

2025 Italian URSI Annual Meeting

Paths from early origins of electricity to modern radio science

Ari Sihvola

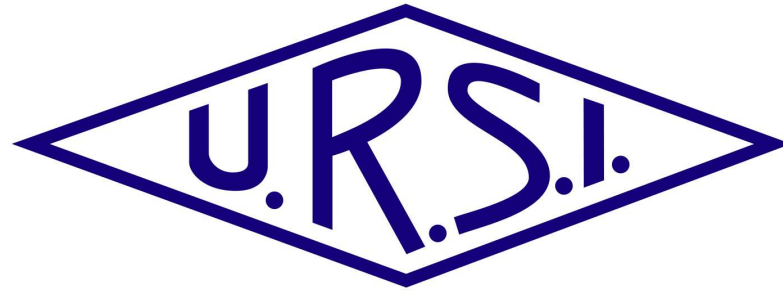
President of the International Union of Radio Science

Aalto University, Finland

26 June 2025



Union Radio-Scientifique Internationale / International Union of Radio Science



is a non-governmental and non-profit organisation under the International Council for Science, responsible for stimulating and co-ordinating, on an international basis, studies, research, applications, scientific exchange, and communication in the fields of radio science

Historical milestones:

Amber and lodestone

Static electricity and magnetism

Magnetism from electricity

Electricity from magnetism

Electromagnetics

Wireless communications

Scientific radio and URSI

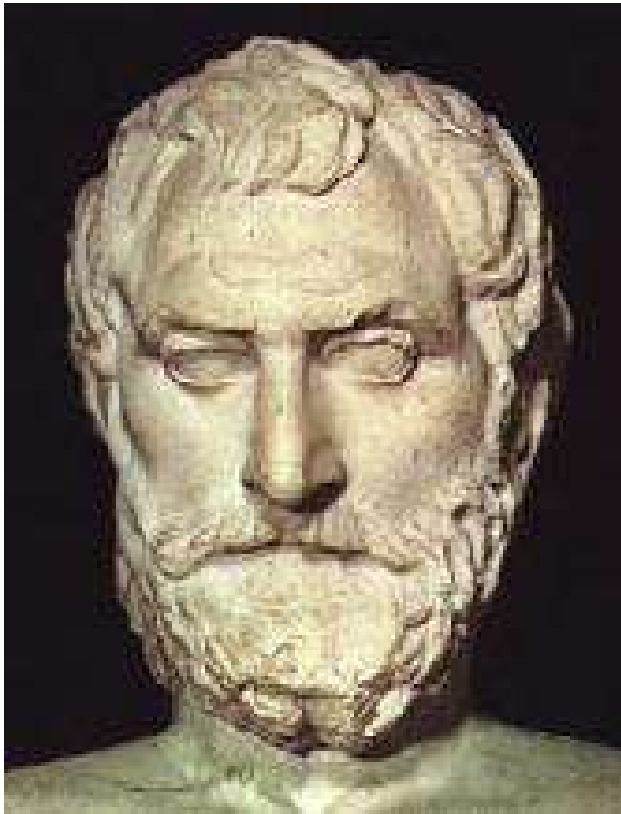
- Thales and Lucretius
- Peregrinus and Gilbert
- Franklin and Coulomb
- Volta, Ørsted, Ampère
- Faraday and Maxwell
- Hertz, Popov, Marconi



Static electricity



Thales (624–546 BC)



ηλεκτρον

electron

electricitas

Elektrizität



electricidad



électricité



electricity



elektricitet



eletricidade



электричество



elektter



ηλεκτρον

elettricità



sähkö



Magnetism

- IRON



Magnetite Fe_3O_4

- Stone Age
- Bronze Age
- Iron Age

Around 3500 BCE

Around 1200 BCE



Plinius the Elder (23–79 AD) (Gaius Plinius Secundus)

iron is attracted by the magnet. The substance that vanquishes all other things rushes into a kind of vacuum [inane nescioquid], and, as it approaches the magnet, leaps towards it and is held fast and embraced by it. Some Greeks call the magnet 'ironstone', some the stone of Heracles. According to Nicander, it was known as magnetite, after its discoverer Magnes. It is said to have been discovered when the nails of Magnes' sandals and the ferule of his staff stuck to the stone, as he was grazing his herds on Mt. Ida. It is, incidentally, found in many places, including Spain.



(1)



T. LUCRETII CARI
DE
RERUM NATURA
Liber Primus.



ENEADUM genetrix, hominum di-
vumque voluptas,
Alma Venus, coeli subter labentia
signa
Quæ mare navigerum, quæ terras fru-
giferentis.

Concelebras : per te quoniam genus omne animantum
Concipitur, visitque exortum lumina solis :
Te, Dea, te fugiunt venti, te nubila coeli,
Adventumque tuum : tibi suavis dædala tellus
Summittit flores, tibi rident æquora ponti,
Placatumque nitet diffuso lumine coelum.
Nam simul ac species patefacta 'st verna diei,
Et referata viget genitabilis aura Favoni :
Aeris primum volucres te, diva, unumque
Significant initum percussæ corda tua vi.
Inde feræ pecudes perfruant pabula læta,
Et rapidos tranant amneis : ita capta lepore
Illecebrisque tuis omnis natura animantum

B

Te

Titus Lucretius Carus (n. 99–55 eKr.)

Now to other things!

And I'll begin to treat by what decree
Of nature it came to pass that iron can be
By that stone drawn which Greeks the magnet call

After the country's name (its origin
Being in country of Magnesian folk).

This stone men marvel at; and sure it oft
Maketh a chain of rings, depending, lo,
From off itself! Nay, thou mayest see at times
Five or yet more in order dangling down
And swaying in the delicate winds, whilst one
Depends from other, cleaving to under-side,
And ilk one feels the stone's own power and bonds—
So over-masteringly its power flows down.

Alexander Neckam

De naturis rerum (1180 ?)

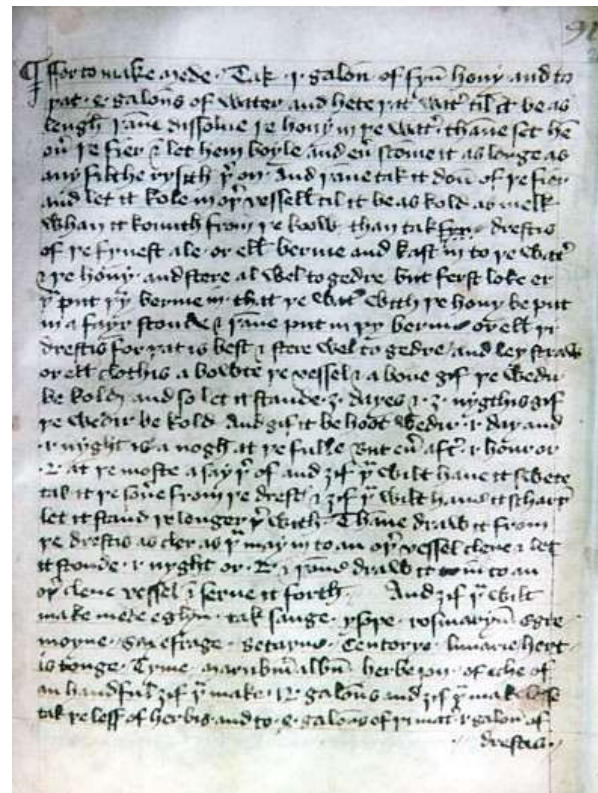
Nautae etiam mare legentes, cum beneficium claritatis solis in tempore nubilo non sentiunt, aut etiam cum caligine nocturnarum tenebrarum mundus obvolvitur, et ignorant in quem mundi cardinem prora tendat, acum super mangentem ponunt, quae circulariter circumvolvitur usque dum, ejus motu cessante.

Mariners at sea, when, through cloudy weather in the day which hides the sun, or through the darkness of night, they lose knowlege of the quarter of the world to which they are sailing, touch a needle with a magnet, which will turn round till, on its motion ceasing, its point will be directed towards the north.

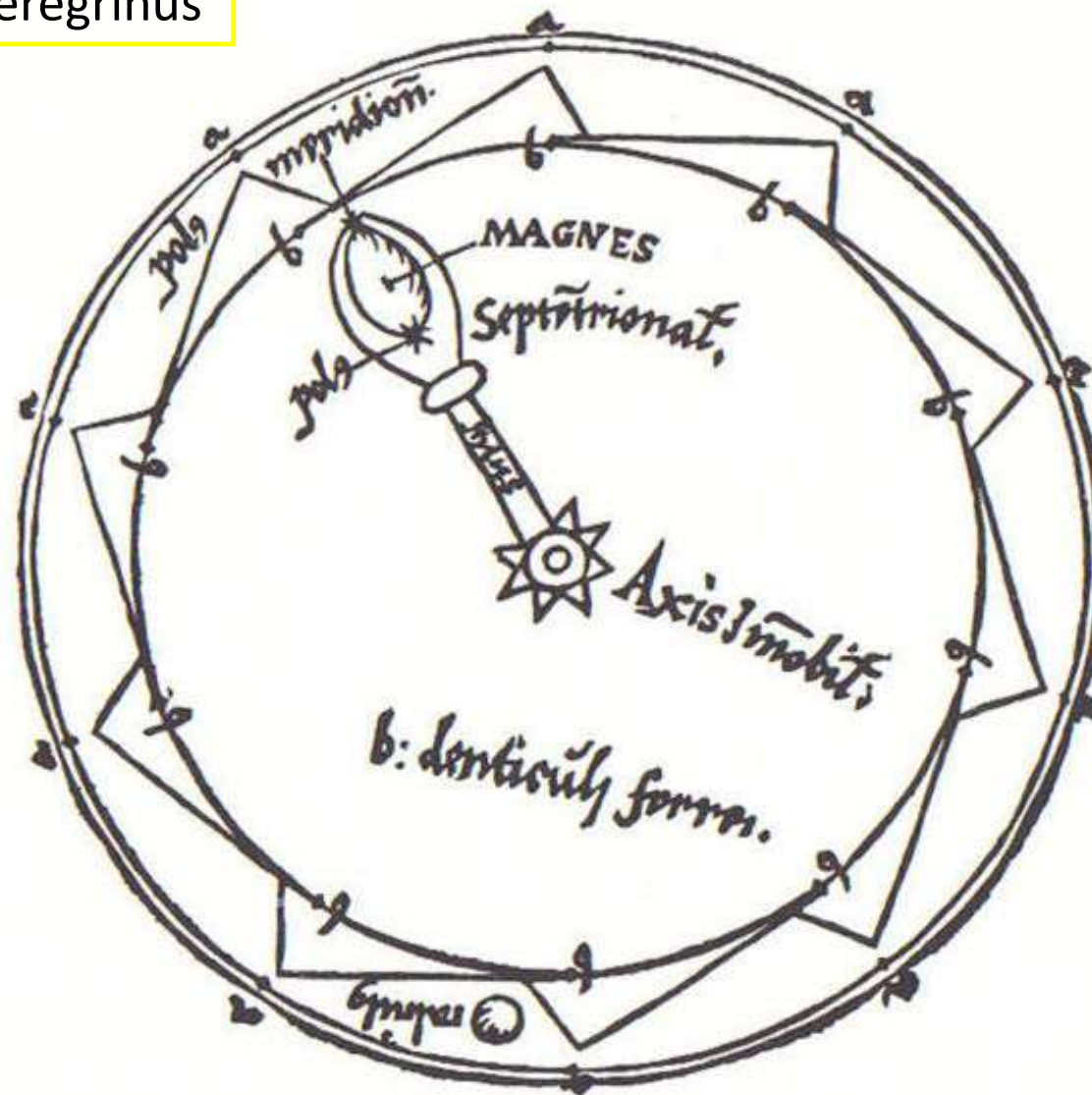
Petrus Peregrinus (Pierre de Maricourt)

Epistola Petri Peregrini de Maricourt ad Sygerum de Foucaucourt (1269)

Part 1: 10 chapters (magnets)
Part 2: 3 chapters (compass
and perpetuum mobile)



Perpetuum mobile by Peregrinus



William Gilbert (1544–1603)



Tractatus, sive Physiologia Nova
DE
MAGNETE,
Magneticisq; corporibus & magno
Magnete tellure, sex libris comprehensus.
a **GUILIELMO GILBERTO** Colce-
strensi, Medico Londinensi.
*In quibus ea, quae ad hanc materiam spectant, plurimis
& Argumentis & experimentis exactissime absolvis-
sent, tractantur & explicantur.*
Omnia nunc diligenter recognita, & emendatius quam ante
in lucem edita, aucta & figuris illustrata, opera & studio D.
WOLFGANGI LOCHMANS, I. U. D.
& Mathematici.
*Ad calcem libri adiunctus est Index capitum, Rerum & Verborum
locupletissimus, qui in prioribus editionibus desiderabatur.*



SEDINI,
Typis **GOTZIANIS:**
ANNO M. DC. XXXIII.

FAC-SIMILE TITLE PAGE OF GILBERT'S "DE MAGNETE," THIRD EDITION.

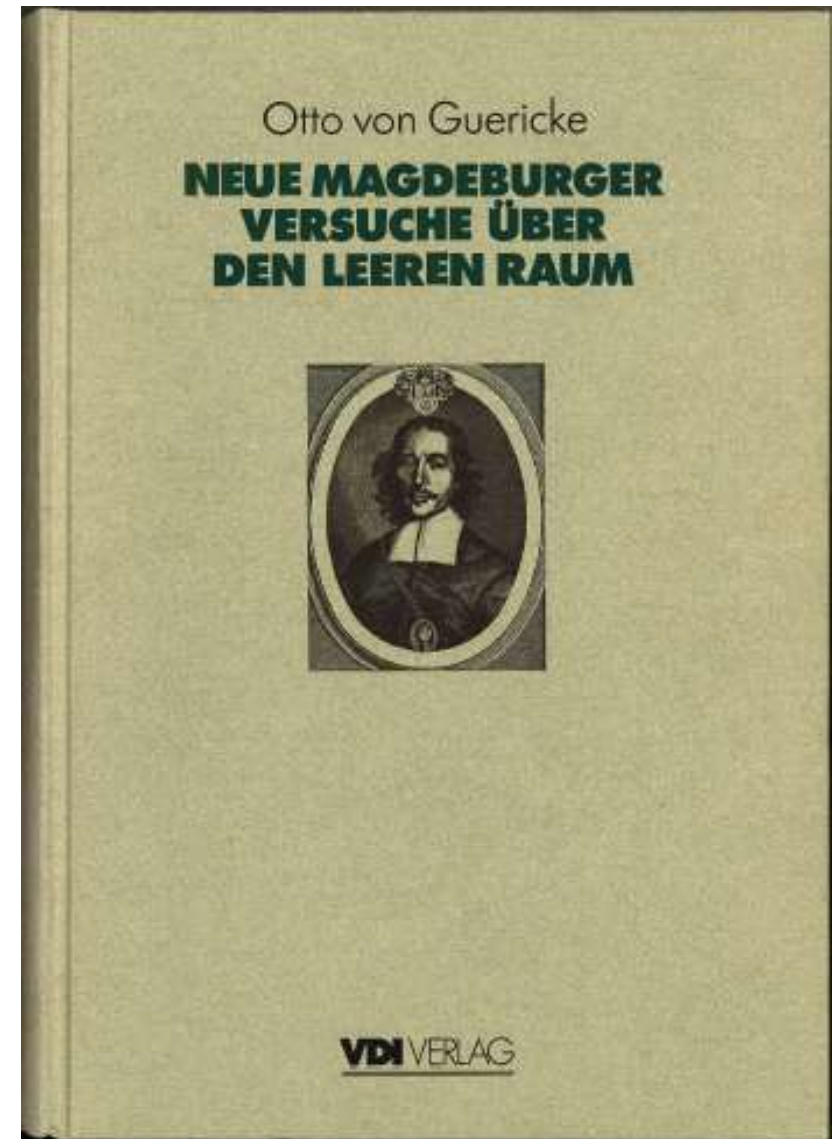
Tractatus sive Physiologia Nova de Magnete, magneticisque Corporibus, et de magno Magnete Tellure; sex libris comprehensus; plurimis & argumentis & experimentis demonstrata



- Book I: Ancient and modern writings on the Loadstone
- Book II: On Magnetick Motions
- Book III: On Direction (turning towards magnetic poles)
- Book IIII: On Variation (declination)
- Book V: On Declination (inclination)
- Book VI: On the Globe of the earth, the great magnet (Earth rotation caused by magnetic force)
- Of electricity only one chapter in Book II

back to electricity...

Otto von Guericke
(1602–1686)





- electricity experiments
- sulphur sphere as model of the Earth (cosmology)
- sparks

OTTONIS DE GUERICKE
EXPERIMENTA
 Nova (ut vocantur) MAGDEBURGICA
 DE
VACUO SPATIO

Primum à R. P. Gaspare Schotto, è Societate
 Jesu, & Herbipolitanae Academiae Mathematicos
 Professore :

Nunc verò ab ipso Autore
*Perfectius edita, variisque aliis Experimentis
 aucta.*

Quibus accesserunt simul certa quaedam
*De Aeris Pondere circa Terram ; de Virtutibus Mundanis, & Sys-
 temate Mundi Planetario ; sicut & de Stellis Fixis, ac Spatio illo Immenso, quod ibi
 intra quam extra eas funditur.*



AMSTELÆDAMI,
 Apud JOANNEM JANSONIUM à WASSERGE, ANNO 1672.
 Cum Privilegio S. Cæs. Majestatis.



Guericke's Versuche über die elektrische Abstoßung

Nach Otto von Guericke's „Experimenta nova Magdeburgica de vacuo spatio“. Amsterdam 1672

Dufay (1698–1739)

(Charles François de Cisternay du Fay)



two-electricity theory:
vitreous and **resinous**

Seventhly, Chance has thrown in my Way another Principle, more universal and remarkable than the preceding one, and which casts a new Light on the Subject of Electricity. This Principle is, that there are two distinct Electricities, very different from one another; one of which I call *vitreous Electricity*, and the other *resinous Electricity*. The first is that of Glafs, Rock-Cryftal, Precious Stones, Hair of Animals, Wool, and many other Bodies: The second is that of Amber, Copal, Gum-Lack, Silk, Thread, Paper, and a vast Number of other Subftances.

(+) glass, wool, silk, paper, amber, resin, metals, sulphur (-)

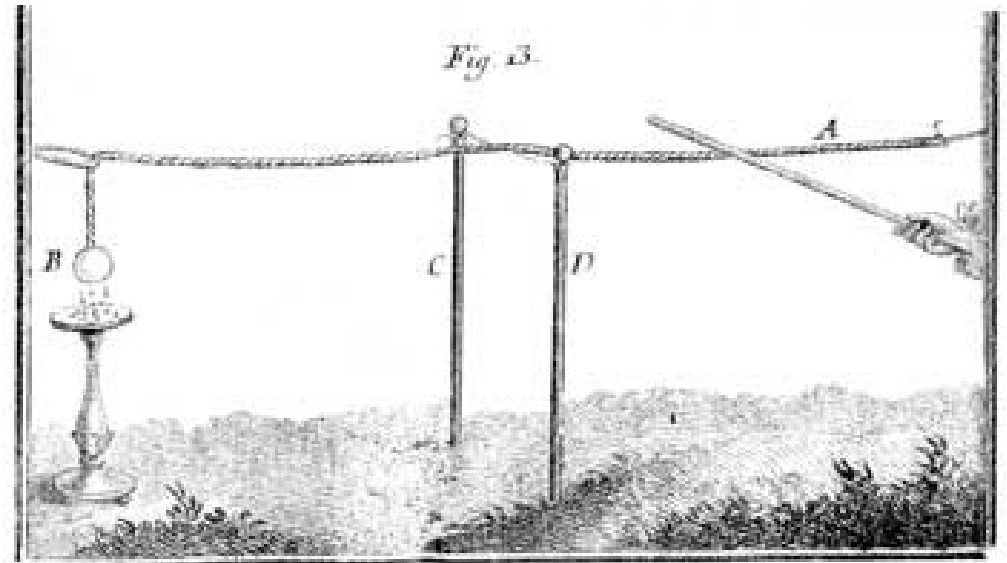
Stephen Gray

(1666–1736)

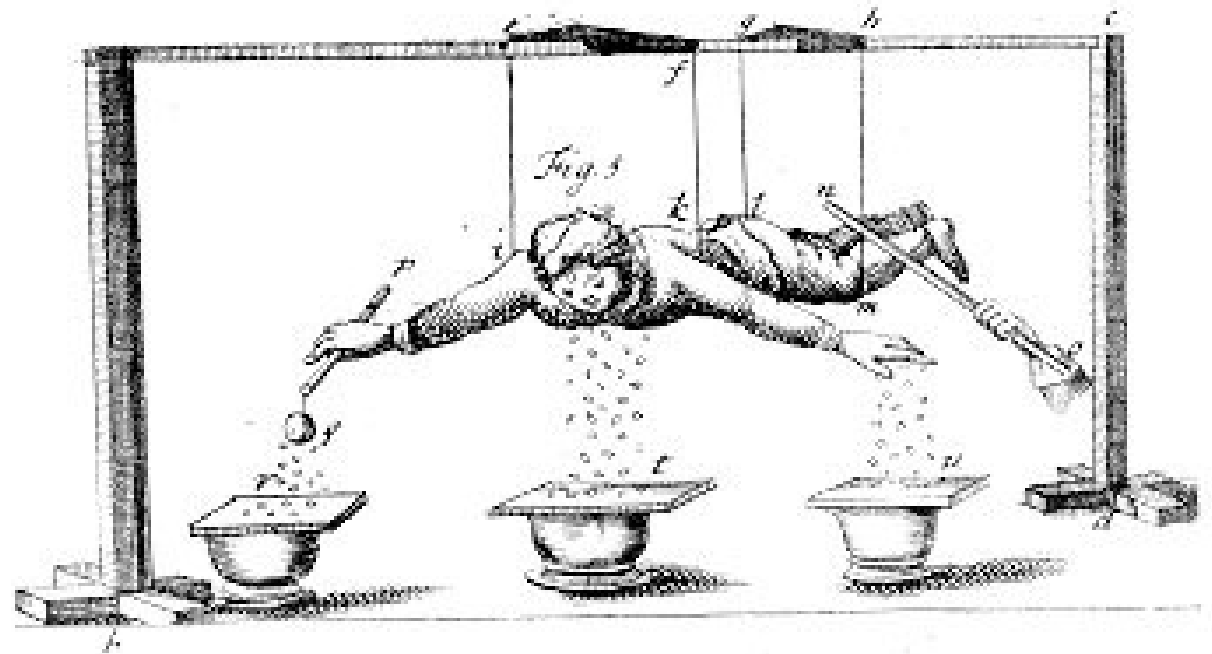
Conduction of electricity



The first Experiment was made in the matted Gallery July 2, 1729, about Ten in the Morning. About four Feet from the End of the Gallery there was a cross Line that was fixed by its Ends to each Side of the Gallery by two Nails; the middle Part of the Line was Silk, the rest at each End Packthread; then the Line to which the Ivory Ball was hung, and by which the Electric Vertue was to be conveyed to it from the Tube, being eighty Feet and a half in Length, was laid on the cross Silk Line, so as that the Ball hung about nine Feet below it: Then the other End of the Line was by a Loop suspended on the Glass Cane, and the Leaf-Brass held under the Ball on a Piece of white Paper; when the Tube being rubbed, the Ball attracted the Leaf-Brass, and kept it suspended on it for some Time.



Electricity in the 18th century



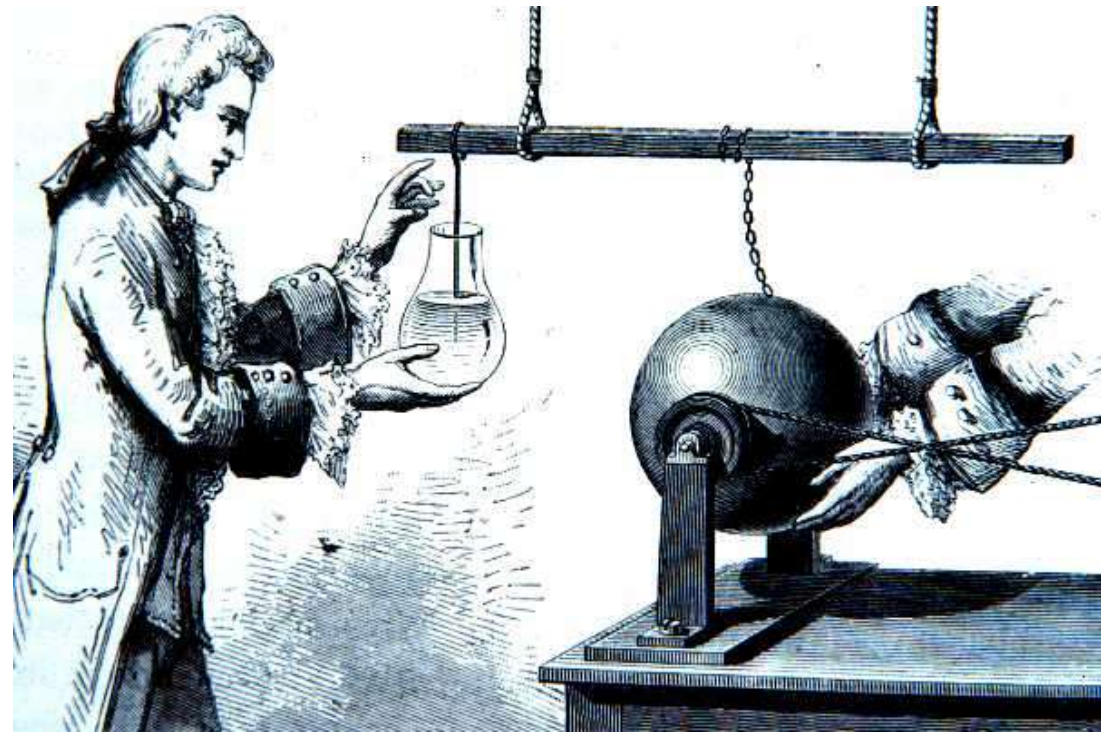
Leyden jar

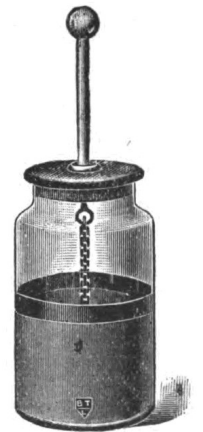
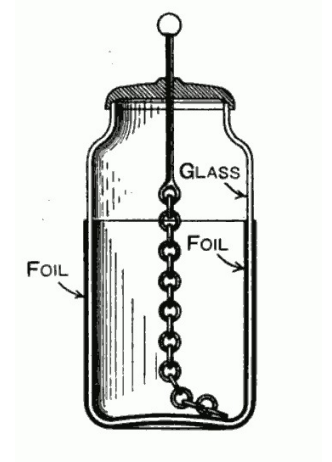
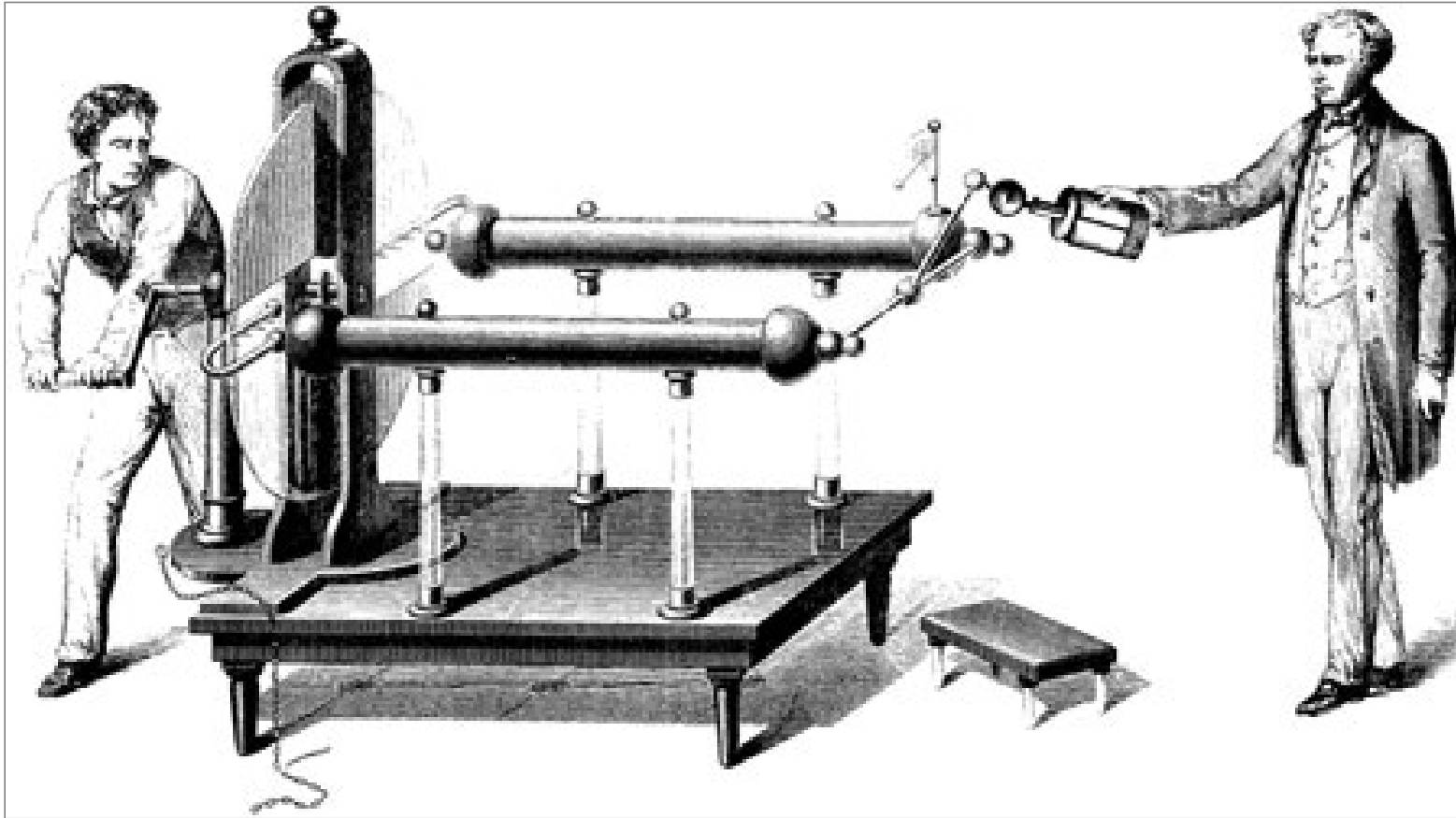
Ewald Jürgen von Kleist

(Pommer 1745)

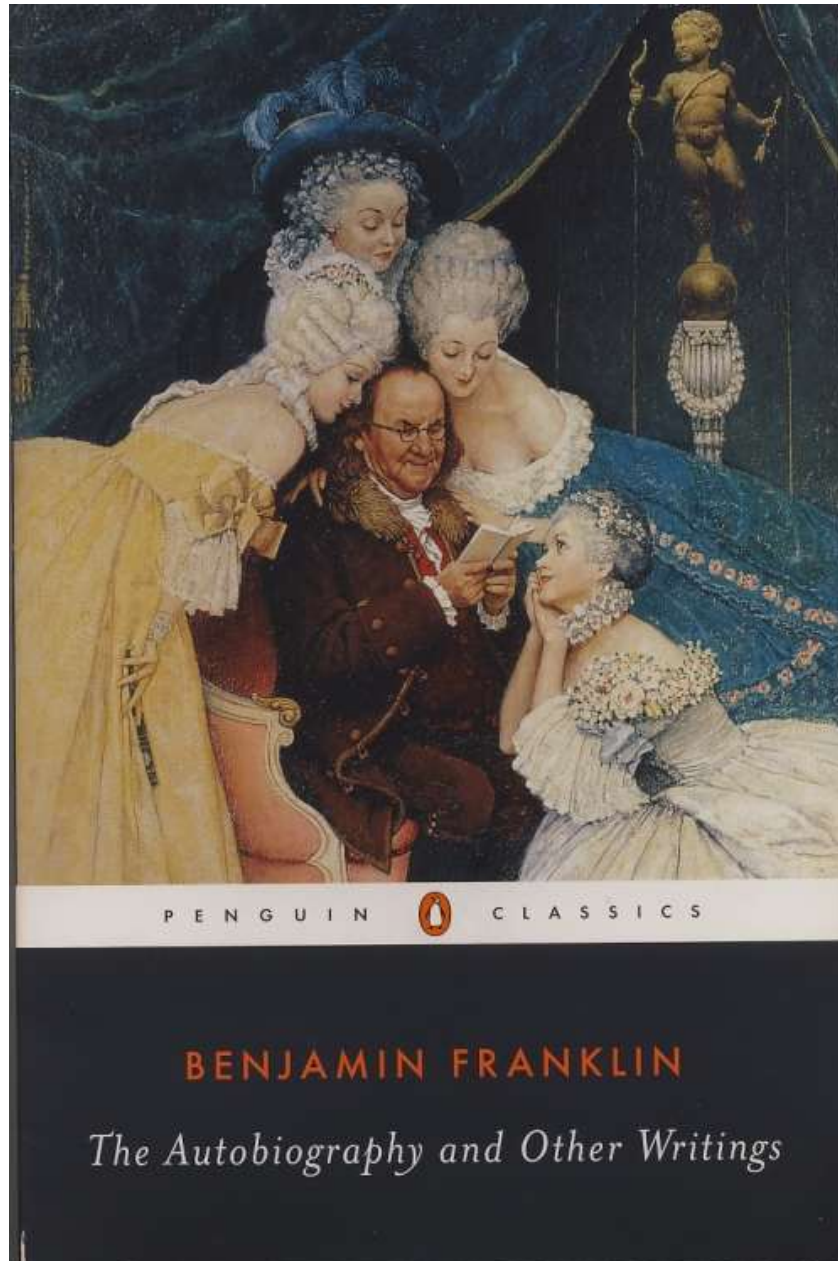
Pieter van Musschenbroek

(Leyden 1746)





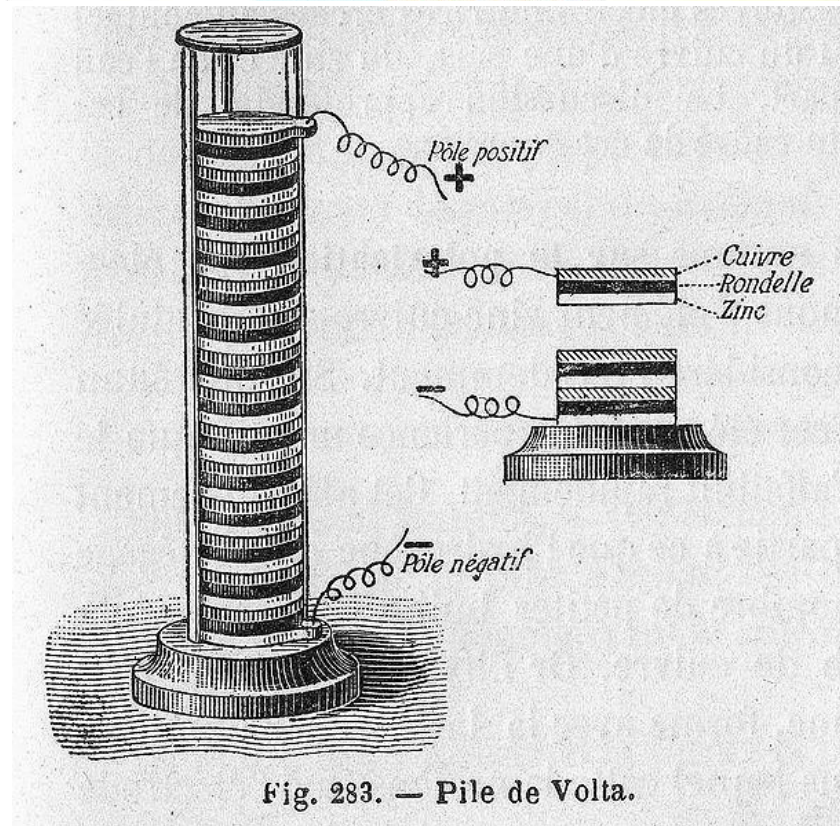
Leyden jar --- excellent capacitor



Benjamin Franklin (1706–1790)



Alessandro Volta (1745–1827)



THE
PHILOSOPHICAL MAGAZINE.

SEPTEMBER 1800.

I. *On the Electricity excited by the mere Contact of conducting Substances of different Kinds. In a Letter from Mr. ALEXANDER VOLTA, F.R.S. Professor of Natural Philosophy in the University of Pavia, to the Right Hon. Sir JOSEPH BANKS, Bart. K. B. P. R. S.**

Como in the Milanese, March 20, 1800.
AFTER a long silence, for which I shall offer no apology, I have the pleasure of communicating to you, and through you to the Royal Society, some striking results I have obtained in pursuing my experiments on electricity excited by the mere mutual contact of different kinds of metal, and even by that of other conductors, also different from each other, either liquid or containing some liquid, to which they are properly indebted for their conducting power. The principal of these results, which comprehends nearly all the rest, is the construction of an apparatus having a resemblance in its effects (that is to say, in the shock it is capable of making the arms, &c. experience) to the Leyden flask, or, rather, to an electric battery weakly charged acting incessantly, which should charge itself after each explosion; and, in a word, which should have an inexhaustible charge, a perpetual action or impulse on the electric fluid; but which differs from it essentially both by this continual action, which is peculiar

* Translated from the author's paper published in French in the Philosophical Transactions for 1800, part 2.



Hans Christian Ørsted (1777–1851)



July 1820



EXPERIMENTA

CIRCA EFFECTUM

CONFLICTUS ELECTRICI IN ACUM MAGNETICAM.

Prima experimenta circa rem, quam illustrare aggredior, in scholis de Electricitate, Galvanismo et Magnetismo proxime-superiori hieme a me habitis instituta sunt. His experimentis monstrari videbatur, acum magneticam ope apparatus galvanici e situ moveri; idque circulo galvanico cluso, non aperto, ut frustra tentaverunt aliquot

Dabam Hafniæ d. 24de Julii 1820.

Johannis Christianus Ørsted.

Eques auratus Ordinis Dannebrogici, in Universitate Haf
niensi Prof. Physices Ord. Secretarius Societatis
Regiæ Scientiarum Hafniensis.





André-Marie Ampère (1775–1836)



THÉORIE
DES
PHÉNOMÈNES ÉLECTRO-DYNAMIQUES,
UNIQUEMENT DÉDUITE DE L'EXPÉRIENCE,
PAR ANDRÉ-MARIE AMPÈRE,

DE L'ACADÉMIE ROYALE DES SCIENCES, DE LA SOCIÉTÉ PHILOMATIQUE, DE LA SOCIÉTÉ ROYALE D'ÉDIMBOURG, DE LA SOCIÉTÉ HELVÉTIENNE DES SCRUTATEURS DE LA NATURE, DE LA SOCIÉTÉ PHILOSOPHIQUE DE CAMBRIDGE, DE CELLE DE PHYSIQUE ET D'HISTOIRE NATURELLE DE GENÈVE, DE L'ACADÉMIE ROYALE DES SCIENCES ET BELLES-LETTRES DE BRUXELLES ET DE L'ACADÉMIE ROYALE DE LISBONNE, CHEVALIER DE LA LÉGION-D'HONNEUR, PROFESSEUR A L'ÉCOLE POLYTECHNIQUE ET AU COLLÈGE DE FRANCE.



A PARIS,

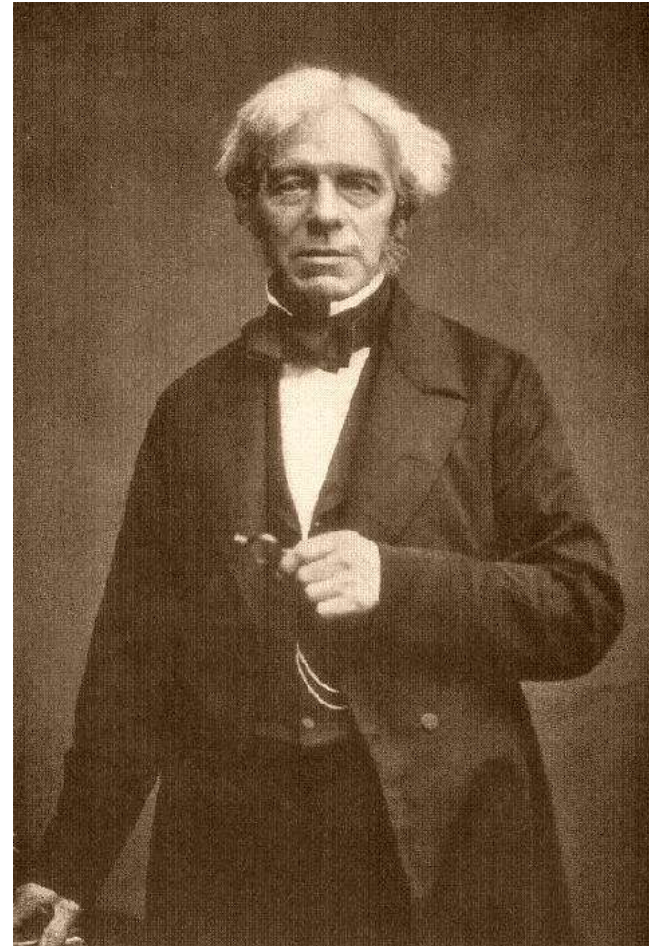
CHEZ MÉQUIGNON-MARVIS, LIBRAIRE-ÉDITEUR, RUE DU JARDINET, N° 13.
ET A BRUXELLES, AU DÉPÔT GÉNÉRAL DE LIBRAIRIE MÉDICALE FRANÇAISE.

NOVEMBRE 1826.



Michael Faraday (1791–1867)

- electromagnetic induction (1831)
 - Faraday law, Faraday cage, Faraday rotation, generator, rotator, permittivity, electrochemistry, diamagnetism, concept of field



$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\text{EMF} = -\frac{\partial \Phi}{\partial t}$$

Faraday's law:

Differential form

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

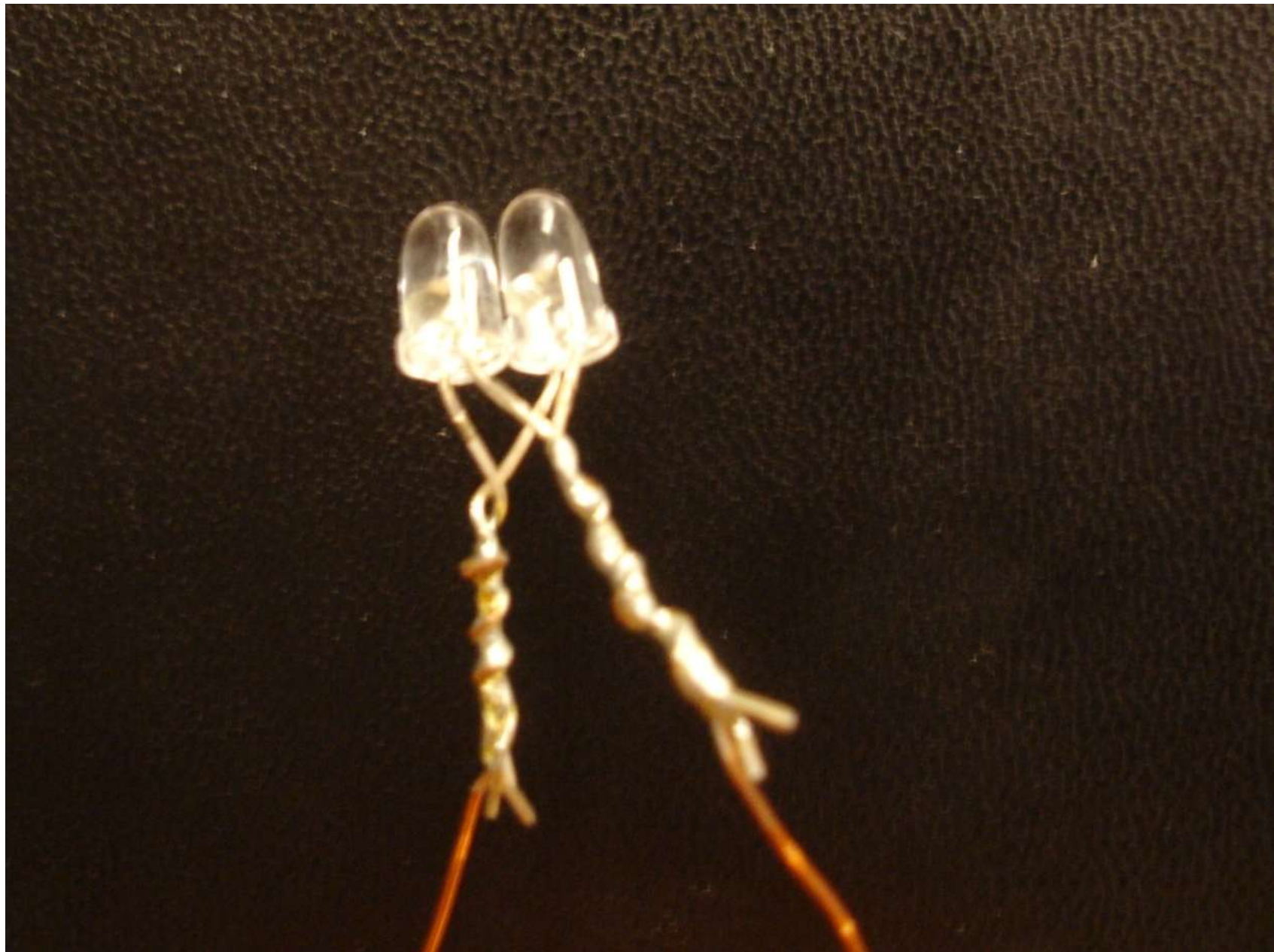
Stokes's law

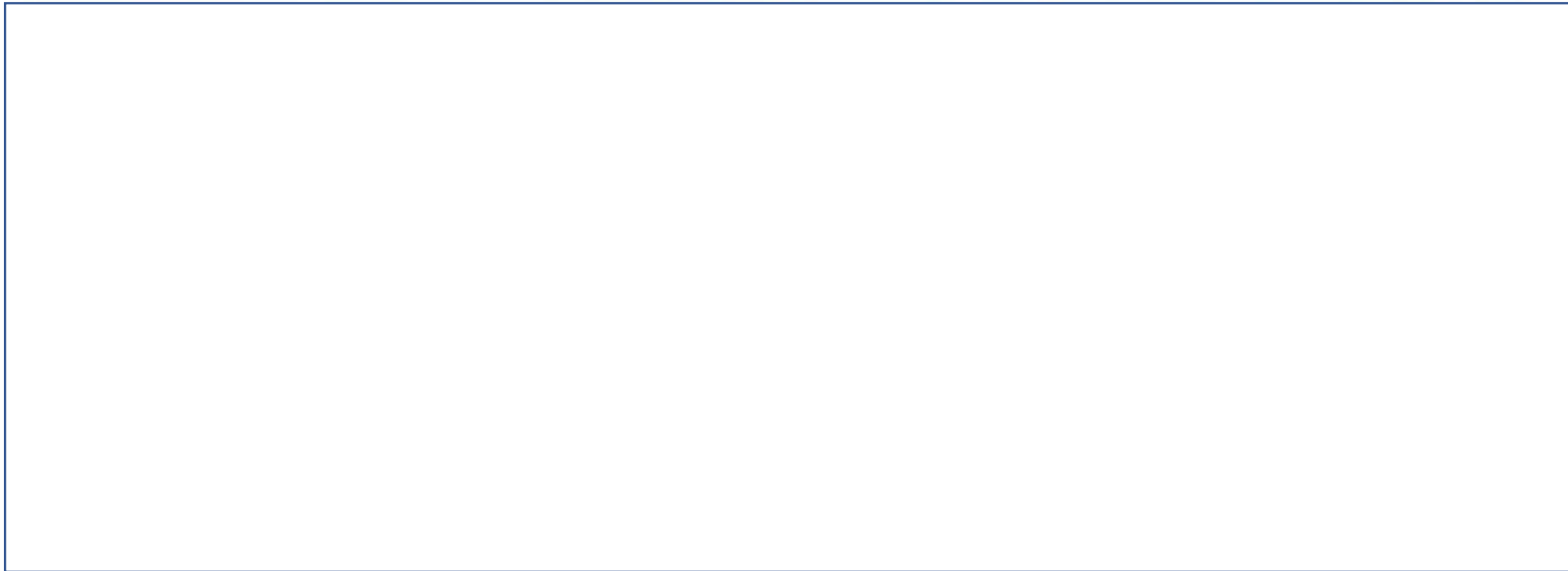
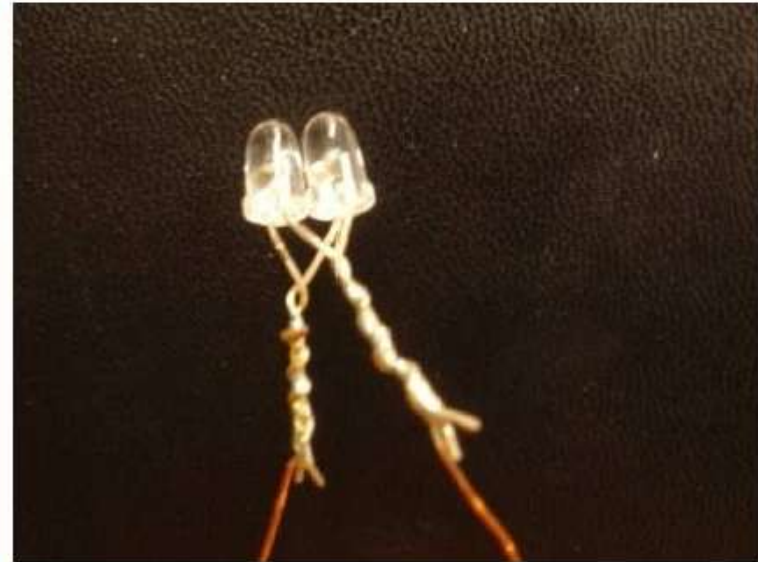
$$\int \nabla \times \mathbf{F} \cdot d\mathbf{S} = \oint \mathbf{F} \cdot d\mathbf{c}$$

Macroscopic form

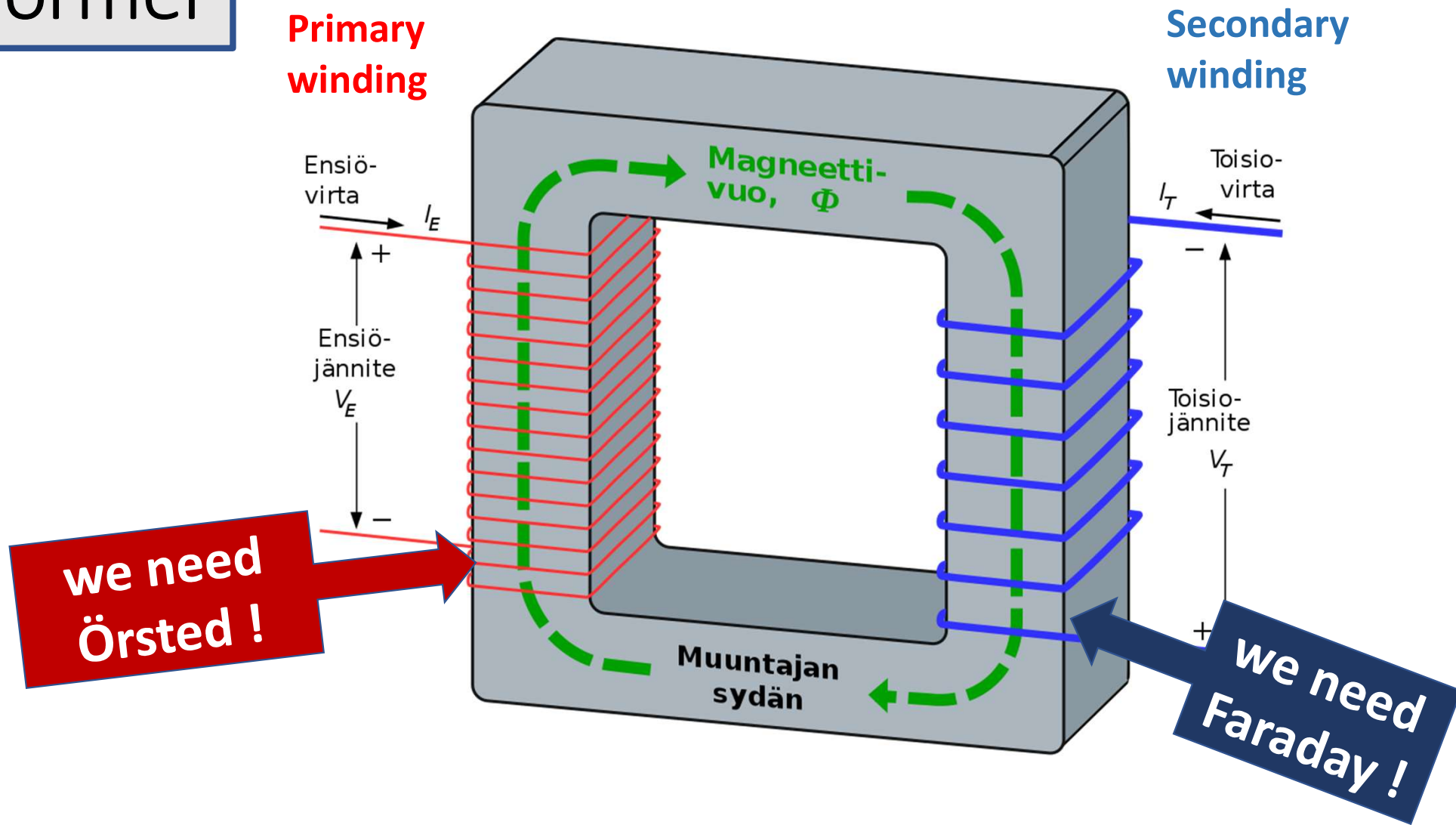
$$\text{EMF} = -\frac{\partial \Phi}{\partial t}$$







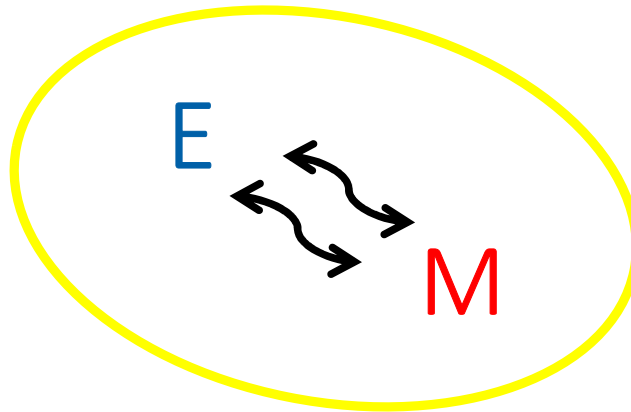
Transformer



— full interaction of electricity and magnetism—

$E \rightarrow M$

$M \rightarrow E$



James Clerk Maxwell (1831–1879)



$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$



Heinrich Hertz (1857–1894)

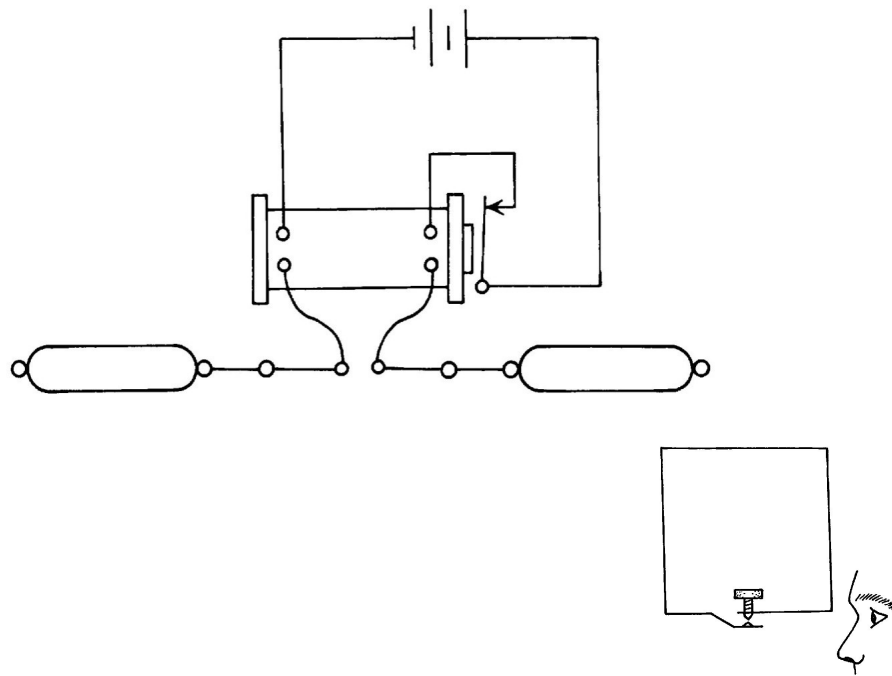


- experiments 1888: electromagnetic waves as light
- except: through walls and past corners
- a dipole radiates well, especially when half-wave
- fast current variations? oscillating spark!

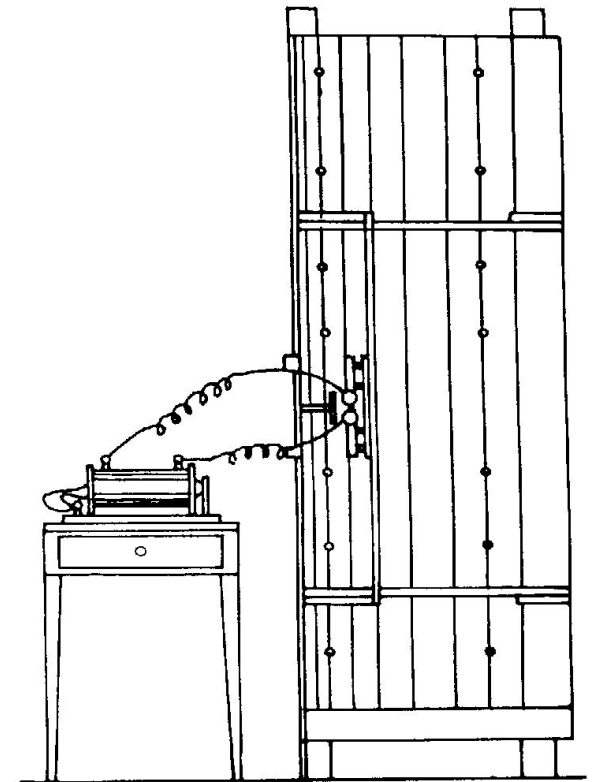


Hertz experiments 1887–88

50 MHz (inductor + "dipole antenna")



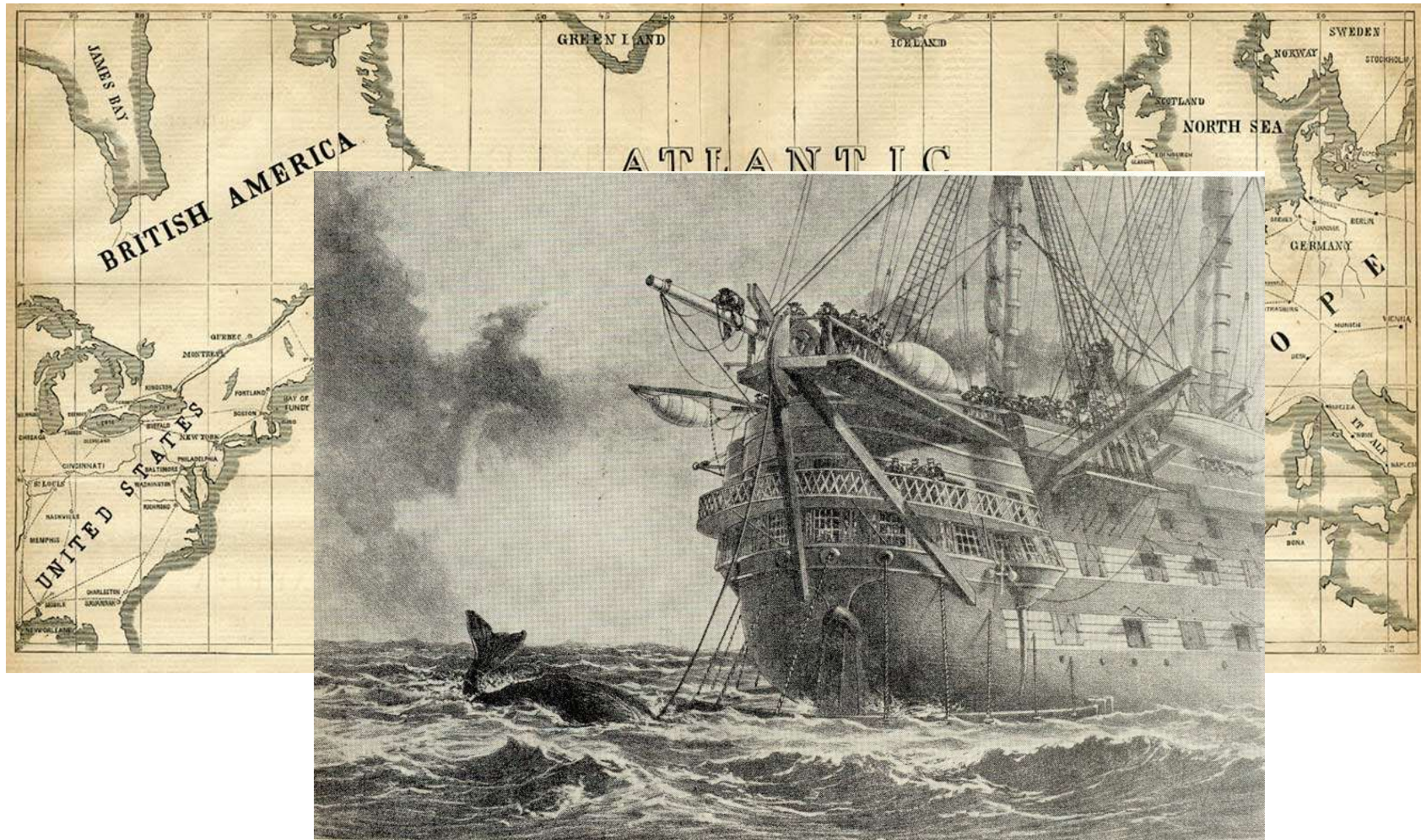
into UHF frequencies
(200–500 MHz):
reflection, interference





AN DIESER STAETTE ENTDECKTE
HEINRICH HERTZ
DIE ELEKTROMAGNETISCHEN WELLEN
IN DEN JAHREN 1885-1889

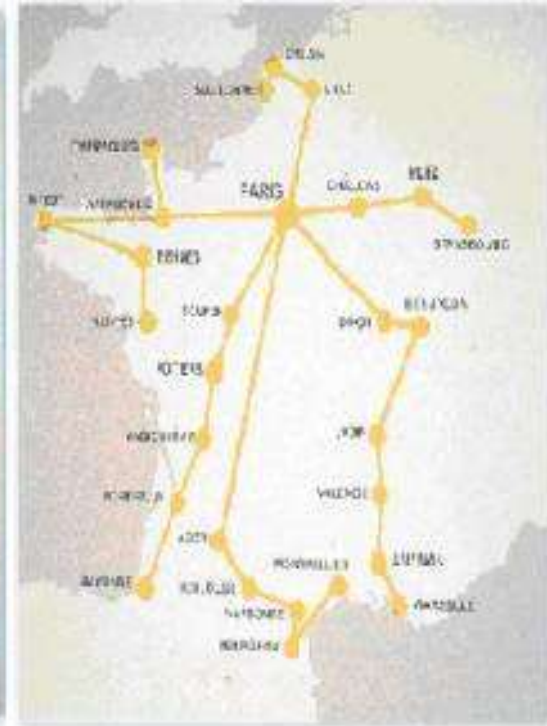
Wired telegraph

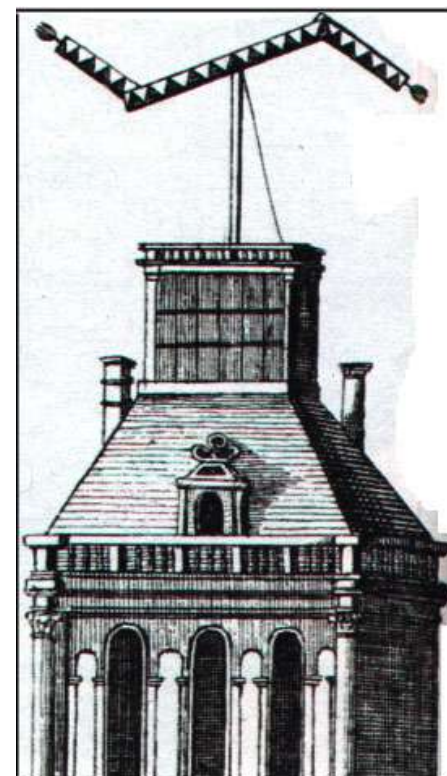
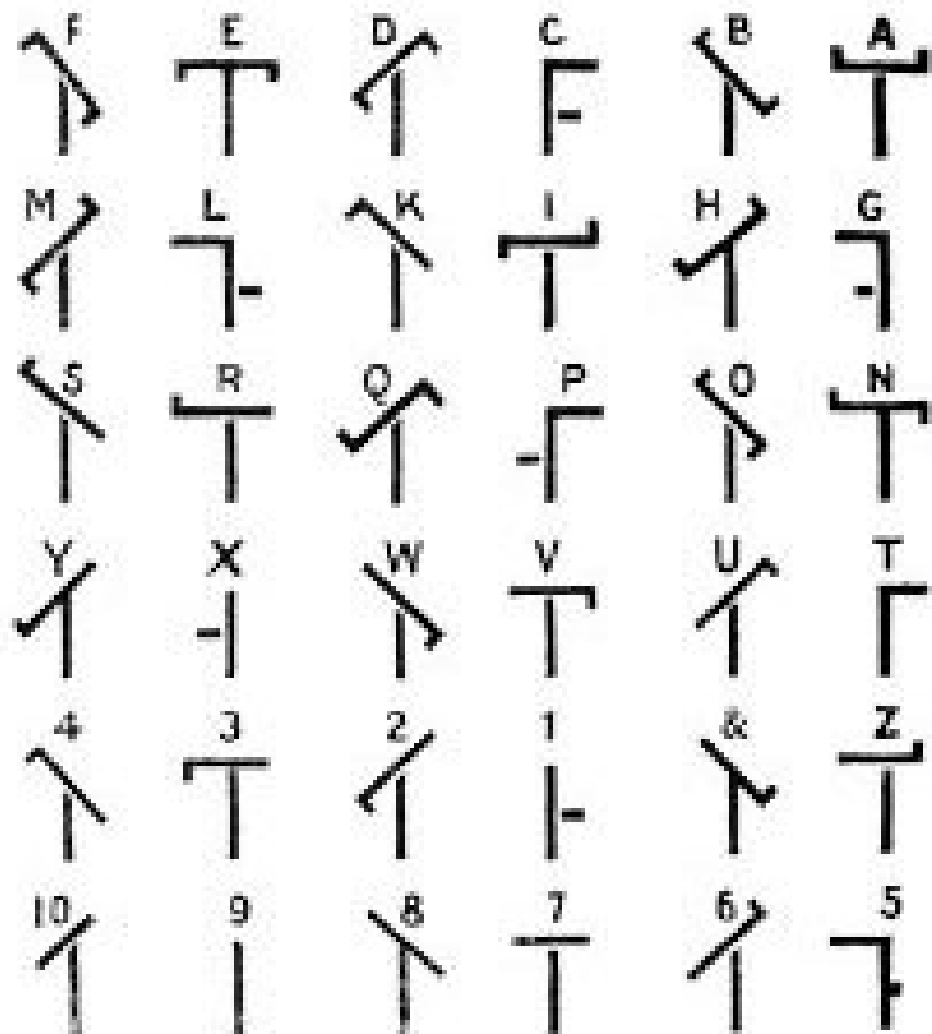


Towards wireless:

- Optical telegraph
- Resistive telegraph
 - conduction of electricity
- Inductive telegraph
 - induction (electro/magnetostatic)
- Electromagnetic telegraph
 - radio waves

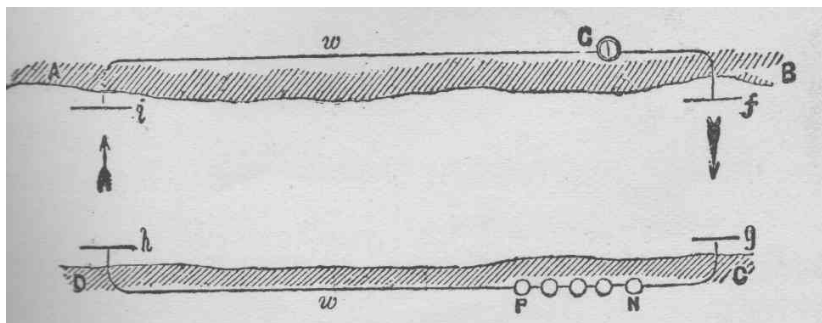
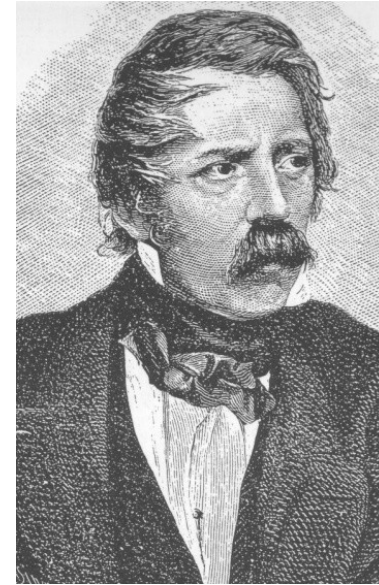
Claude Chappe (1763–1805)



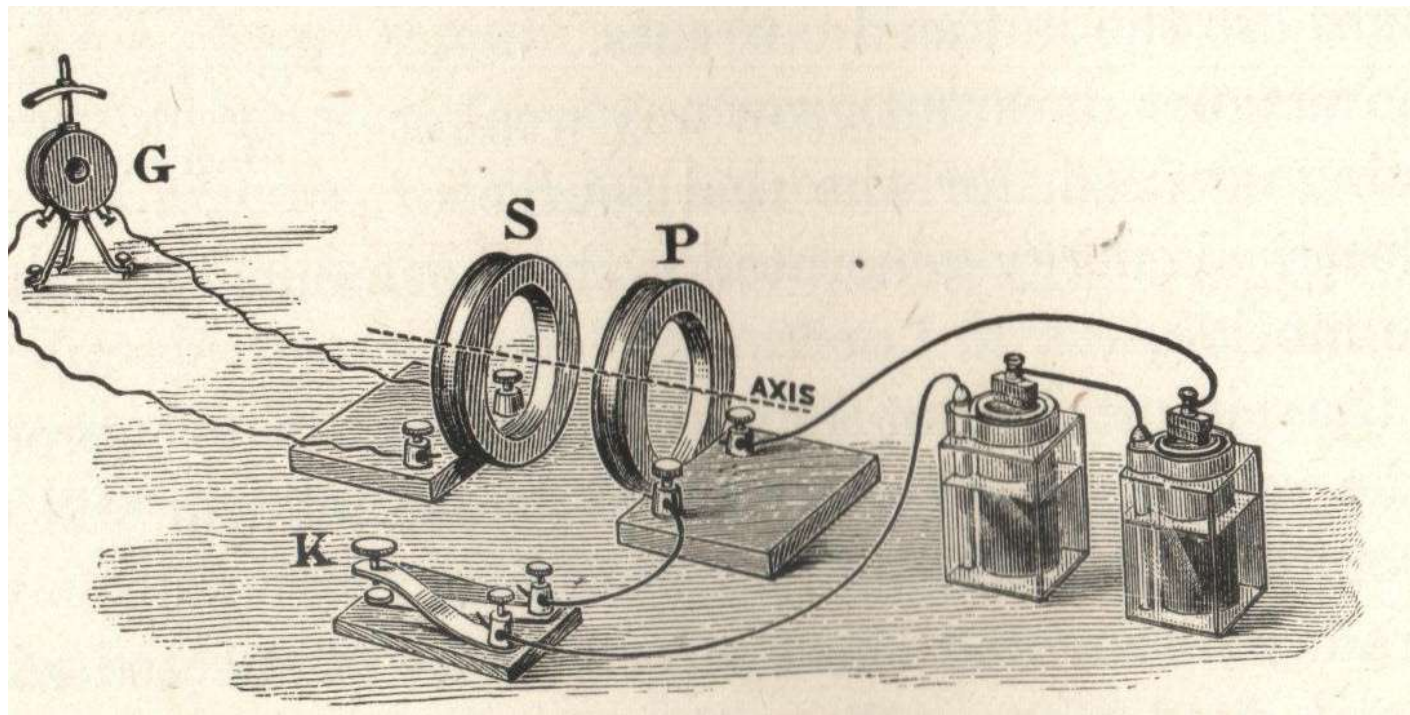


Resistive telegraph

- Karl Steinheil 1838: conduction of electricity on ground
 - attenuation $1/r^2$
 - grounded electrodes
- Samuel Morse (1791–1872), resistive connection: water (over Susquehanna river, 1,5 km)



Inductive telegraph



- Joseph Henry (1797–1878): magnetic induction: attenuation $1/r^2$ (like the volume current field)

William Henry Preece (1834–1913)
Chief Electrician of British Post Office



The Americans have
need of the telephone,
but we do not.
We have plenty of
messenger boys.

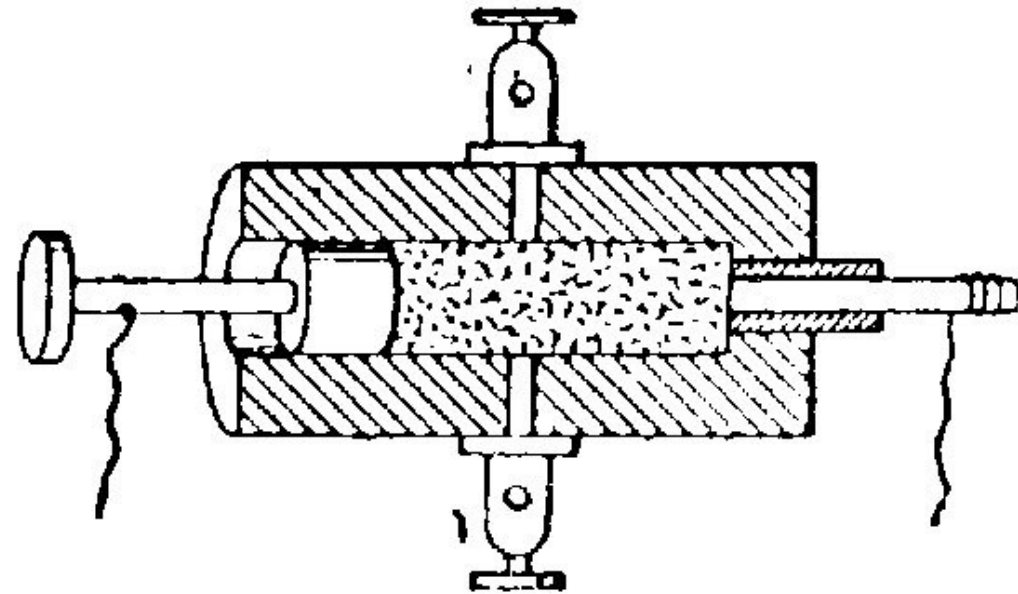
Heinrich Hertz to Heinrich Huber (1889)




But the vibrations of the transformer and the telephone are far too slow. Even if we had a thousand vibrations per second, the wavelength in the ether would be 300 kilometers, and the focal length of the mirrors required would be about the same. If you could build a concave mirror the size of a continent, you could set up an experimental arrangement, but in practice you can't do that...

Detector of radio waves — coherer

- galvanometer
 - not sensitive to AC
- loudspeaker
 - not sensitive to fast variations
- Hertz spark gap
 - weak sensitivity
- 1890 Eduard Branly
 - discharging Leyden jar reduces greatly the resistance of metal powder; shaking restores the resistance
- 1892 Oliver Lodge
 - (electric cohesion), (Branly: "radioconductor")





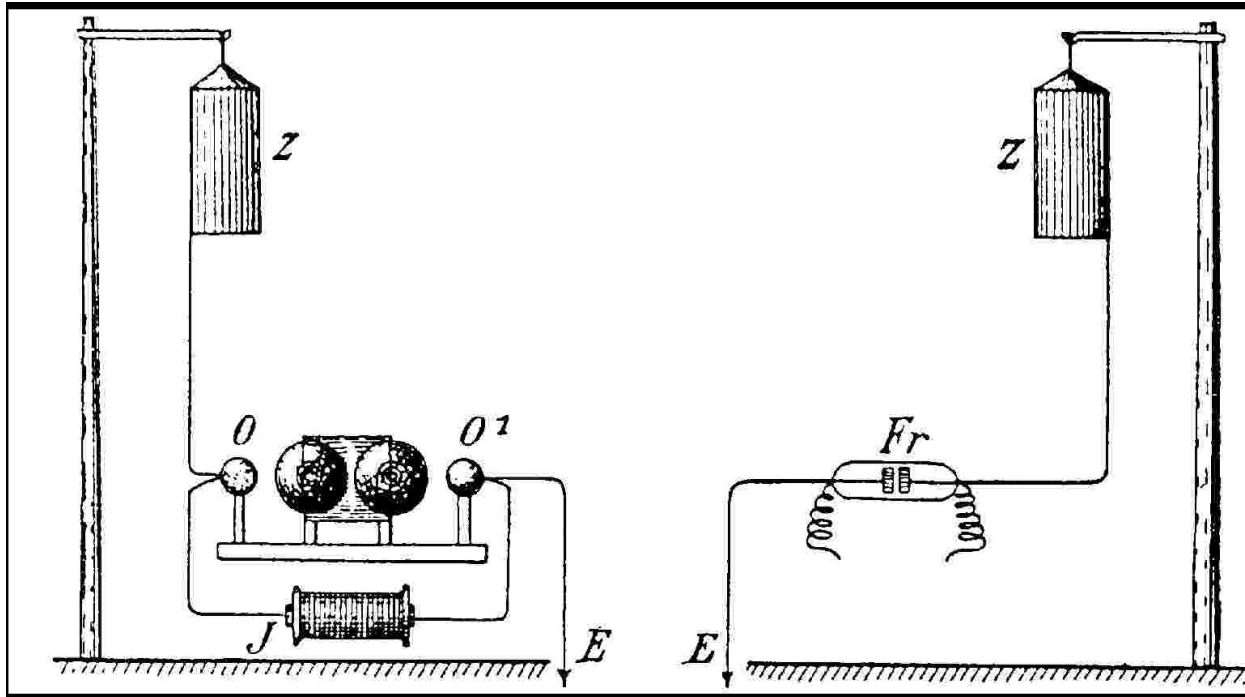
Guglielmo Marconi (1874–1937)



© Fondazione Guglielmo Marconi

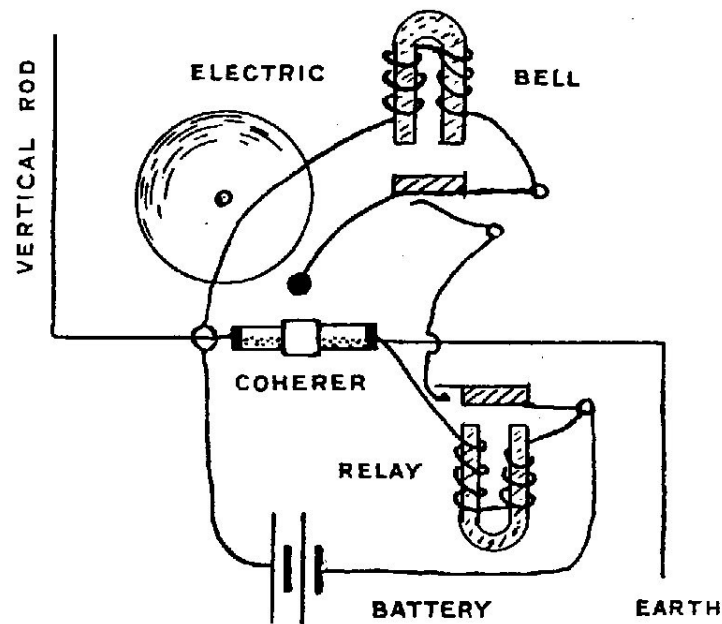


Guglielmo Marconi (1874–1937)



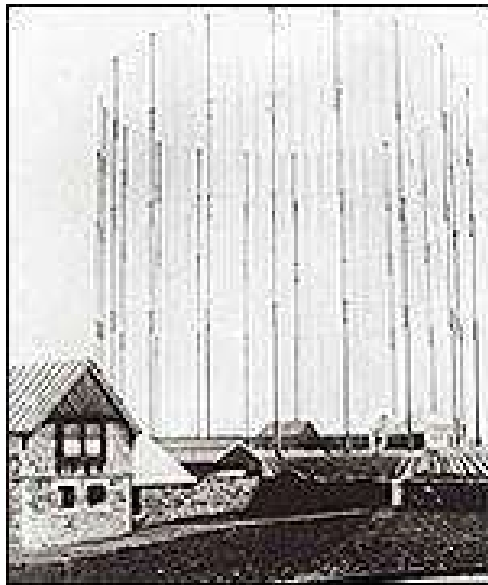
Aleksandr Stepanovich Popov (1859–1906)

- was aware of the experiments by Lodge
- 1895: receiver for thunderstorm detection

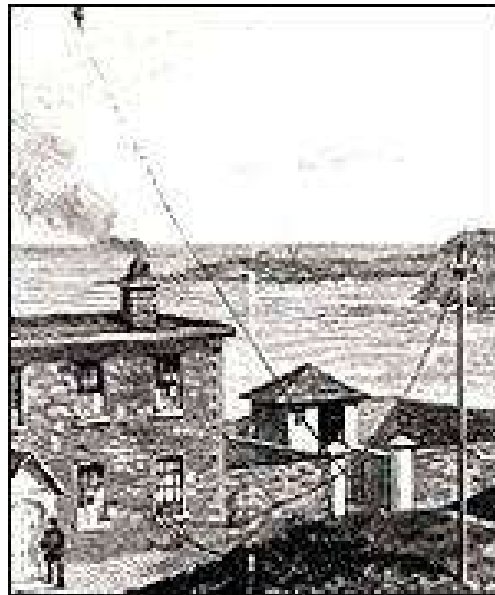


Over the Atlantic

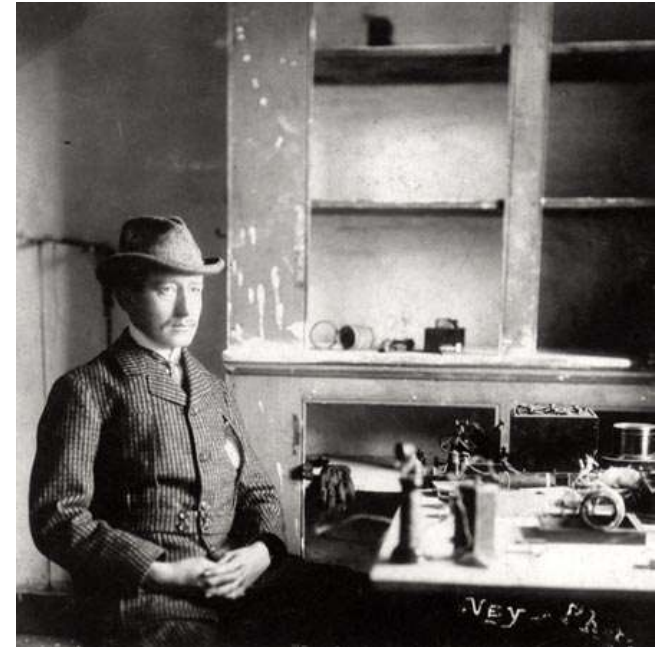
- 12 December 1901
- Poldhu (Cornwall) – Signal Hill (Newfoundland)
2900 km !



Poldhu



Signal Hill



Towards international co-operation

- Maritime radio (Titanic, 1912)
- Companies (de Forest, Telefunken, Marconi)
- Competition, interference
 - need for administration and frequency allocation
- Belgium: King Leopold II and King Albert I
 - communications in Congo with radio links
 - Dr. Robert Goldschmidt
- International Research Council 1919

