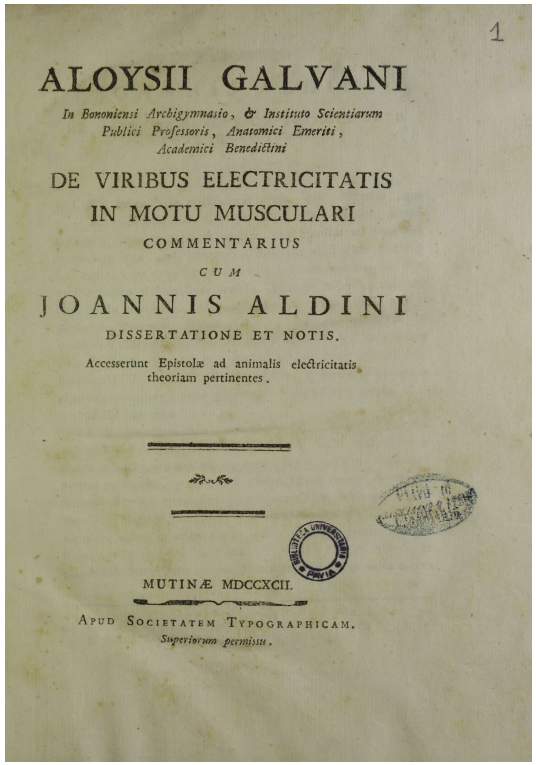
- Henry Cavendish FRS (10 October 1731 – 24 February 1810) was an English natural philosopher and scientist.
- Henry Cavendish in 1776 made experiments that convinced him that the variations in the intensity of the shock released by electric fish were understandable in terms of electric fields. In attempting to clarify the concept of electrical resistance, he made an artificial torpedo which simulated the action of the living animal when excited by a battery of Leyden jars.



Luigi Galvani

- Luigi Galvani (9 September 1737 – 4 December 1798) was an Italian physician, physicist, biologist and philosopher, who studied animal electricity.
- In 1780, he discovered that the muscles of dead frogs' legs twitched when struck by an electrical spark.

Luigi Galvani



ALOYSII GALVANI

In Bononiensi Archigymnasio, & Instituto Scientiarum Publici Professoris, Anatomici Emeriti, Academici Benedictini

DE VIRIBUS ELECTRICITATIS IN MOTU MUSCULARI

COMMENTARIUS

CUM

JOANNIS ALDINI

DISSERTATIONE ET NOTIS.

Accesserunt Epistolæ ad animalis electricitatis theoriam pertinentes.

MUTINÆ MDCCXCII.

APUD SOCIETATEM TYPOGRAPHICAM.

Superiorum permissu.

- The details of the experiment are provided by Galvani himself, who in 1791 published *De viribus electricitatis in motu musculari*, a pamphlet in which all the processes that led to the discovery of animal electricity are illustrated.

Luigi Galvani

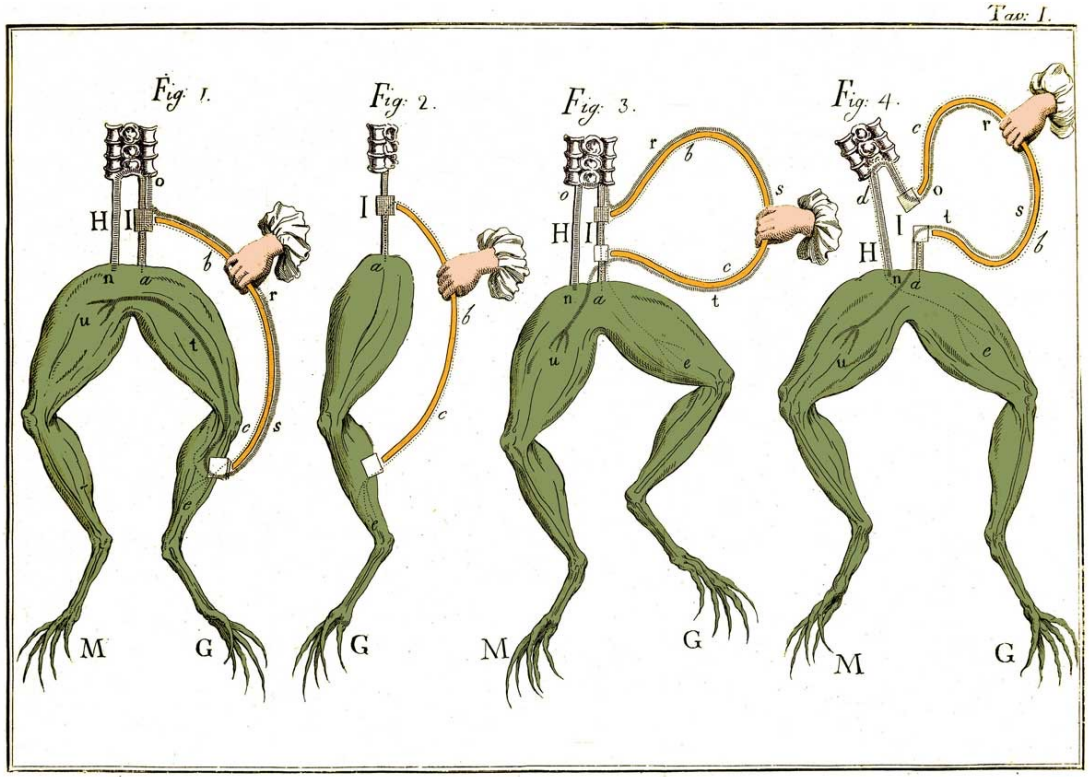
- Galvani therefore hypothesized a relationship between electricity and life, and decided to continue conducting experiments on frogs, observing the movement of the muscles in relation to the electrostatic charge with which they were touched.
- Galvani hypothesized the existence of a relationship between electricity and life, defined as *"electricity intrinsic to the animal"* which produces the contraction of the muscles, which, in addition to being very sensitive detectors, were "reservoirs" of electricity.

Luigi Galvani

- This idea was welcomed with enthusiasm by many physiologists, but met with strong opposition from other colleagues, such as Alessandro Volta, at the time an esteemed professor of physics at the University of Pavia.
- Indeed, Volta believed that the contractions of the muscles were not caused by the electricity present in the animal, but were due to an irritation of the nerves; while Galvani thought that electricity was produced - and transmitted - by the brain and controlled through the nerves

Luigi Galvani

Does “Animal Electricity” Exist ?



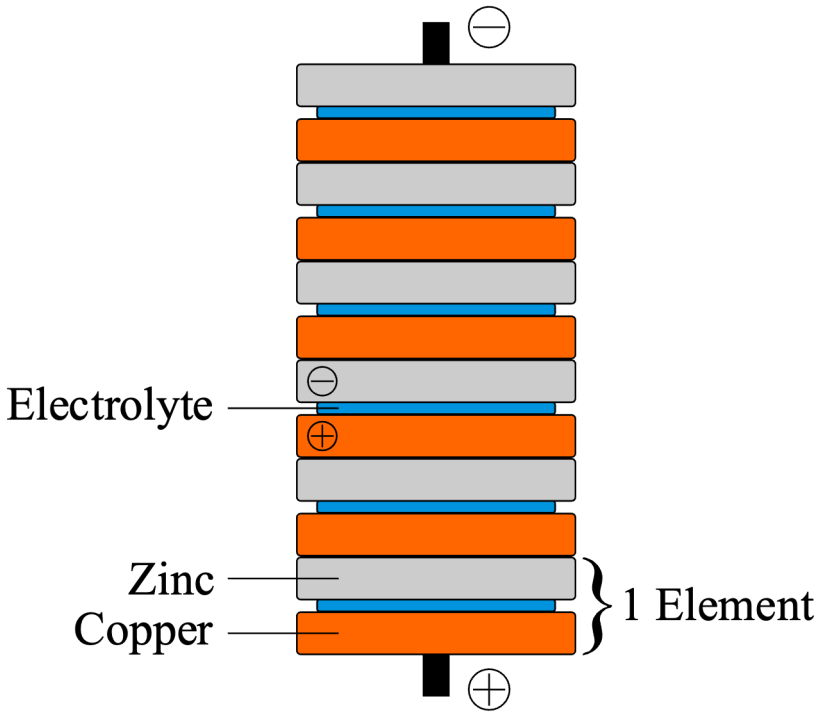
Alessandro Volta

Alessandro Giuseppe Antonio Anastasio Volta (18 February 1745 – 5 March 1827) was an Italian physicist and chemist who was a pioneer of electricity and power who is credited as the inventor of the electric battery and the discoverer of methane.

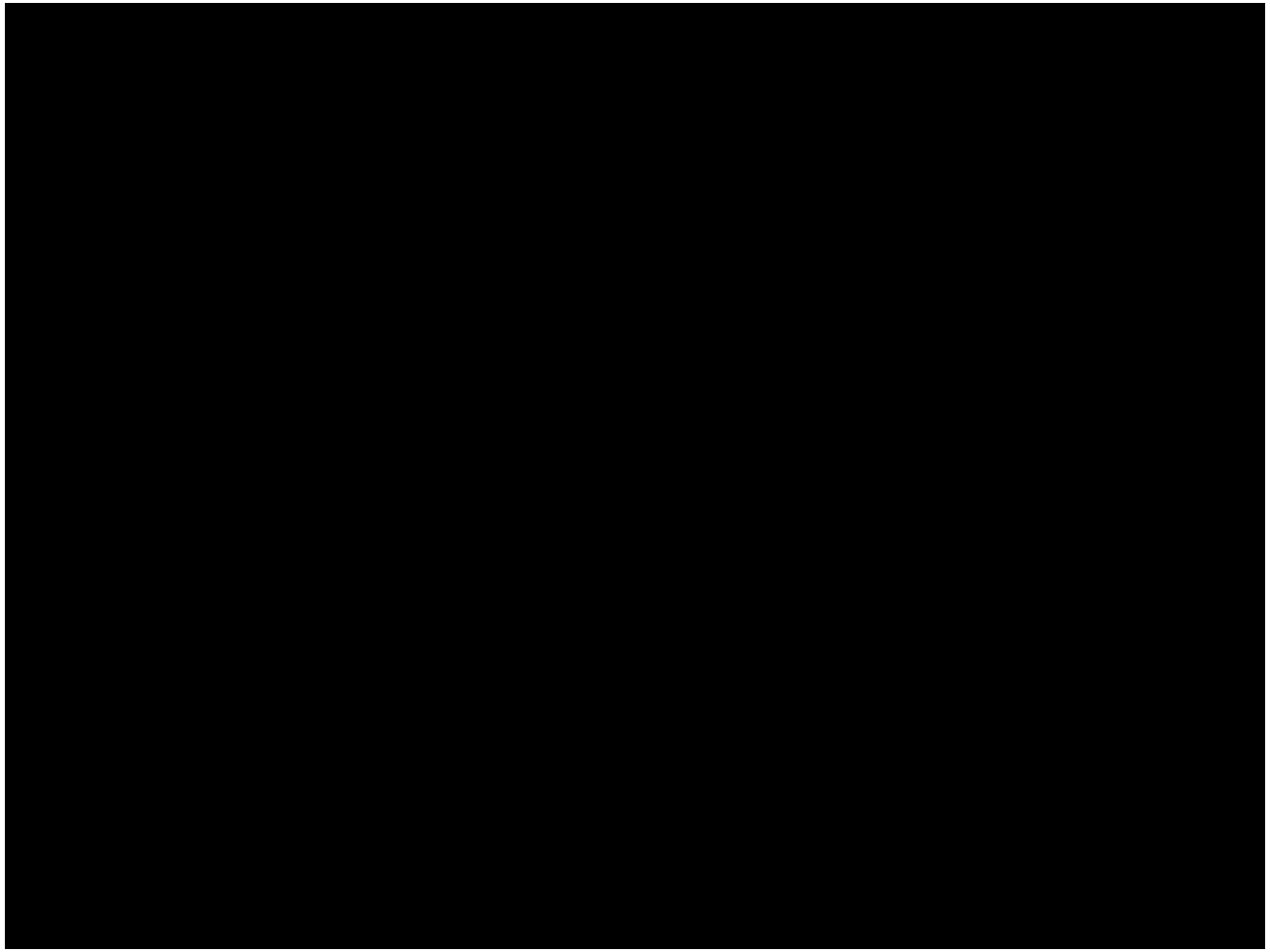
He invented the voltaic pile in 1799.

With this invention Volta proved that electricity could be generated chemically and debunked the prevalent theory that electricity was generated solely by living beings.

Alessandro Volta



- The voltaic pile was the first electrical battery that could continuously provide an electric current to a circuit.
- It was invented by Italian chemist Alessandro Volta, who published his experiments in 1799.
- Its invention can be traced back to an argument between Volta and Luigi Galvani, Volta's fellow Italian scientist who had conducted experiments on frogs' legs.



Galvanotherapy

- Ironically, bimetallic electricity, whose existence Galvani denied to the end of his life, soon became known as *"*Galvanic electricity" or "Galvanism".
- "Galvanotherapy" is the name used up to the present day for the therapeutic use of the new DC currents drawn from voltaic piles.
- This form of electrotherapy was not least pioneered by Galvani's nephew, Giovanni Aldini, professor of experimental physics at Bologna.
- In his *Improvements in Galvanism* (1803), Aldini praised the utility of galvanic currents in the resuscitation of the drowned and asphyxiated, and maintained he had successfully treated asthmatics with electricity.

Galvanotherapy

Alexander von Humboldt

- In 1800, the explorer Alexander von Humboldt joined a group of indigenous people who went fishing with horses, some thirty of which they chased into the water.
- The pounding of the horses' hooves, he noted, drove the fish, up to 1.5 m long out of the mud and prompted them to attack, rising out of the water and using their electricity to shock the horses. He saw two horses stunned by the shocks and then drowned. The electric eels, having given many shocks, "now require long rest and plenty of nourishment to replace the loss of galvanic power they have suffered", "swam timidly to the bank of the pond", and were easily caught using small harpoons on ropes.
- Humboldt recorded that the people did not eat the electric organs, and that they feared the fish so much that they would not fish for them in the usual way.

Alexander von Humboldt

Friedrich Wilhelm Heinrich Alexander von Humboldt (14 September 1769 – 6 May 1859) was a German polymath, geographer, naturalist, explorer, and proponent of Romantic philosophy and science.

Between 1799 and 1804, Humboldt travelled extensively in the Americas, exploring and describing them for the first time from a modern Western scientific point of view.

Humboldt resurrected the use of the word cosmos from the ancient Greek and assigned it to his multivolume treatise, Kosmos, in which he sought to unify diverse branches of scientific knowledge and culture. This important work also motivated a holistic perception of the universe as one interacting entity, which introduced concepts of ecology leading to ideas of environmentalism.

Alexander von Humboldt

- Humboldt repeated Volta's and Galvani's experiments and extended them.
- He concluded that Galvani had uncovered two different phenomena, both genuine: bimetallic electricity and intrinsic animal electricity, which were not mutually exclusive.

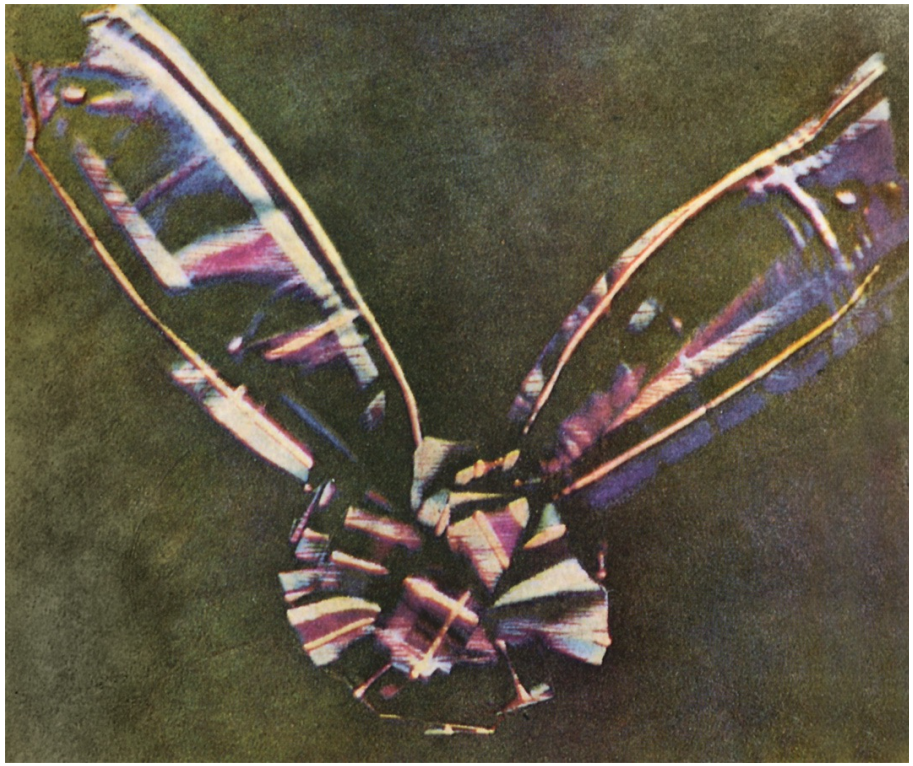
The instrumental era

- A new era of bioelectromagnetics began when in 1820 Hans Christian Oersted accidentally discovers the long-suspected connection between electricity and magnetism.
- Ampere shows that magnetism could be caused by electricity and invented the solenoid.
- Michael Faraday demonstrates that a time changing magnetic field produces an electric field. This law is at the basis of electrical engines.
- James Clerk Maxwell understands that electrical and magnetic fields are two side of the same unique phenomenon.

James Clerk Maxwell

$$\begin{cases} \nabla \times \vec{e} = -\dfrac{\partial \vec{b}}{\partial t} \\ \nabla \times \vec{h} = \vec{j} + \dfrac{\partial \vec{d}}{\partial t} \\ \nabla \cdot \vec{d} = \rho \\ \nabla \cdot \vec{b} = 0 \end{cases}$$

James Clerk Maxwell



$$\begin{cases} \nabla \times \vec{e} = 0 \\ \nabla \times \vec{h} = \vec{j} \\ \nabla \cdot \vec{d} = \rho \\ \nabla \cdot \vec{b} = 0 \end{cases}$$

The instrumental era

- The first decades of the 19th century also saw the beginnings of the application of electrical currents through acupuncture needles.
- Since about 1820, interest in the phenomenon of animal electricity had generally receded; only Aldini, Nobili and particularly Matteucci continued to make measurements and to theorize about it.
- Nonetheless, they improved the instrumentation and conclusively demonstrated the existence of bioelectric currents, thus providing a confirmation of 'animal electricity'.

Carlo Matteucci

- Carlo Matteucci (20 June 1811 – 25 June 1868) was an Italian physicist and neurophysiologist who was a pioneer in the study of bioelectricity.
- Starting from 1830, under the influence of the results of Luigi Galvani (1737-1798), he develops a research program in electrochemistry and electrophysiology, sectors of which he is considered a precursor. He had the merit of having first discovered the muscular current, i.e. the electrical phenomenon connected to muscular effort.

Wimshurst machine

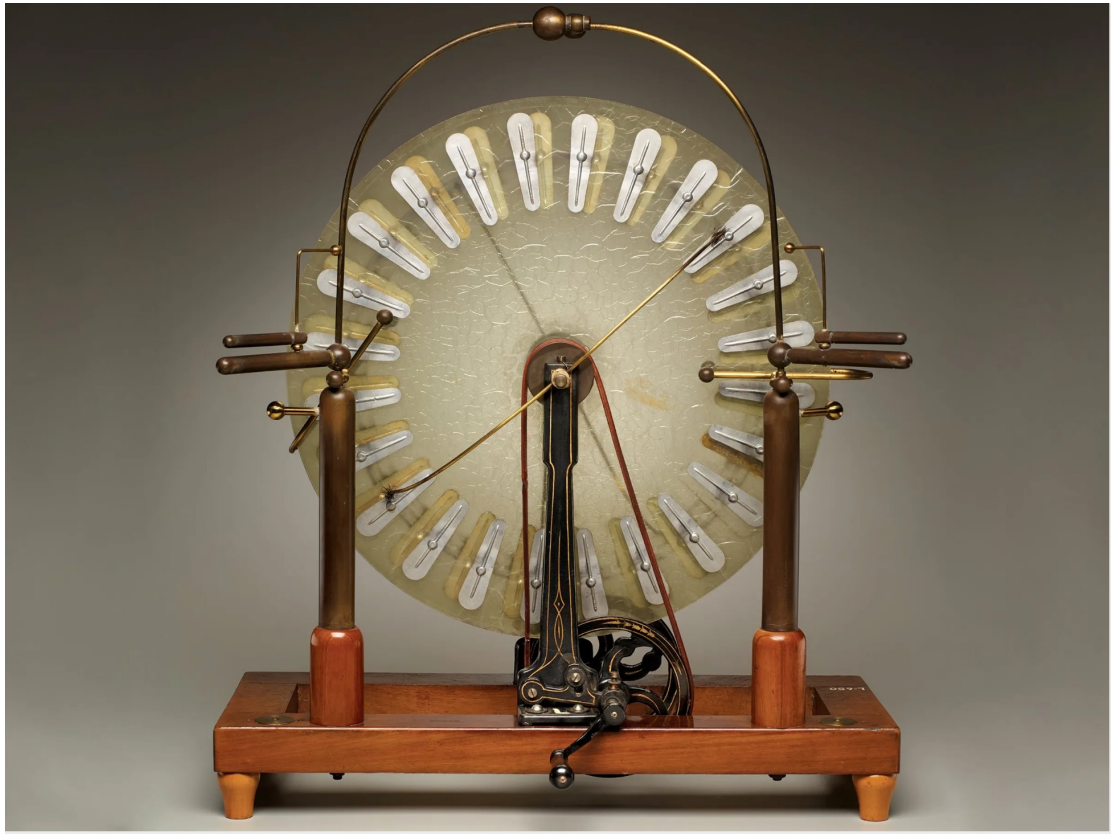
The British engineer James Wimshurst did not invent the machine that bears his name. But thanks to his many refinements to a distinctive type of electrostatic generator, we now have the Wimshurst influence machine.

The Wimshurst machine as it exists today has two insulated disks, often made from plastic but sometimes still made from glass, with metal conducting plates positioned around the rims. The disks are mounted on a single axle and rotate in opposite directions when driven by a hand crank.

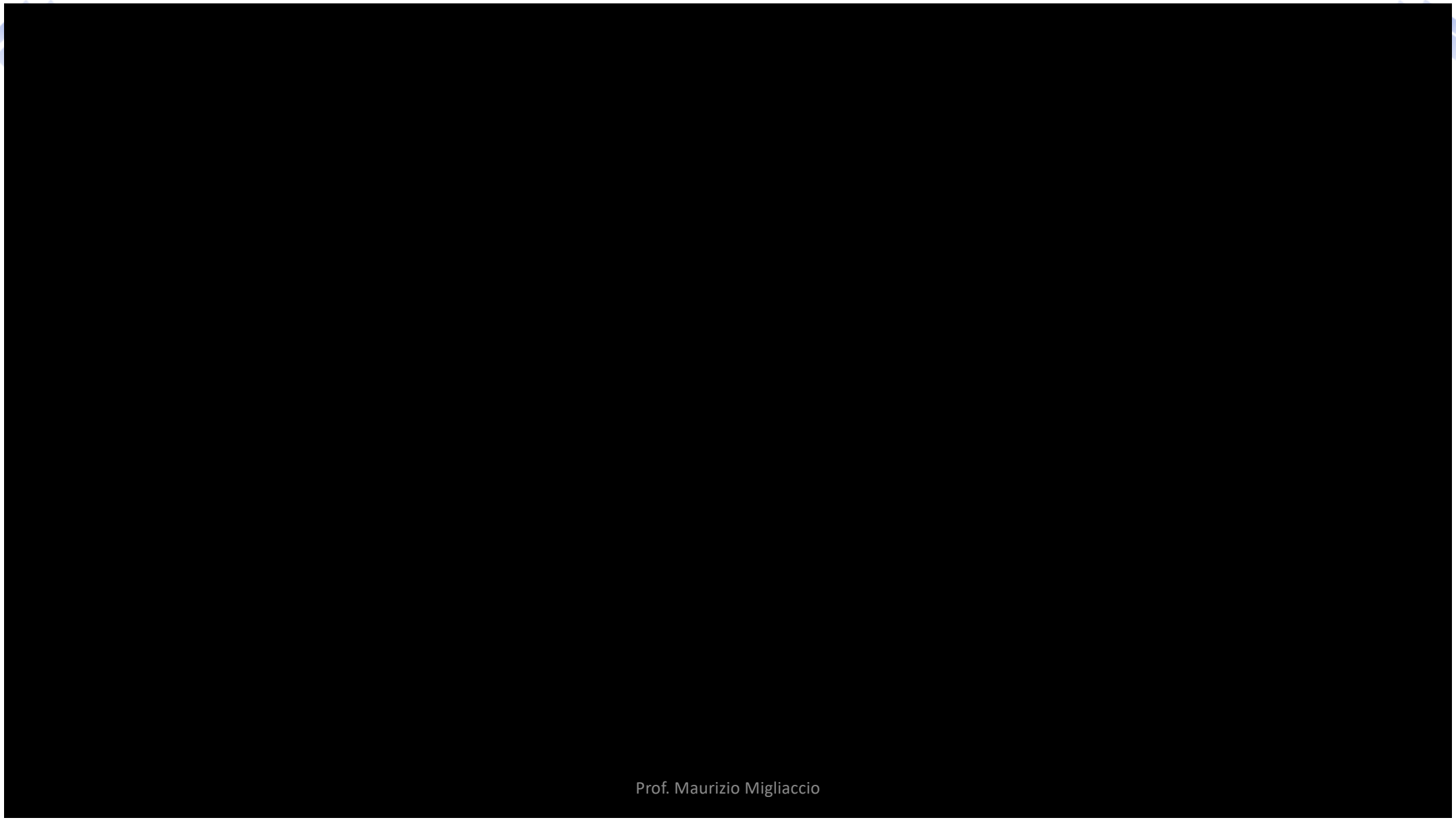
As the disks rotate, a small starting charge, either positive or negative, on one metal plate will move toward a double-ended brush on the second disk. When the plate aligns with the brush, it will induce an equal and opposite charge on the plate that's directly across from it on the other disk. The resulting charge in turn causes an opposite charge on a plate on the first disk. Meanwhile, plates on the second disk induce charges on the first disk. Metal collector combs separate the charges into positive and negative and conduct them to two Leyden jar capacitors.

https://spectrum.ieee.org/wimshurst-machine

https://www.youtube.com/watch?v=XMO2NGrW1mU&t=1s



In the late 1800s, James Wimshurst perfected the static-electricity generator that now bears his name. YALE



Diathermy

- In 1899, the Austrian chemist Zeynek determined quantitatively the heating rate of tissue as a function of frequency and current density and first proposed the use of high-frequency currents for the therapeutic heating of tissue deep inside the body
- The concept of diathermy has also greatly contributed to the conviction that the biological effects of electro magnetic fields were restricted to thermal effects, a notion which has dominated the field until recently and severely hindered bioelectromagnetic research.

Diathermy

- The earliest observations on the reactions of high-frequency electromagnetic currents upon the human organism were made by Jacques Arsene d'Arsonval.
- The field was pioneered in 1907 by German physician Karl Franz Nagelschmidt, who coined the term diathermy from the Greek words dia and θέρμη therma, literally meaning "heating through".
- Diathermy is produced by three techniques: ultrasound (ultrasonic diathermy), short-wave radio frequencies in the range 1-100 MHz (shortwave diathermy) or microwaves typically in the 915 MHz or 2.45 GHz bands (microwave diathermy), the methods differing mainly in their penetration capability.

Hyperthermia

- Hyperthermia therapy (or hyperthermia, or thermotherapy) is a type of medical treatment in which body tissue is exposed to temperatures above body temperature, in the region of 40–45 °C.
- Hyperthermia is usually applied as an adjuvant to radiotherapy or chemotherapy, to which it works as a sensitizer, in an effort to treat cancer.
- While the cancer treatment depends on heating and not on the e.m. frequency used the side effects change.

A new era

Precision medicine is changing the way therapies are being developed. It has widespread implications for everything from genomics to medical devices, and creates new models for enterprises.