Physics-L2

Electromagnetism :

LC: 24 hours approx
EX: 24 hours approx
Teachers: Yannick Hinschberger and Gulyaz Najafova
Exams: 1 midterm (coeff : 1.5), 1 final (coeff : 2.5)

Practical Works

PW: 21 hours
Teachers: Yannick Hinschberger, Gulyaz Najafova and Alihuseyn Dovlatov
Exams: 1 report and 1 lab evaluation (coeff: 2)

Physics-L2

Electromagnetism

Chapter 1: Electrostatics
Chapter 2: Magnetostatics
Chapter 3: Time-dependent regime-Induction phenomena
Chapter 4: Maxwell equations
Chapter 5: Dielectric media and applications
Chapter 6: Conducting media and applications
Chapter 7: Magnetic media and applications

Physics-L2 Electromagnetism

Approximative program

Chap 1: Electrostatics
Chap 2: Magnetostatics
Chap 3: Time-dependent regime-Induction phenomena
Chap 4: Maxwell equations
Chap 5: Dielectric media and applications
Chap 6: Conducting media and applications
Chap 7: Magnetic media and applications

week	Magistral lectures
1	Electrostatics
2	Electrostatics
3	Electrostatics
4	Electrostatics
5	Magnetostatics
6	Magnetostatics
7	Induction
8	Induction
9	Maxwell equations
10	Maxwell equations
11	Dielectric media
12	Dielectric / Metallic media
13	Metallic Media
14	Magnetic media

About Practical Works

week	Practical Work (SP2)
1	
2	
3	
4	Discovery of Oscilloscope
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	

PW0: Oscilloscope
Same PW for all groups

PW1: Coaxial cable
PW2: Transformator
PW3: Sound Wave
PW4: Interference sound waves
PW5: Interference Optics
PW6: Electron canon

UNIVERSITÉ DE STRASBOURG

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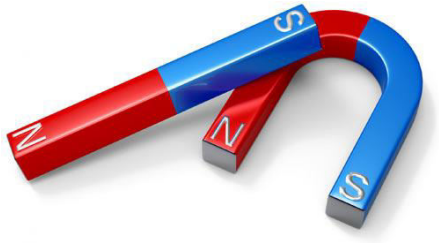
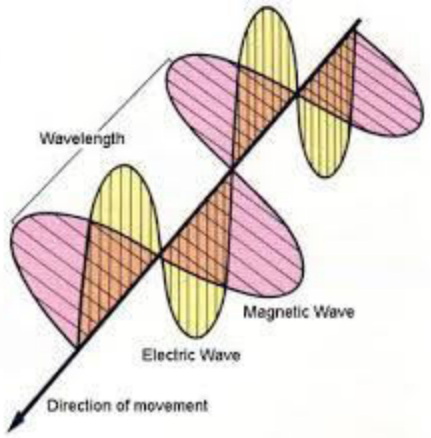
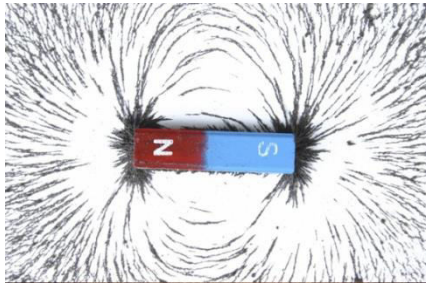
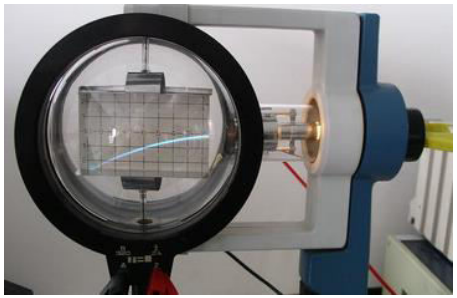
Lectures Physics L2
Electromagnetism

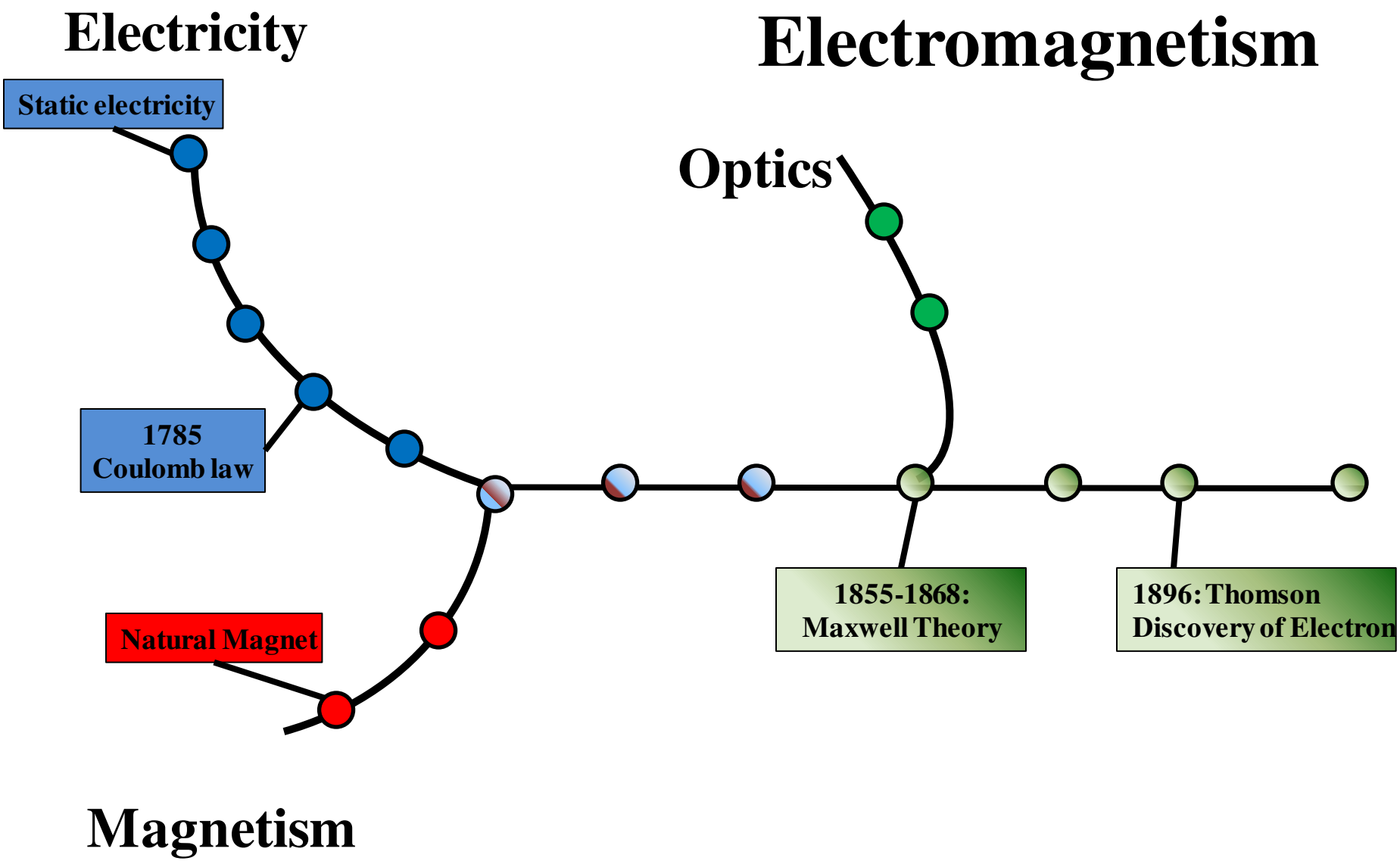


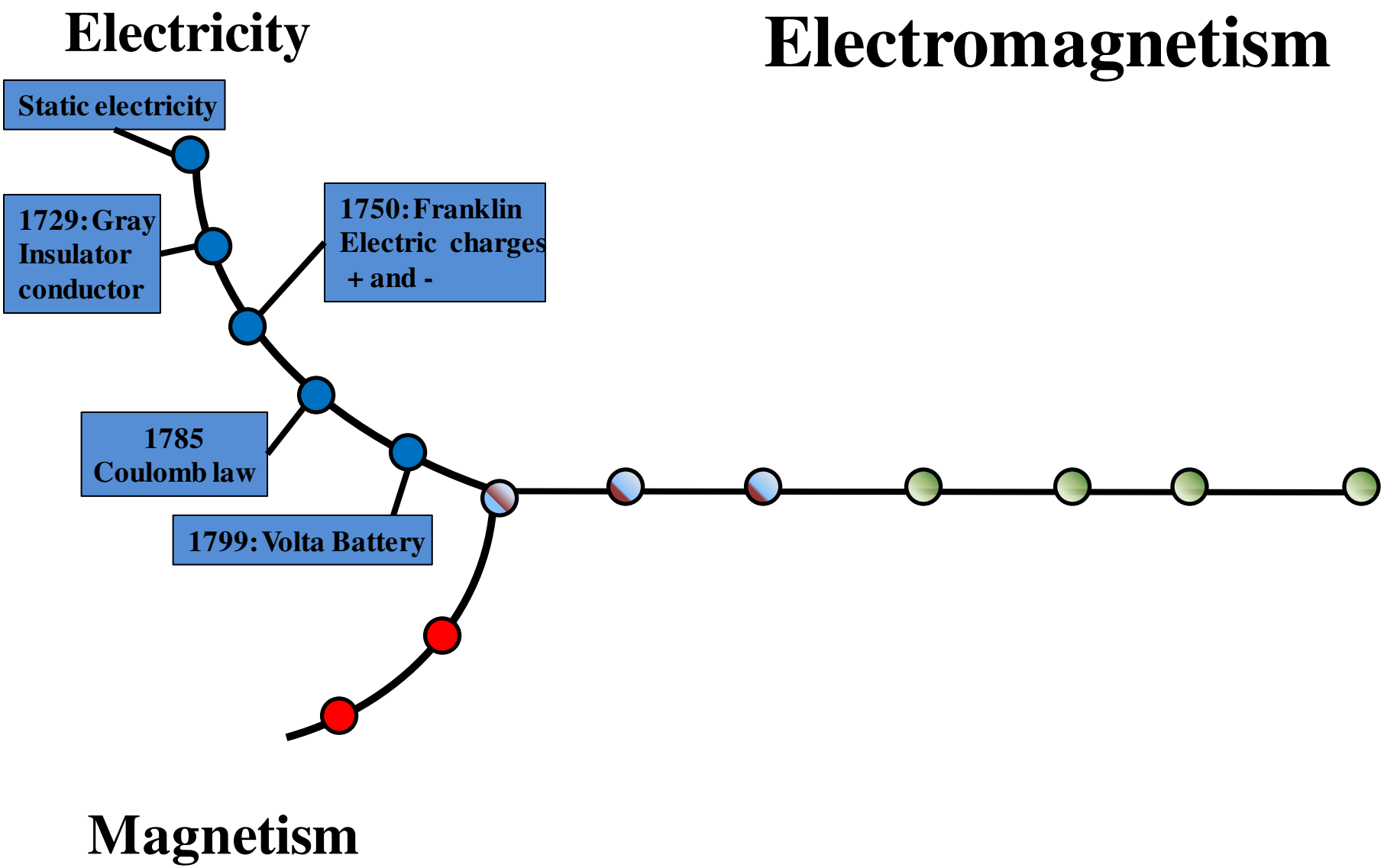
Electromagnetism



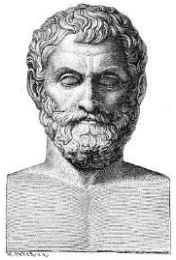





Electricity
Electromagnetism
Static electricity
Optics
1785
Coulomb law
Natural Magnet
1855-1868:
Maxwell Theory
1896: Thomson
Discovery of Electron
Magnetism


Electricity
Electromagnetism
Static electricity
1729: Gray
Insulator
conductor
1750: Franklin
Electric charges
+ and -
1785
Coulomb law
1799: Volta Battery
Magnetism

Static Electricity



Thales
625-547 BC

Amber

From ancient greek:

ἤλεκτρον elektron:

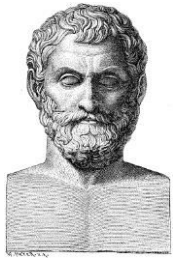
Electrisation by friction

Old greek
hand

After rubing amber with, it can attract light objects

Electricity

Static Electricity



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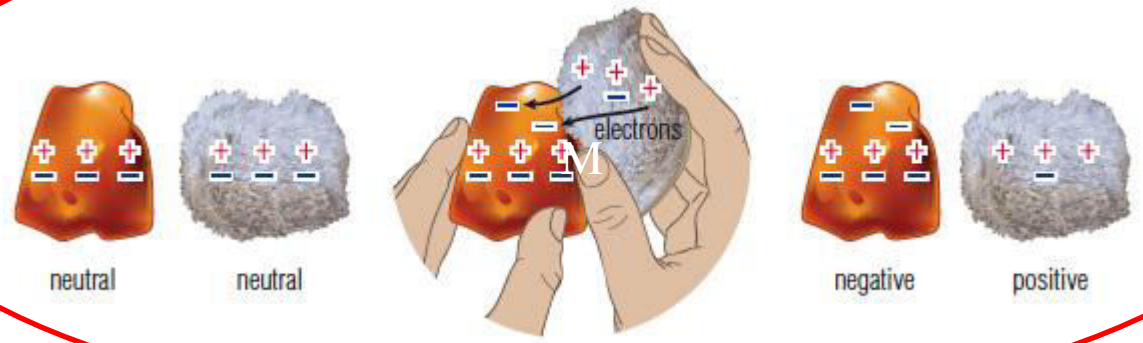
Modern explanation



Two types of electricity

Electricity is seen as a fluid

Charles Du Fay
1698-1739

Resineous electricity:
obtained after friction with **amber**

Vitreous electricity:
obtained after friction with **glass**

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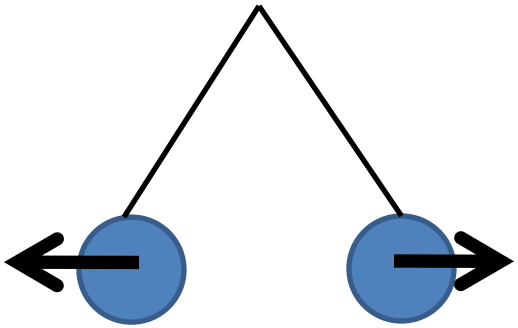
2 pendulums
rubbed with amber
REPULSION



2 pendulums
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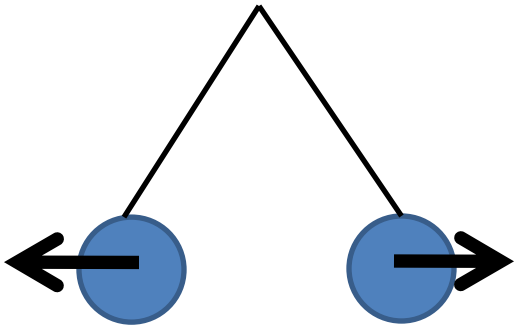
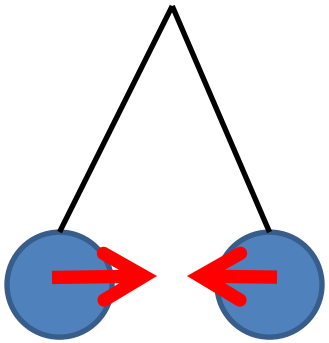


1 pendulum rubbed with glass and
1 pendulum rubbed with amber
ATTRACTION

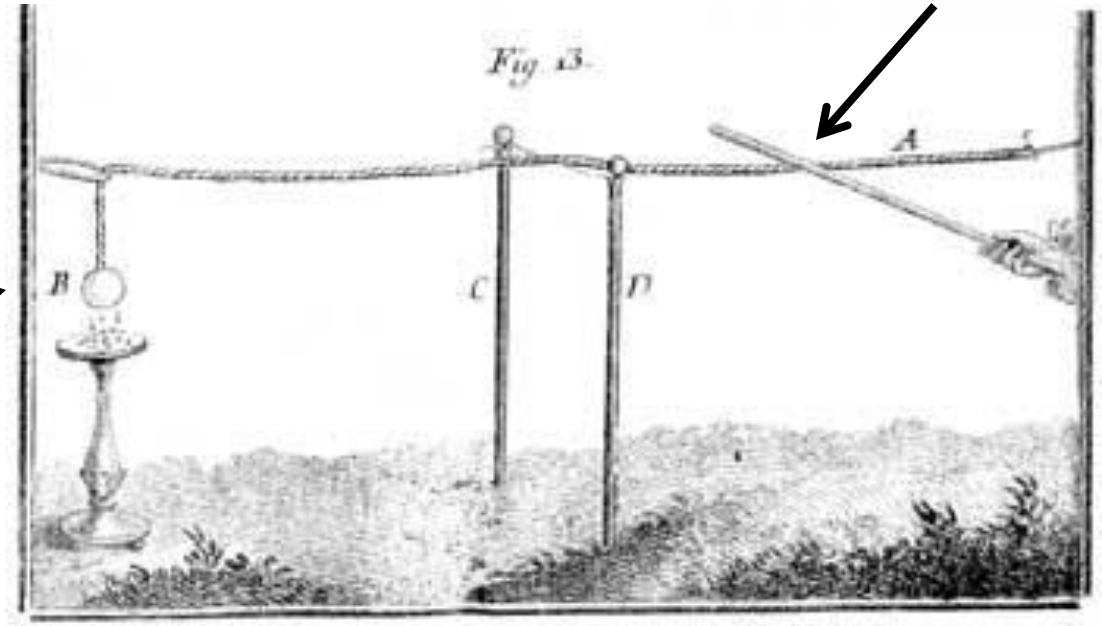


Propagation of electricity: conductor-insulator

Stephen Gray
1666-1736

- One can propagate electricity
- existence of materials that propagate electric fluids and others not.

Electrisation by contact with a glass stick

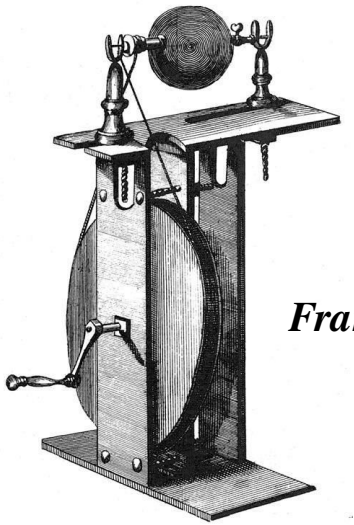


The electric fluid propagates until the sphere because it attracts little papers

Eletrostatic devices

1706

Electrisation by contact with a rotating sulfur sphere



Francis Hauksbee
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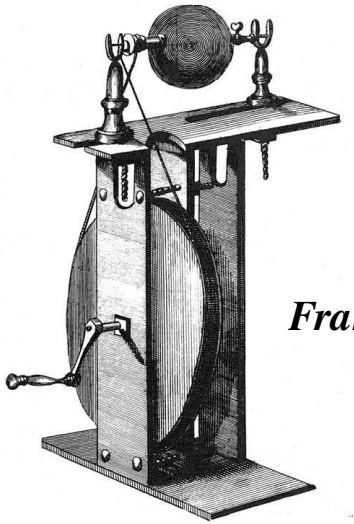
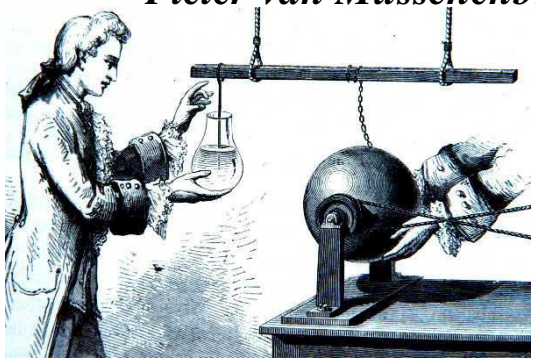


Francis Hauksbee
1666-1713

1746: University of Leiden

Pieter van Musschenbroek (1692-1761)



Leiden Jar (bottle)….first capacitor

Deliver electric discharge

Eletrostatic devices

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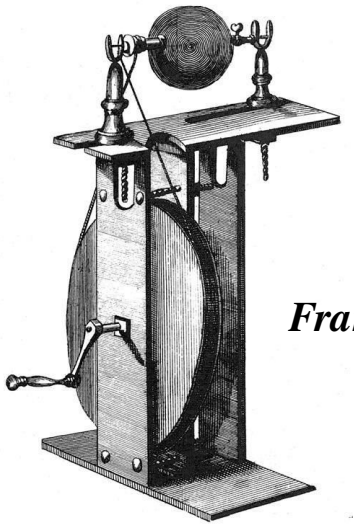
Electrisation by contact with a rotating sulfur sphere



Francis Hauksbee
1666-1713

Jean-Antoine Nollet
1700-1770

1746: University of Leiden

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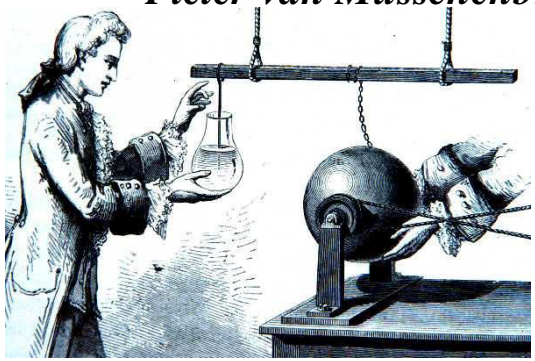

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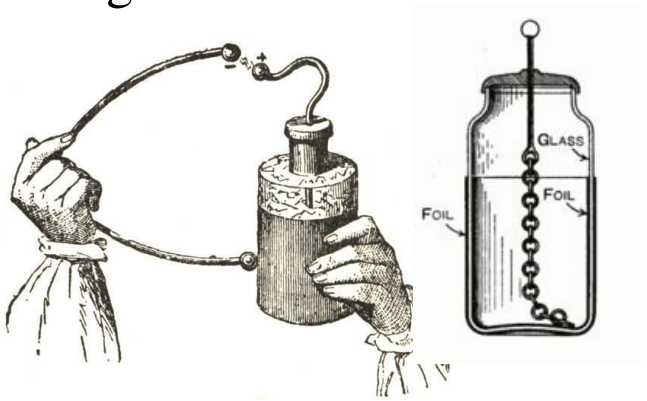

Fig. 213. Leyden Jar with Discharger.

Benjamin Franklin
1706-1790

Negative and Postive charges

Vitreous electricity and resineous electricity represent the same fluid at different pressures, the circulation of electricity put the two states at equilibrium.

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Lightning rod

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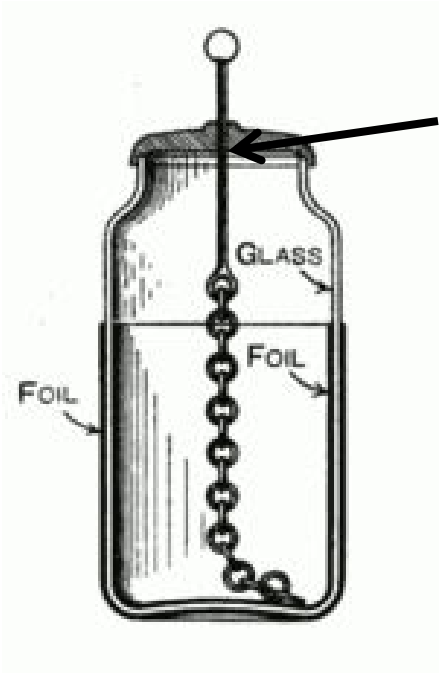
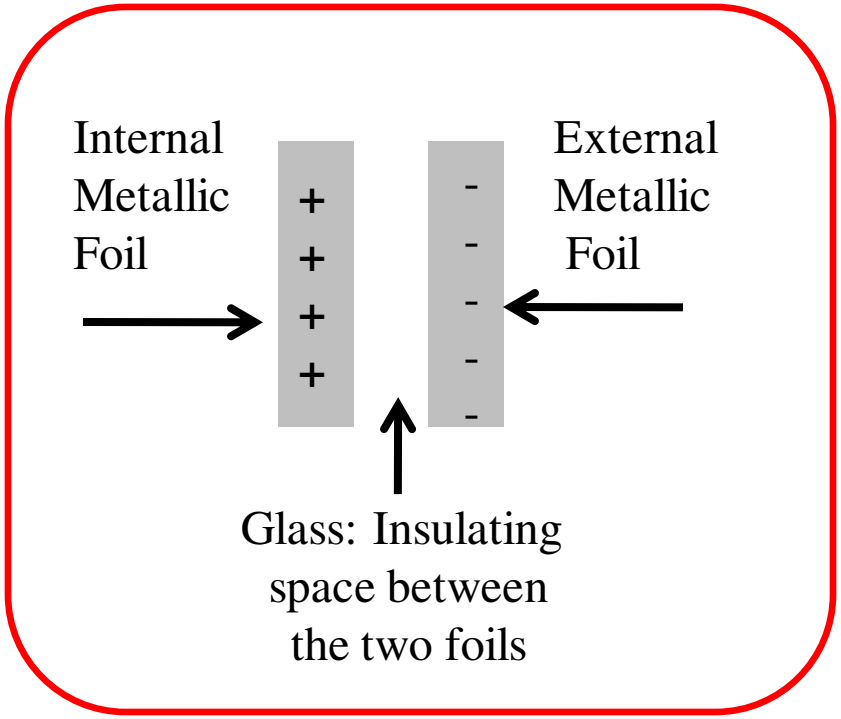
Lightning rod

- **Charge conservation**
- **Phenomena acting at distance**
- **Explanation of Leiden jar phenomena**

Interpretation of Leyden Jar



Metallic Chain propagates electric perturbation to the internal foil



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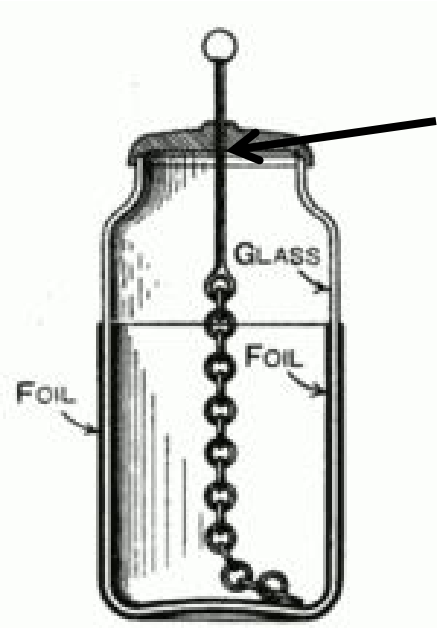

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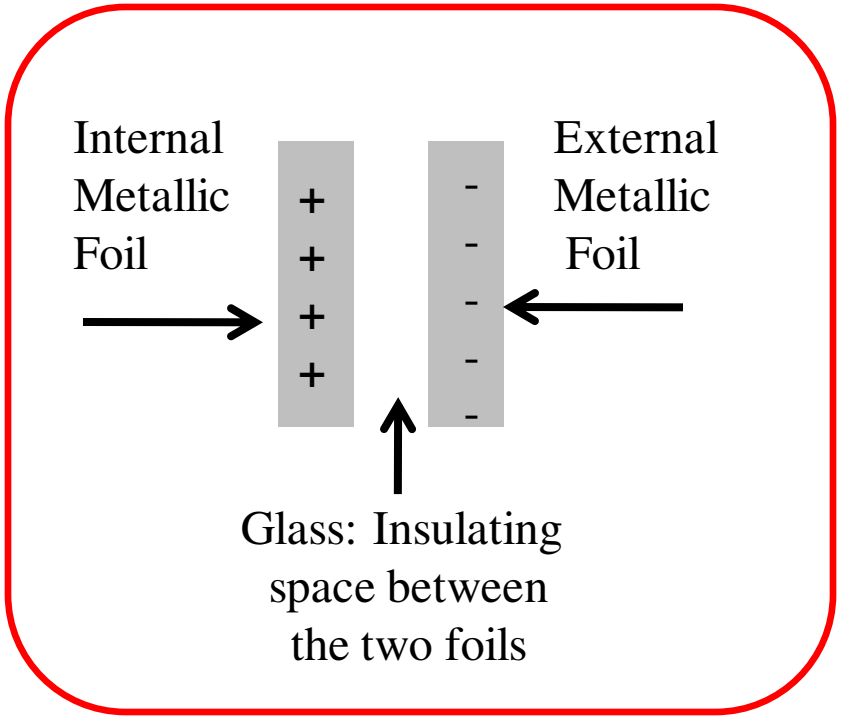


- Possibility to **close the circuit** and to induce an **electric discharge !!**

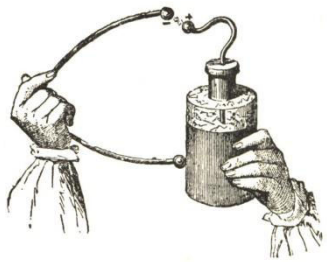
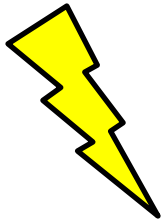
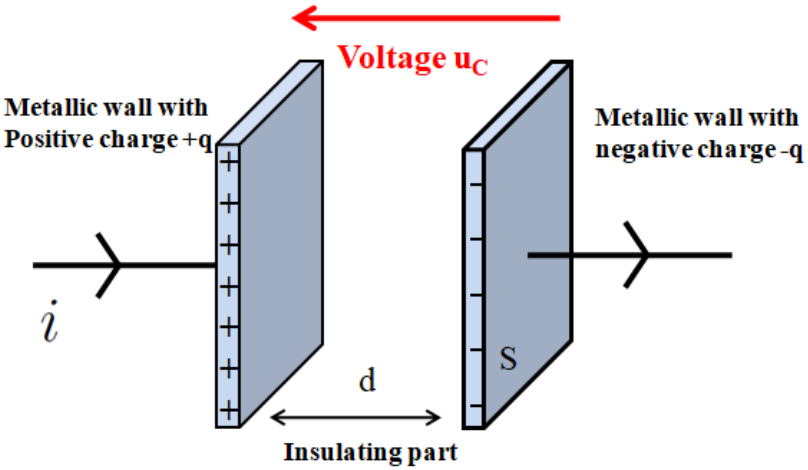


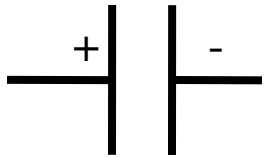
Fig. 213. Leyden Jar with Discharger.



Quick Modern description: Principle of a capacitor

- Can accumulate and stock electric charges:





Electric symbol

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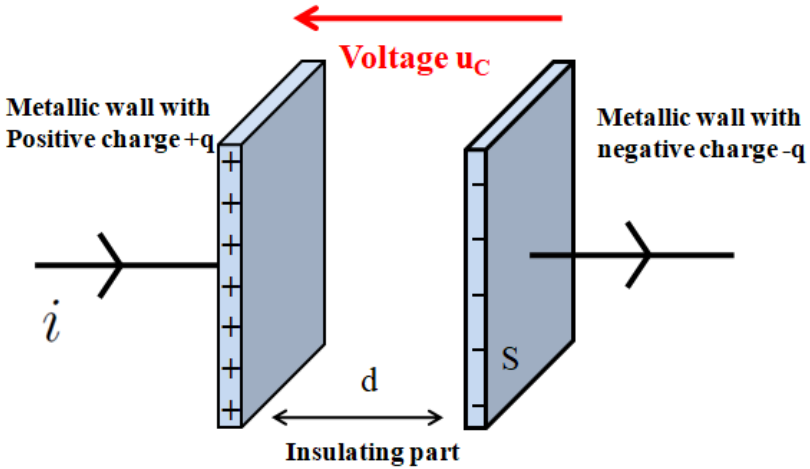
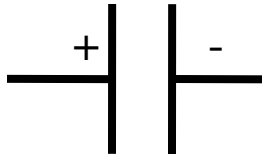




Electric symbol

- Described by its Capacitance C (or capacity) in Farad (Coulomb/Volt):

$$q = Cu_C$$

$$C = \frac{\epsilon_0 S}{d}$$ (if insulating part is the vaccum)

C: from µF to pF

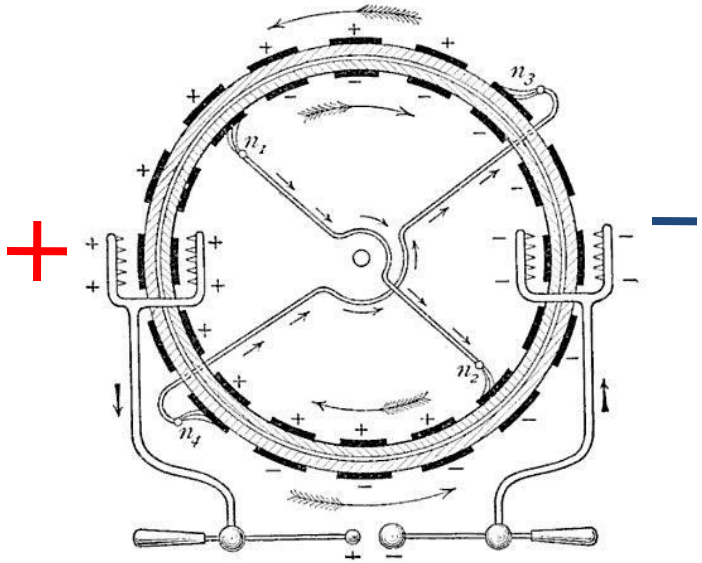
- Relation between current and voltage

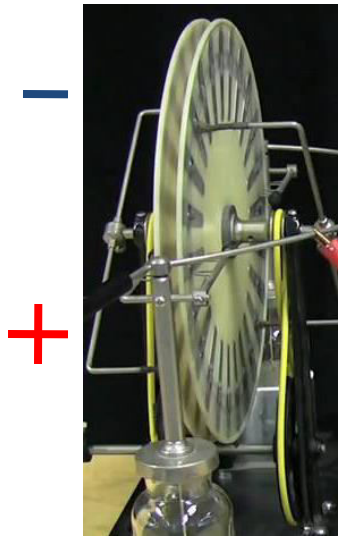
$$i = \frac{dq}{dt} = C\frac{du_C}{dt}$$

Wimshurst Machine (1882)

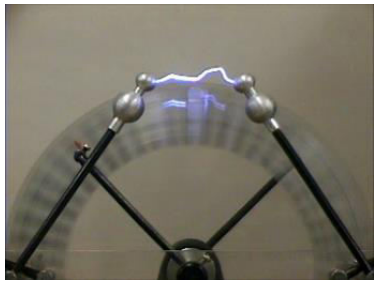
Wimshurst Machine (1882)

- Two wheels rotating in opposite direction in contact with metallic brushes.
- Creation of negative charge induces apparition of a a positive charge on the other side of the brush
- By the weels rotation, charges are transported and collected





When electric charges become to high: lightning

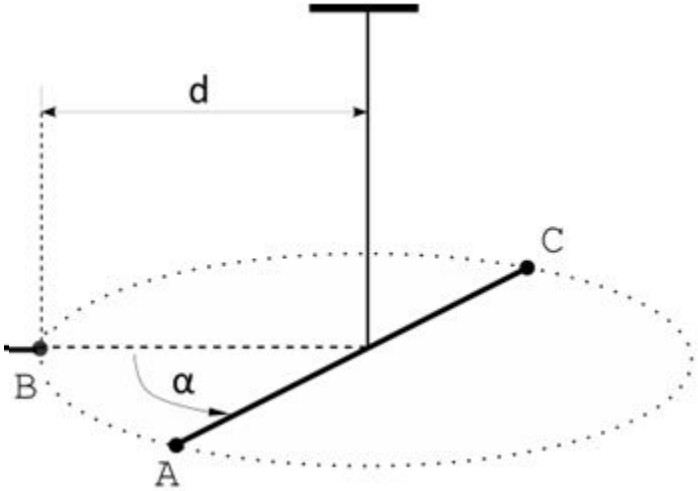


You Might watch
https://www.youtube.com/watch?v=Zilvl9tS0Og

Charles Coulomb
1736-1806

Parameters that influence the electric force

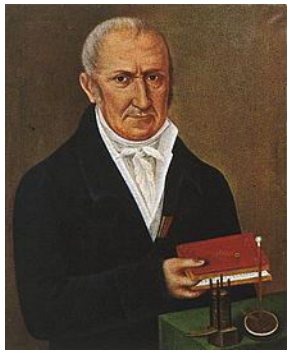
Coulomb balance: device composed with a torsion balance able to measure weak electric forces.



$$F \approx \frac{q_1 q_2}{r^2}$$

Repulsion of two spheres after electrisation of neutral sphere A by charged sphere B.

Coulomb: unit of electric charge

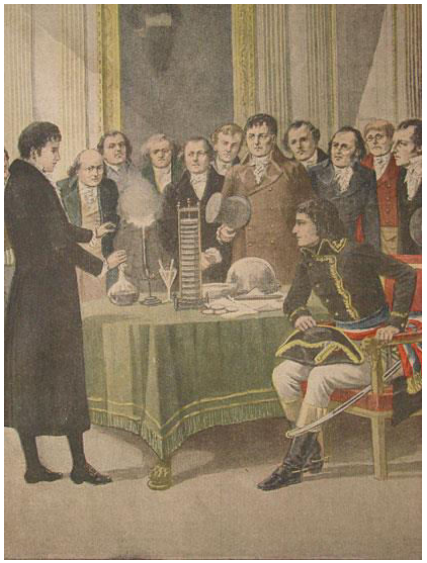


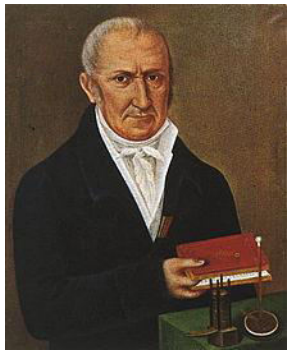
Alessandro Volta
1745-1827

First Generator

1800: <u>Volta Battery</u>: can deliver electricity <u>without interuption</u>, not only by a discharge.

Unit of electric tension: Volt





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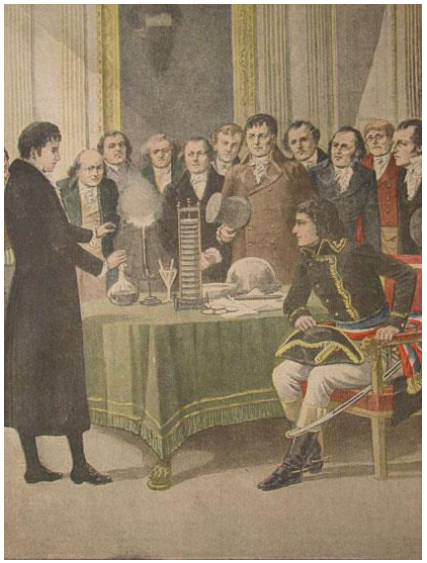
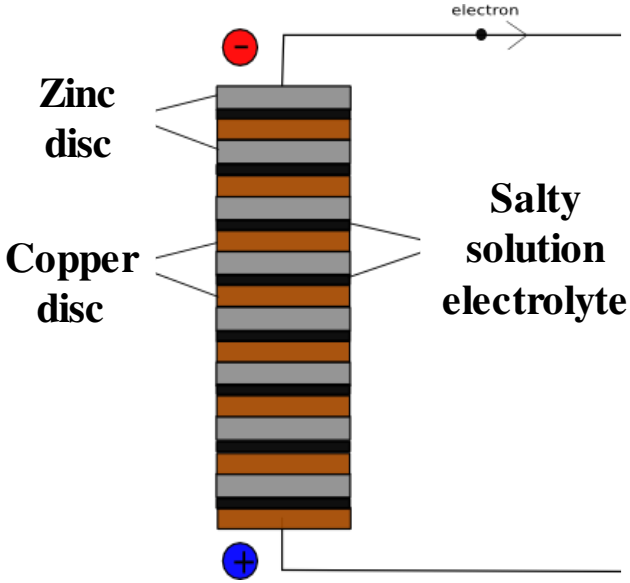
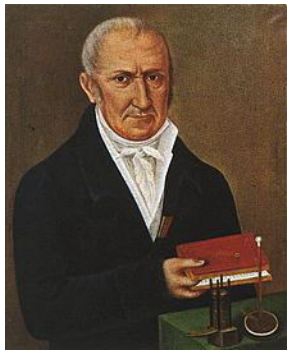


Exemple of voltaic battery (cell)





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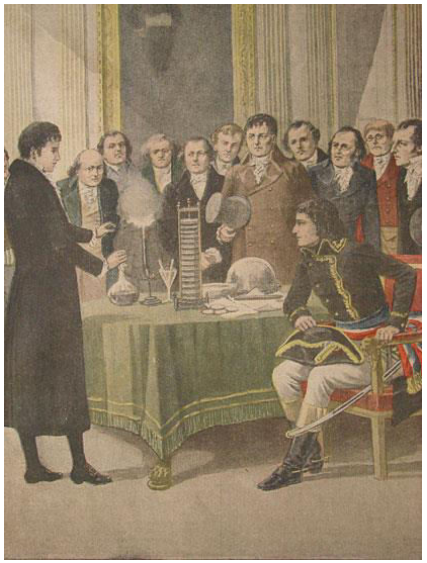

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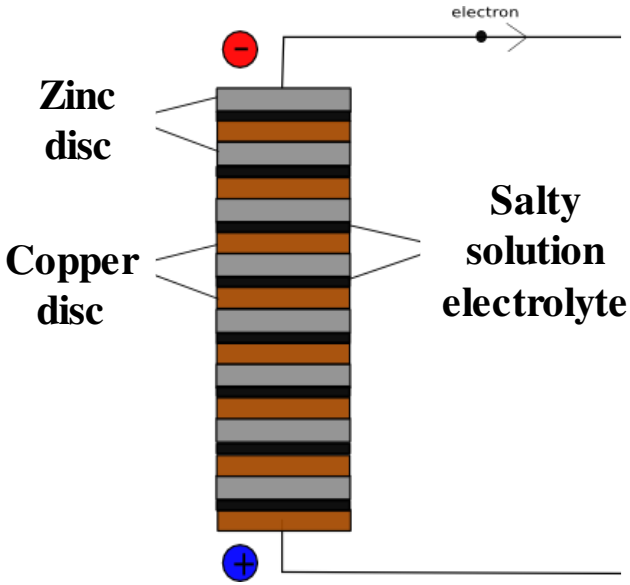
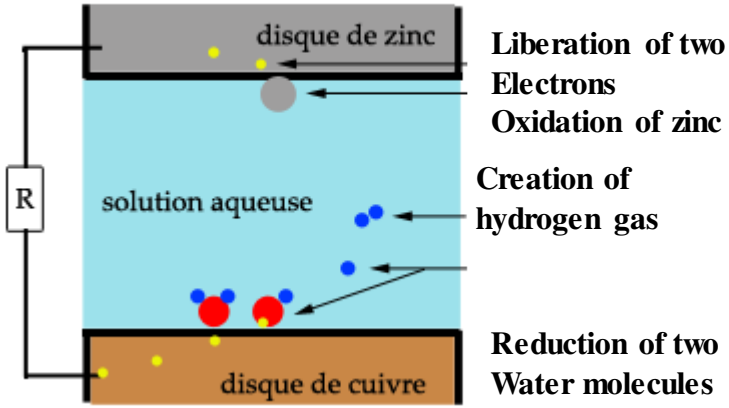


Chemical explanation: redox reactions

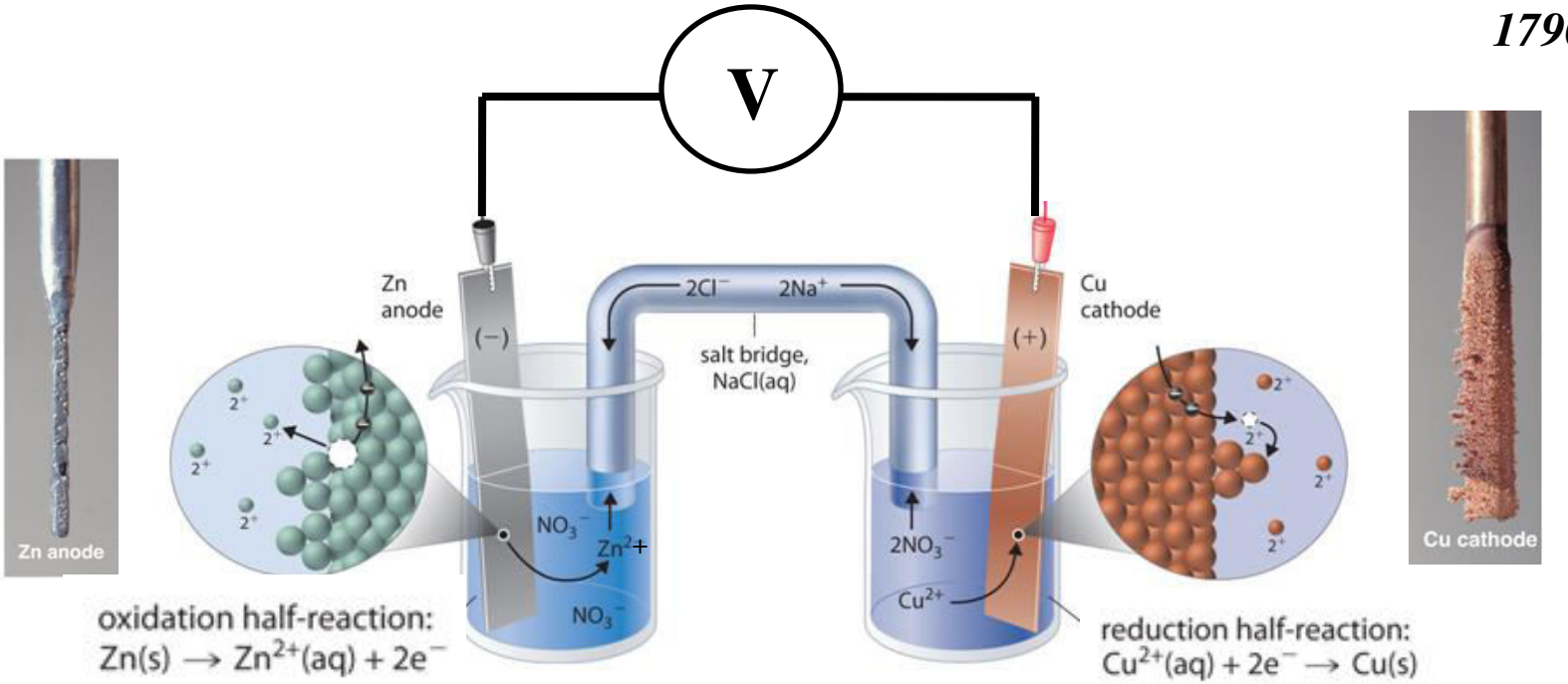


A famous pedagogic example: Daniell Cell (1836)

Field of Electrochemistry

John. F. Daniell
1790-1845

Voltmeter gives ≈ 1,1 Volt



Electricity

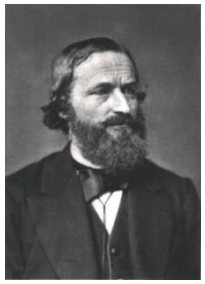
Further development : birth of electric circuits…and electric civilisation

Notion of electric current Voltage –Tension

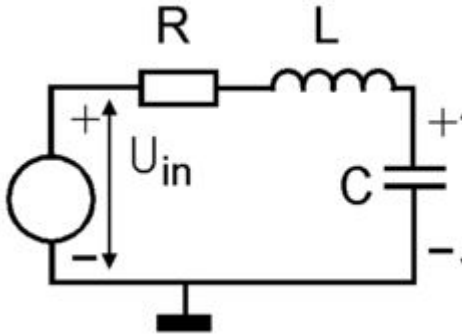
Georg Ohm
1789-1854

André-M. Ampère
1775-1836

Gustav Kirchhoff
1824-1887

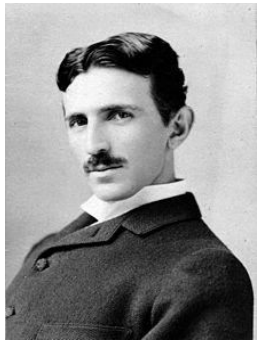


Current and voltage laws

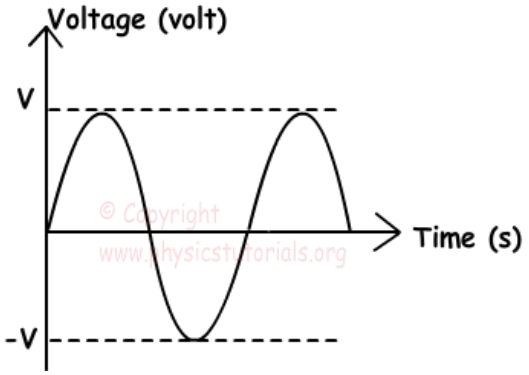


Resistance

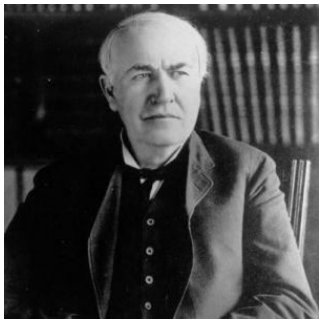
Nikola Tesla
1856-1943



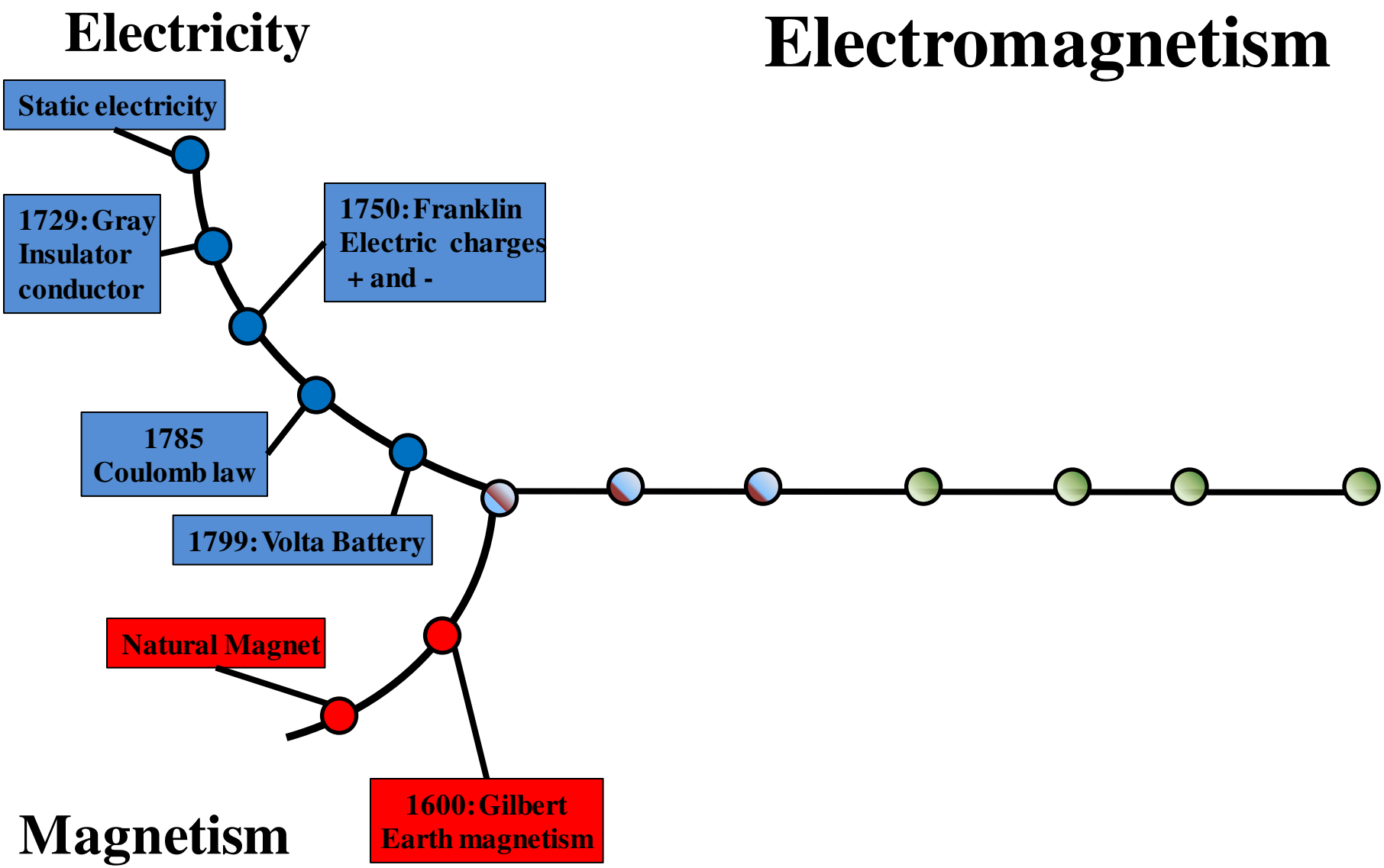
Use of alternative current
After discovery of induction…



Thomas Edison
1847-1931



Incandescent light bulb


Electricity
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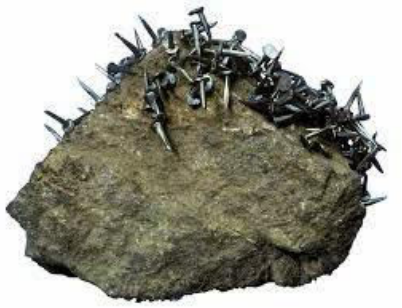
1799: Volta Battery
Natural Magnet
1600: Gilbert
Earth magnetism
Magnetism

Magnet

Magnetite (Iron oxide) has attractive or Repulsive properties (known since antiquity)



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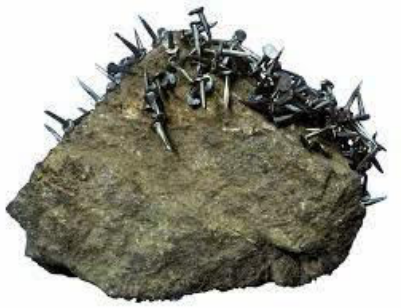
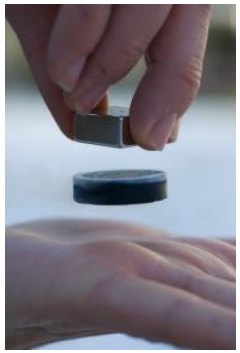
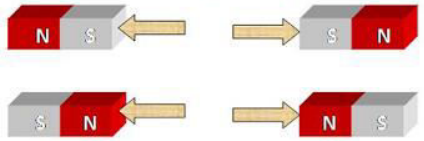


Defining poles: North and South poles



opposite poles attract

same poles repel



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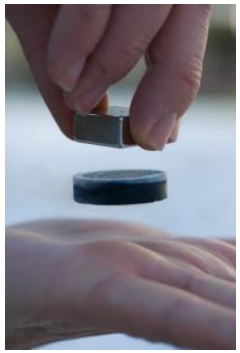

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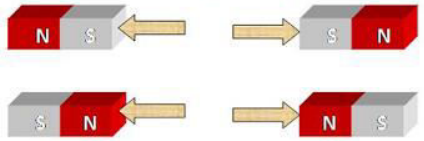


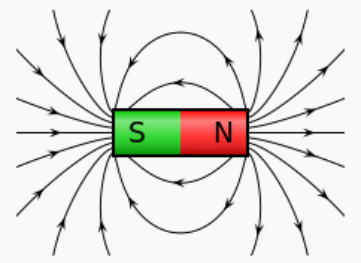
Existence of a natural geographic orientation….North

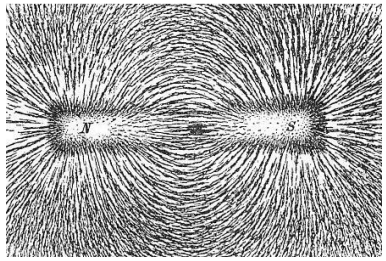
Who invented the magnetic compass ?

Each civilization pretends to did it…

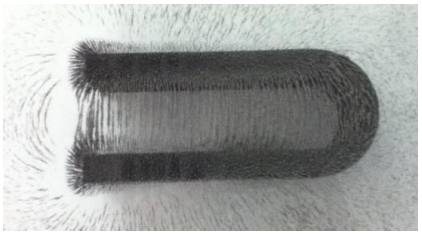
Magnetic orientation

With small iron filings near magnets one can see… *lines*…





Iron fillings



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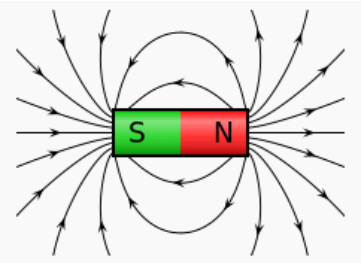

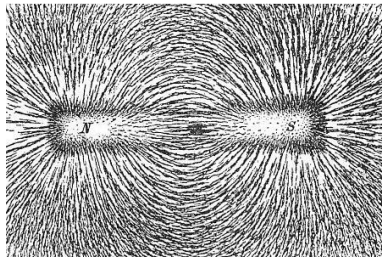

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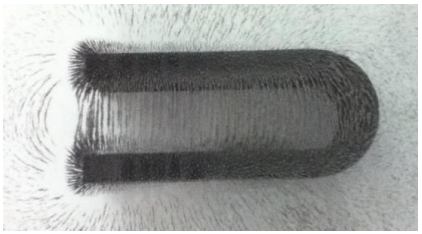
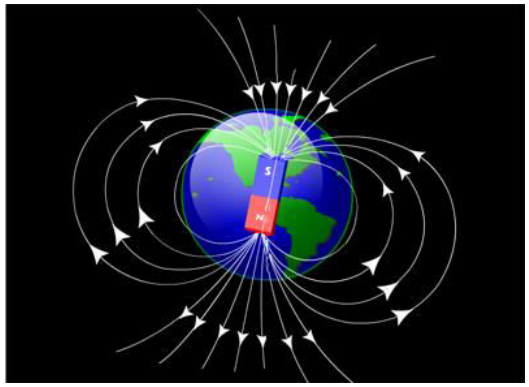


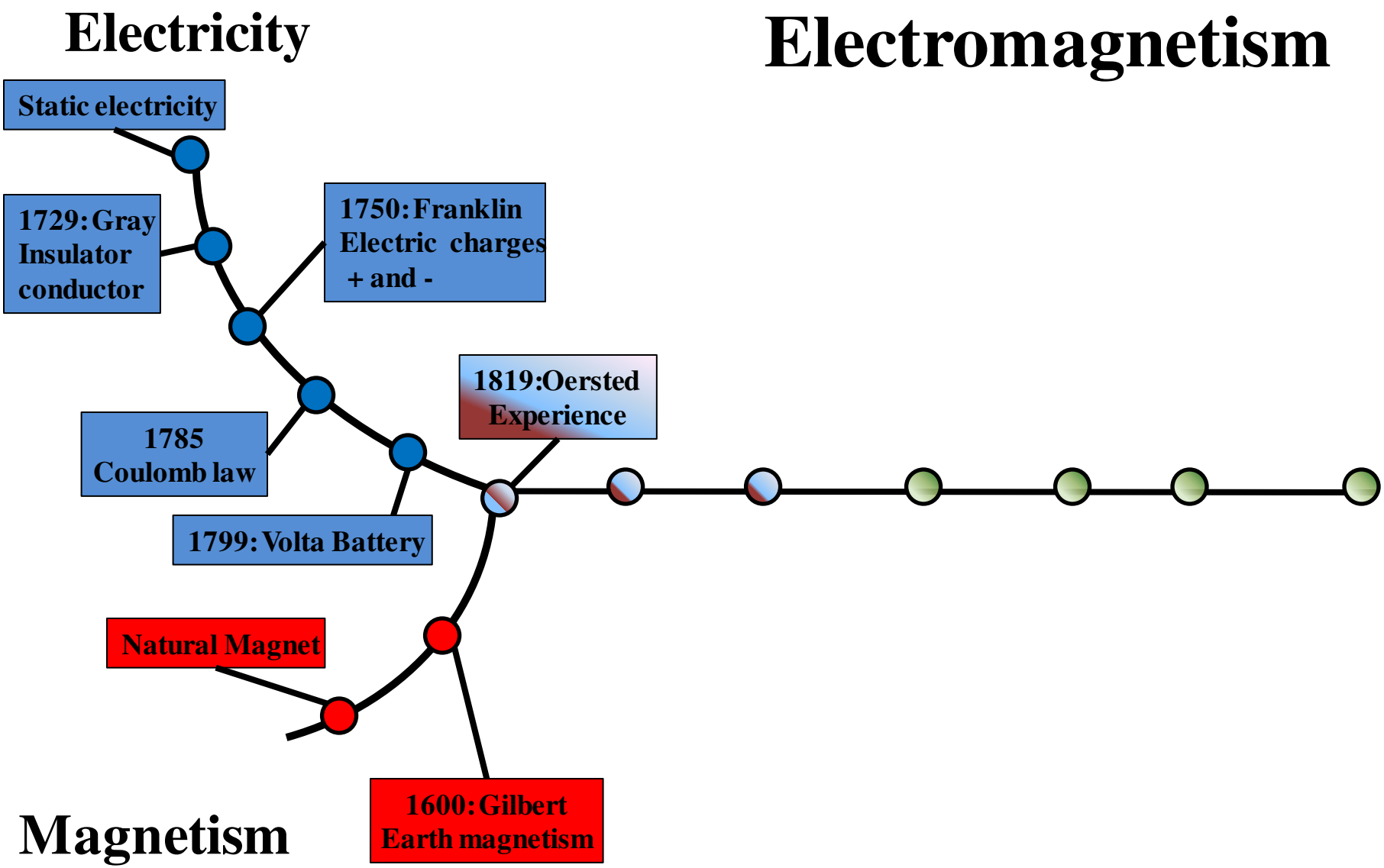
Earth Magnetism

Geographic North is a magnetic south

William Gilbert
1544-1603

The magnetic compass should react in the same way than with a magnet

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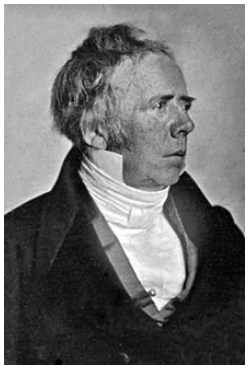
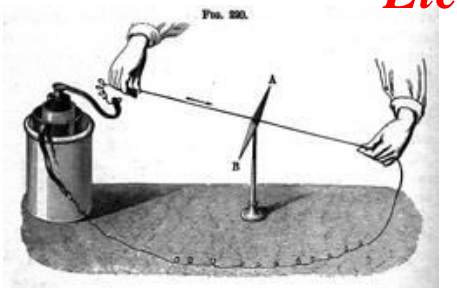
1819: *A Link between electricity and magnetism*

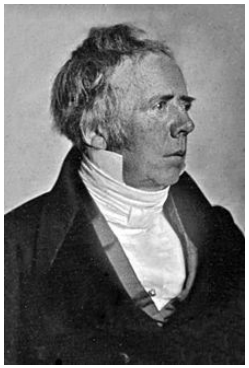


Hans. C Oersted
1777-1851



Electricity induces motion of magnetic compass

1819: *A Link between electricity and magnetism*



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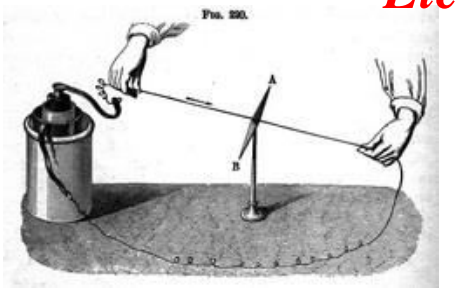

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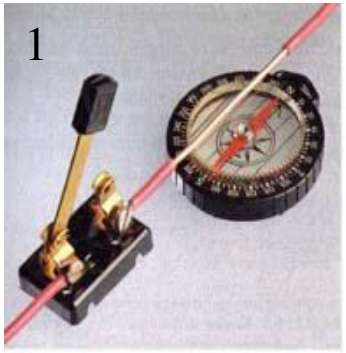
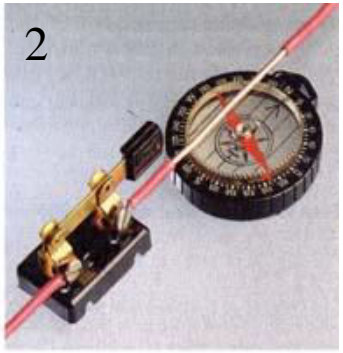
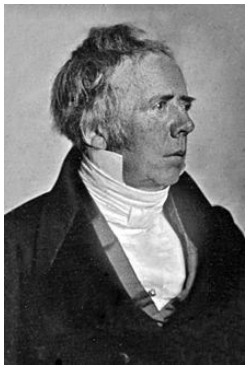




1. No conduction: initial orientation of magnetic compass

2. Circulation of electricity modifies the orientation of magnetic compass.

1819: *A Link between electricity and magnetism*



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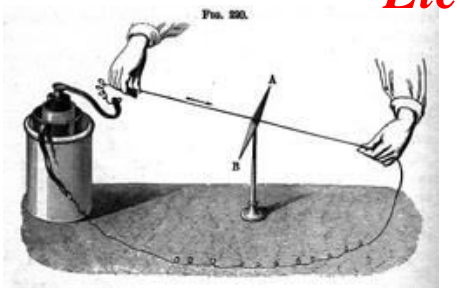

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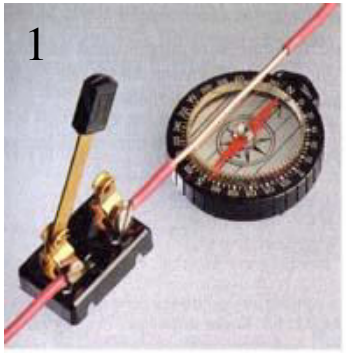

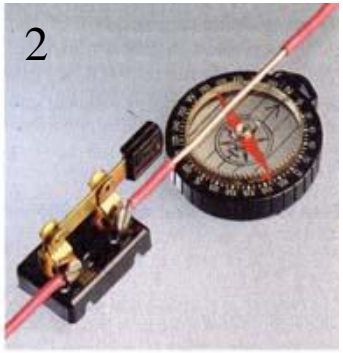

1. No conduction: initial orientation of magnetic compass

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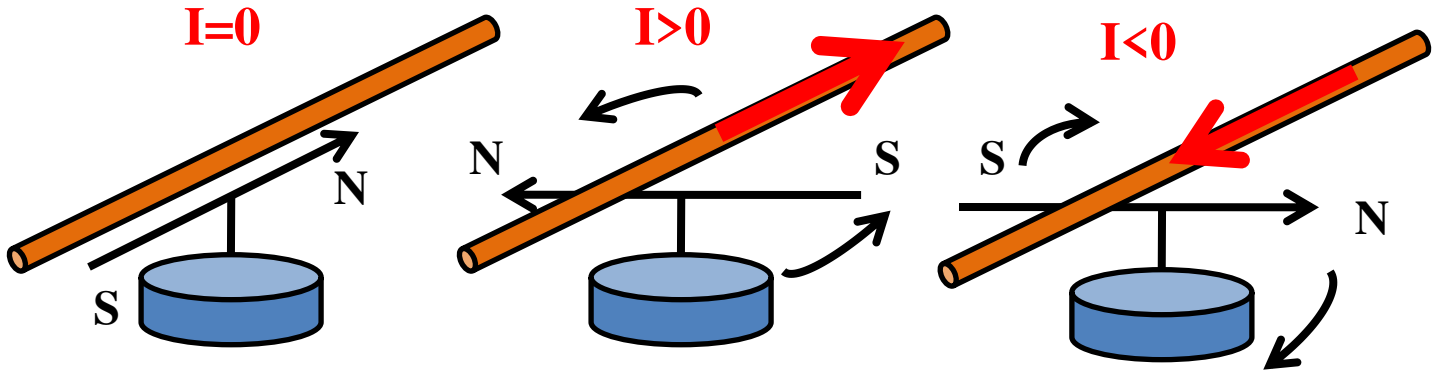
Electricity can have similar action than a natural magnet

Eletrodynamic theory

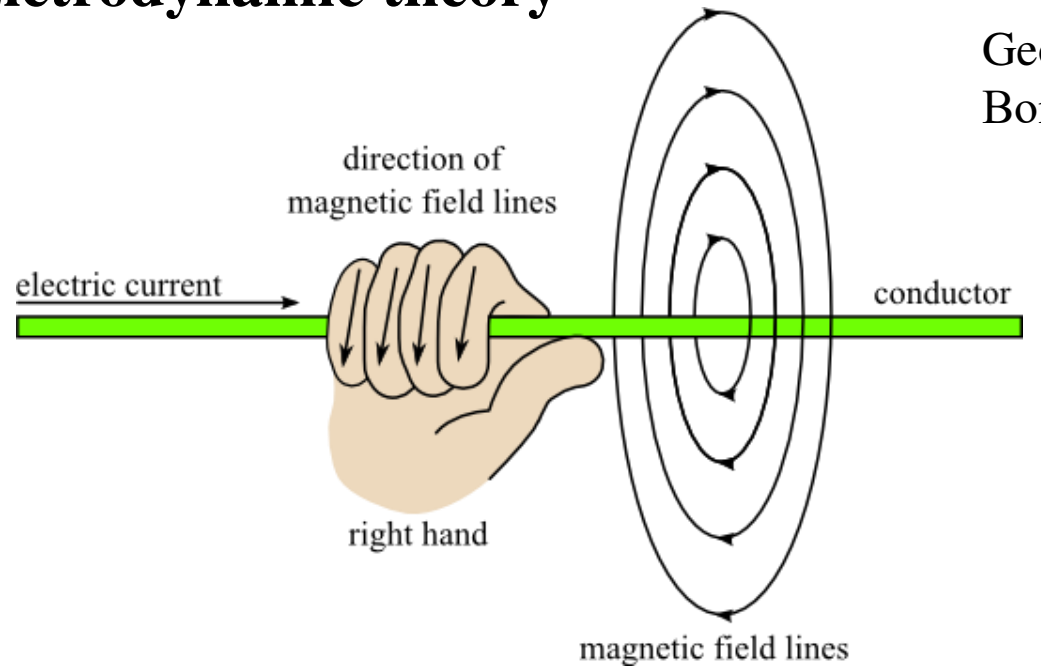
André-M. Ampère
1775-1836

Interpretation of Oersted Experiment
Electric current creates magnetic action

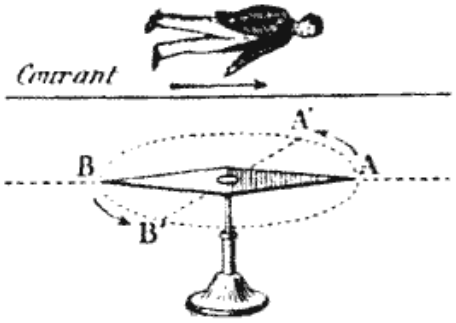
- Notion of **electric current I**: motion of microscopic electric charges
- Direction of the current I influences direction of magnetic compass



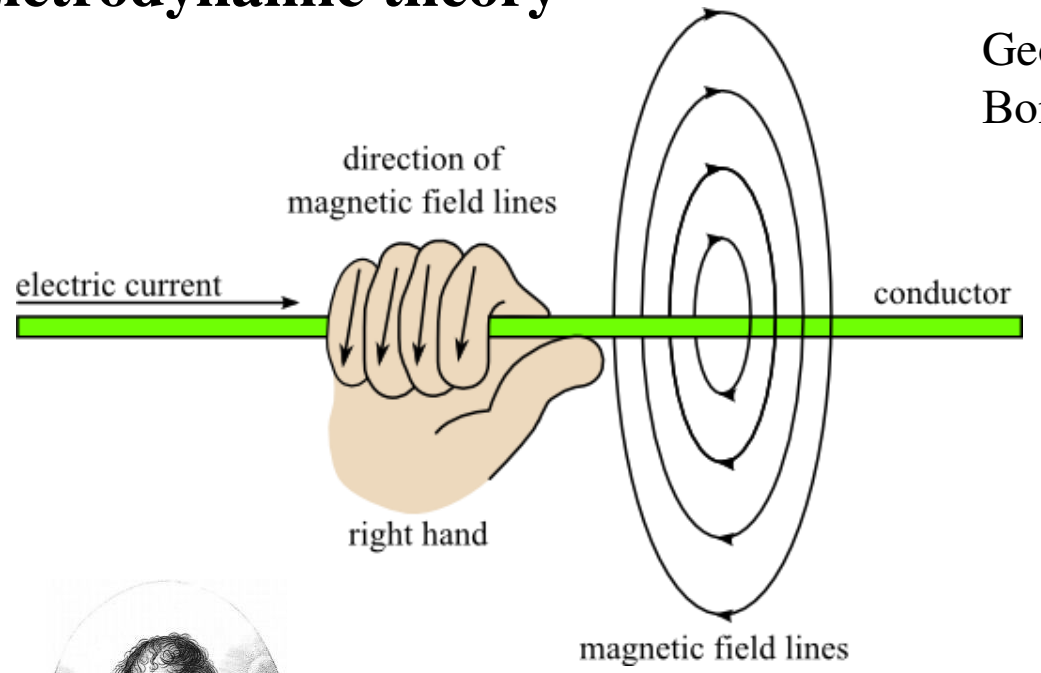
Eletrodynamic theory



Geometric analysis: Right-hand rule
Bonhomme d'Ampère



Eletrodynamic theory



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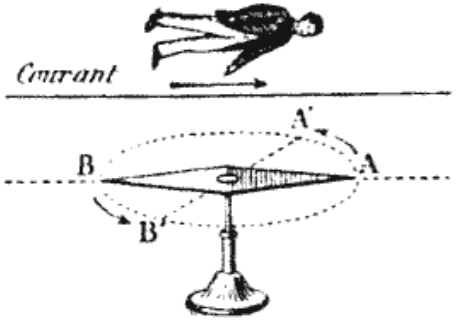
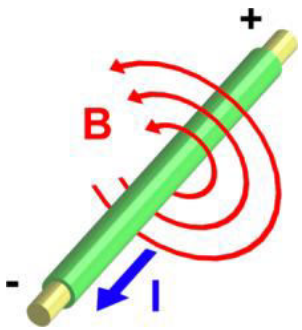


J.B Biot
1774-1862

Biot-Savart Law

$$\vec{B} = \int \frac{\mu_0 i \vec{dl}}{4\pi r^2} \wedge \vec{u_r}$$

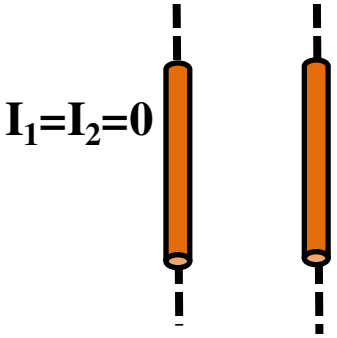
$\mu_0 = 4\pi 10^{-7}$ H/m
Magnetic permeability



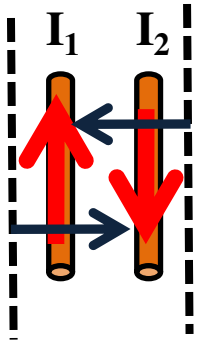
Felix Savart
1791-1841

Further discovered phenomena

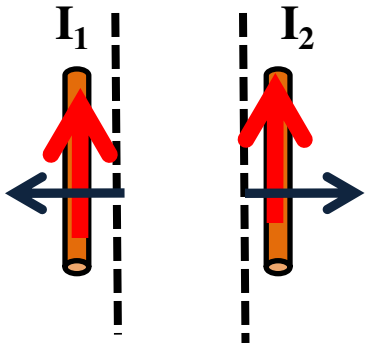
Interaction between two electric currents



Initial position



$I_1>0$ and $I_2<0$
Or $I_1<0$ and $I_2>0$
ATTRACTION



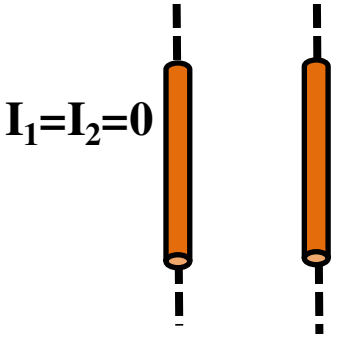
$I_1>0$ and $I_2>0$
Or $I_1<0$ and $I_2<0$
REPULSION

Definition of Ampere:
Unit of electric current:

1 A= current needed to have a lineic force of $2*10^7$ N/m between two infinite wires separated from one meter.

Further discovered phenomena

Interaction between two electric currents



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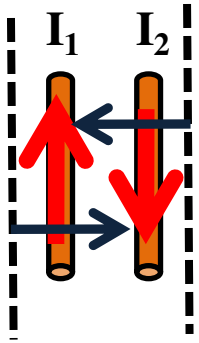

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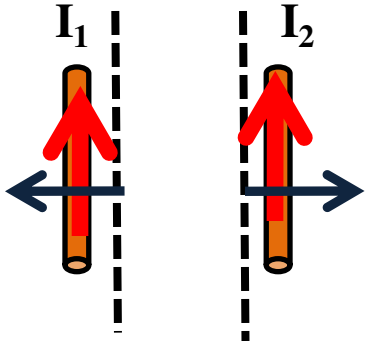
ATTRACTION



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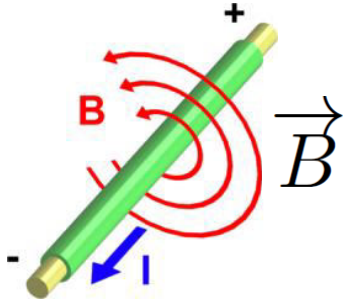
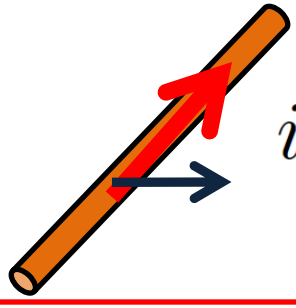
Magnetic field acts also on other electric current



$\vec{B}$



$i\vec{dl}$

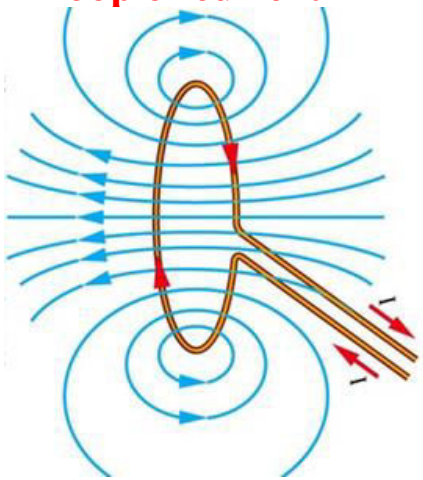
Laplace Force

$$d\vec{F} = i\vec{dl} \wedge \vec{B}$$

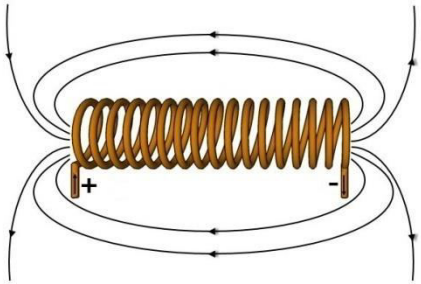
Further discovered phenomena

Important device: *Solenoid- or self or magnetic coil*

1 loop of current



Many loops of current



Creation of magnetic field inside the solenoide

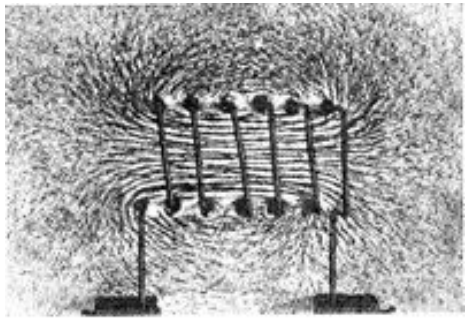
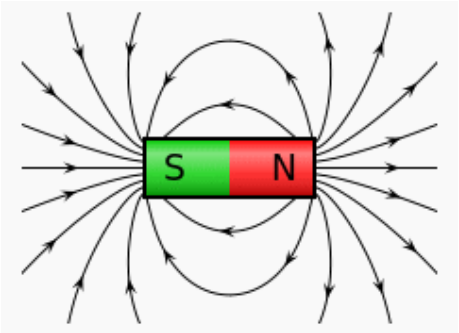
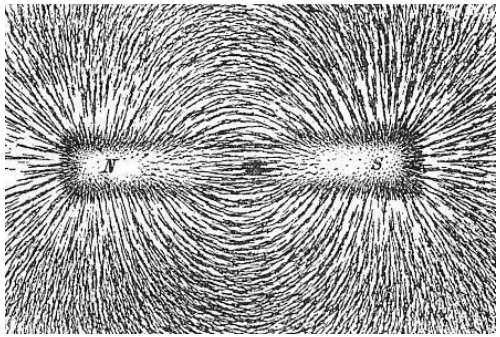


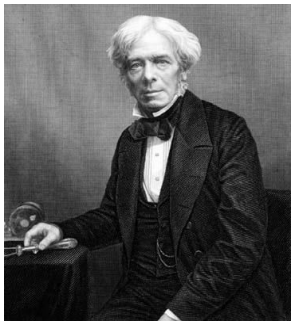
Fig. 3

Similar properties than Ones given by natural magnet





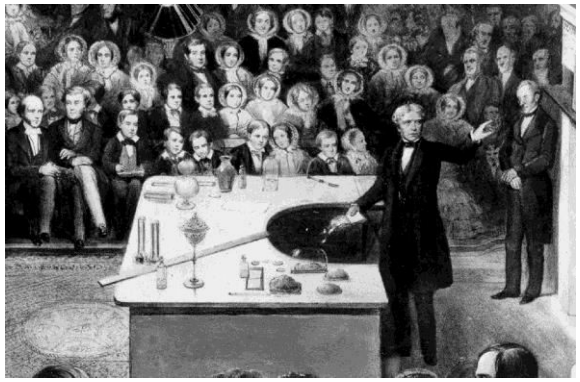
1831: Magnetism can induce electricity



Michael Faraday
1791-1867

Important contribution

- **Chemistry (electrolysis)**
- **Notion of *vectors fields***
- ***Electromagnetic Induction***



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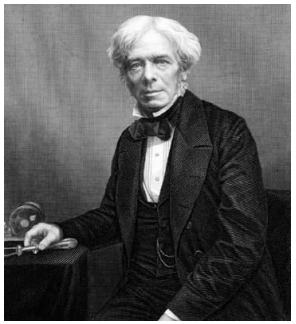

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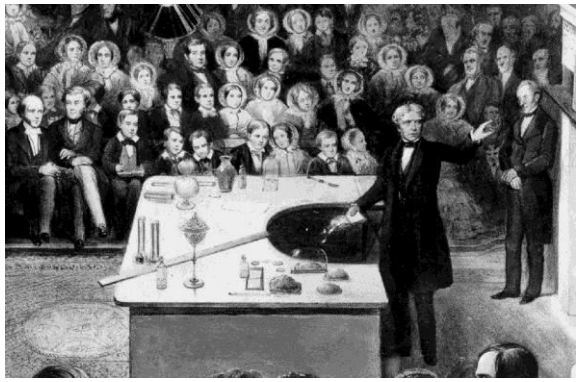
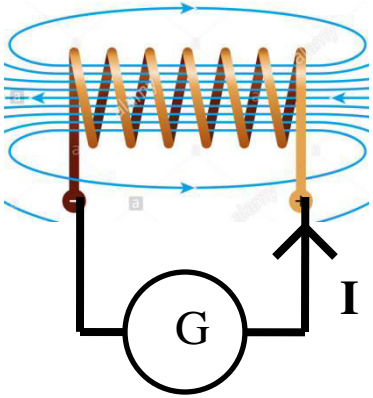
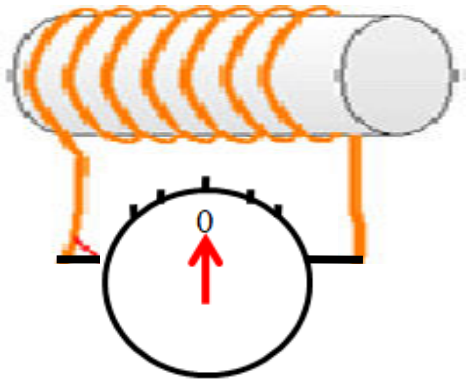
- **Notion of *vectors fields***
- ***Electromagnetic Induction***



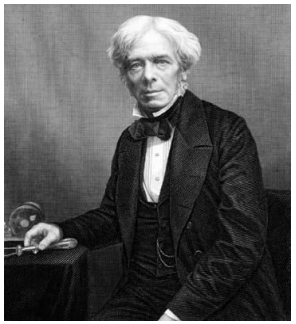


A magnetic coil
that produces
a magnetic field



A magnetic coil related to
a voltmeter.

1831: Magnetism can induce electricity



Michael Faraday
1791-1867

Important contribution

- **Chemistry (electrolysis)**
- **Notion of *vectors fields***
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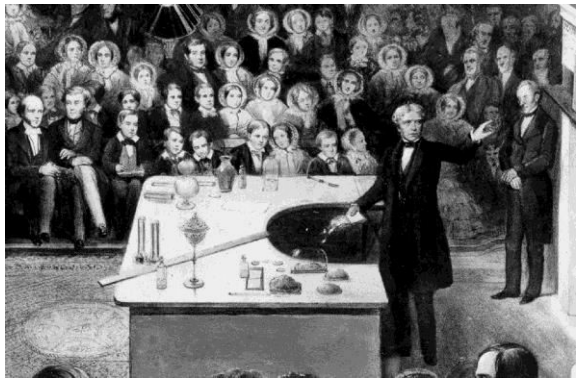
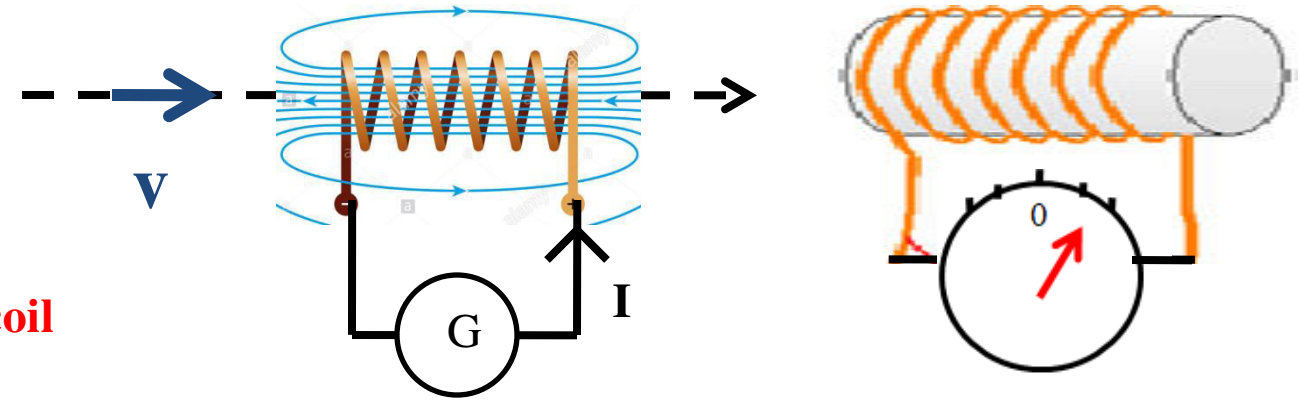
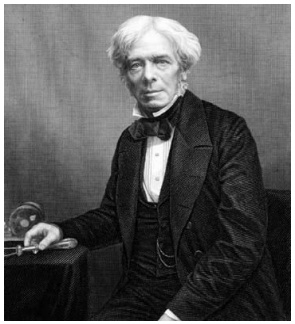




We move the first coil close to the second and a voltage appears during the motion !

If motion is faster, voltage
In the second coil is higher !

1831: Magnetism can induce electricity



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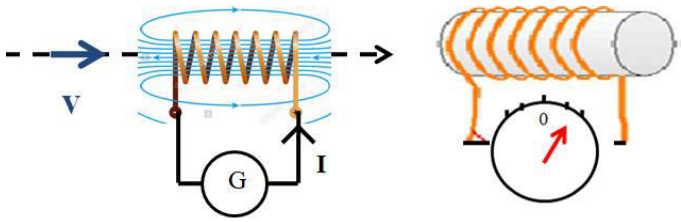
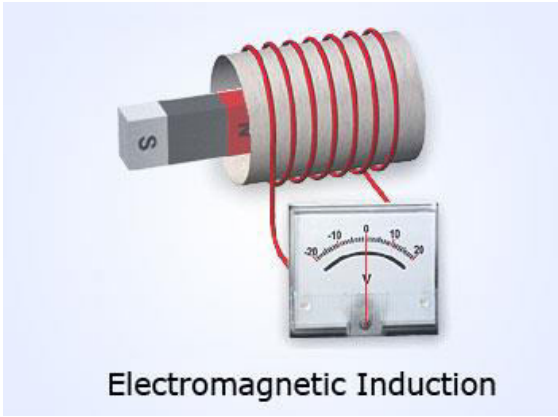


It works also with a magnet

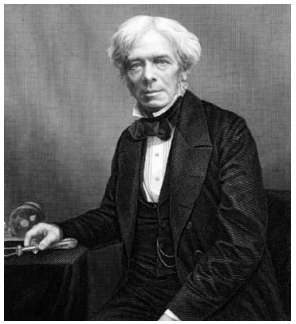
Motion of magnet inside the self…

…generates electric tension !!!



Electromagnetic Induction

1831: Magnetism can induce electricity



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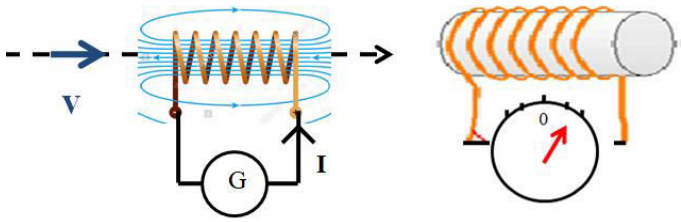

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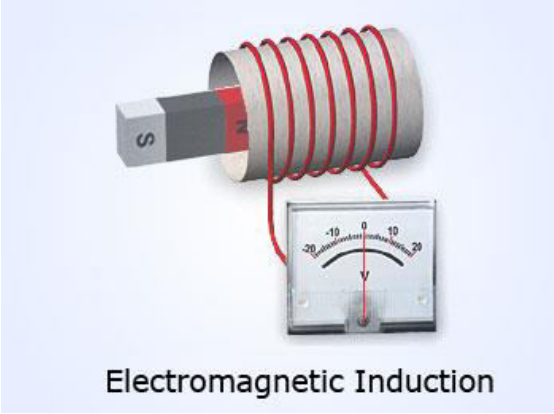
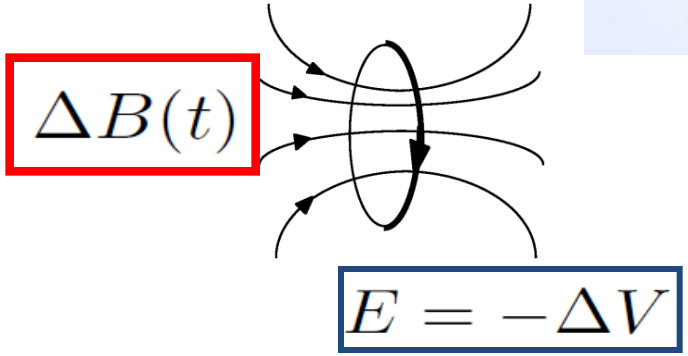


Electromagnetic Induction

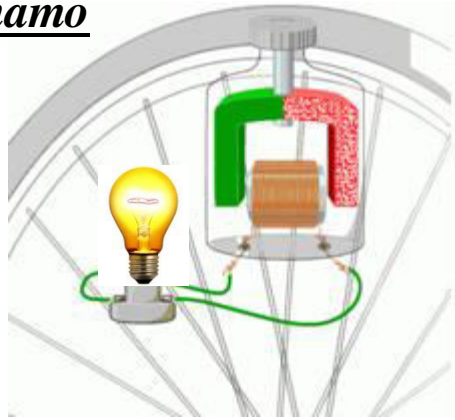
Induction:

Time-dependent modification of magnetic field through the loop surface generates a **voltage**

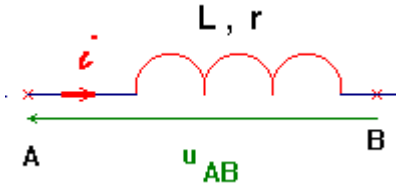


Examples or applications

Dynamo



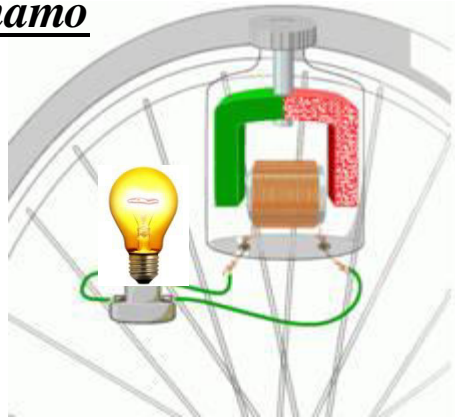
1832: Self-induction (Henry):
induction created by the magnetic field created by the current it self



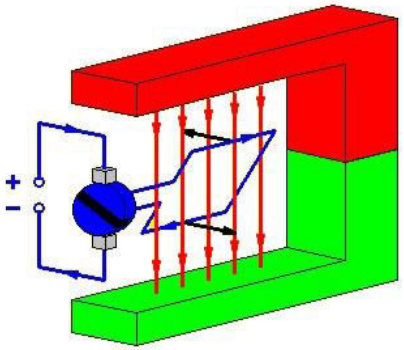
$$U = L\frac{di}{dt}$$

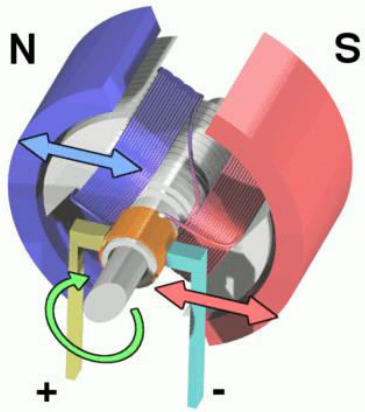
Examples or applications

Dynamo



Continous current motor





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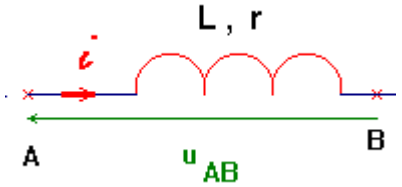
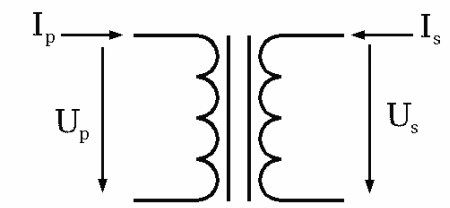
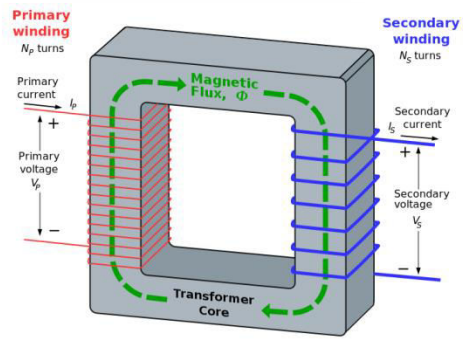


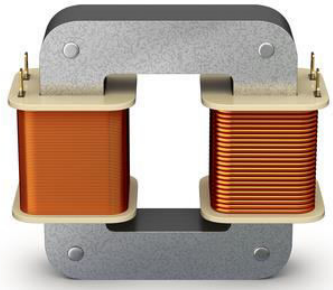
$$U = L\frac{di}{dt}$$

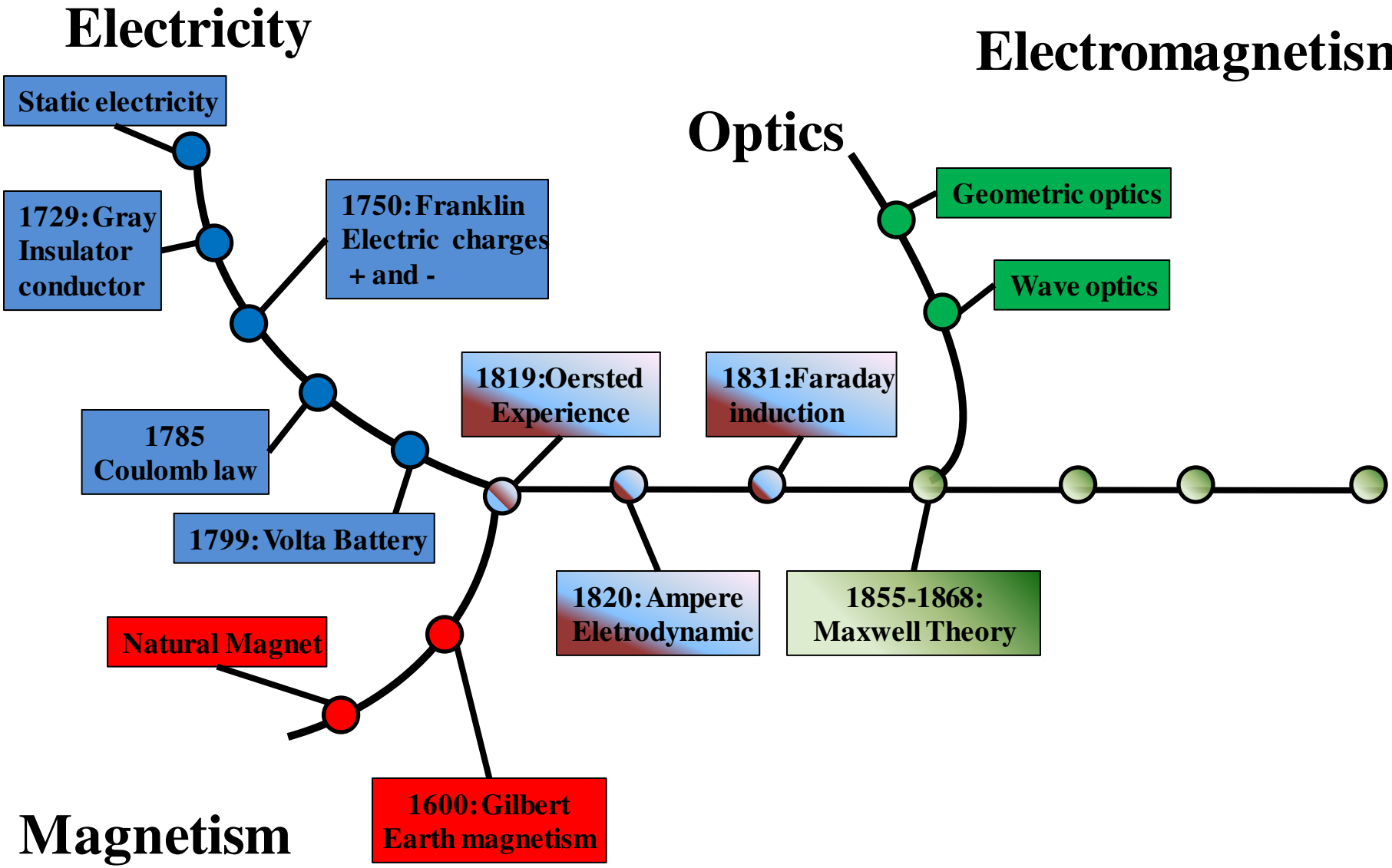
Transformator: modifying voltage



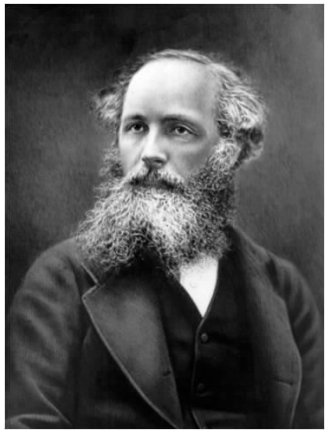
$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$






Electricity
Electromagnetism
Static electricity
Optics
1729: Gray
Insulator
conductor
1750: Franklin
Electric charges
+ and -
Geometric optics
Wave optics
1819:Oersted
Experience
1831:Faraday
induction
1785
Coulomb law
1799: Volta Battery
1820: Ampere
Eletrodynamic
1855-1868:
Maxwell Theory
Natural Magnet
1600: Gilbert
Earth magnetism
Magnetism

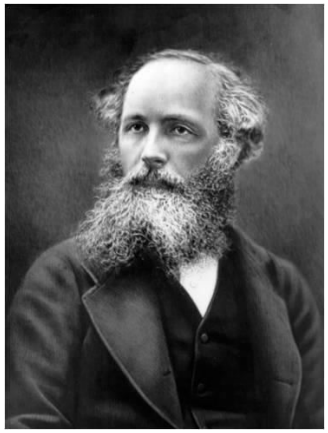
The synthesis: 1855-1864



James C. Maxwell
1831-1879

- Mathemathical description (vectorial theory) that explains all the electromagnetic phenomena.
- Dynamic theory that makes the relations between **the fields** (**electric and magnetic fields**) and **the sources** (**charges and currents**)
- Electric and magnetic fields are **waves propagating at the speed of the light c** (connexion with optics).

The synthesis: 1855-1864



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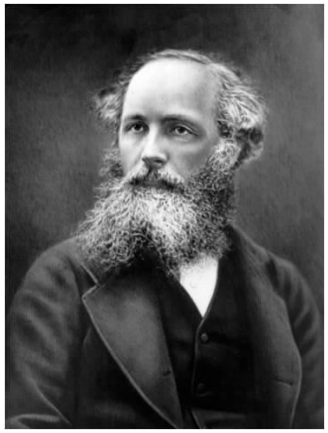
This theory is known today as Maxwell's equations

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \wedge \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \vec{\nabla} \wedge \vec{B} = \mu_0 \vec{j} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

The synthesis: 1855-1864



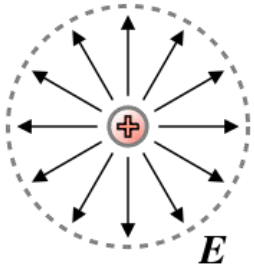
James C. Maxwell
1831-1879

Will be seen in two years during Electromagnetic lectures

Each equation traduces a vectorial situation

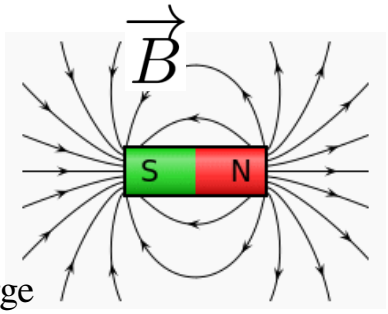
$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

Maxwell-Poisson
Coulomb Law



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

Maxwell-Gauss
NO magnetic charge



Maxwell-Faraday
Induction phenomena

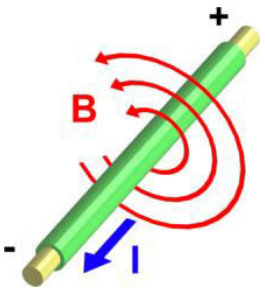
$$\vec{\nabla} \wedge \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$\Delta B(t)$

$$E = -\Delta V$$

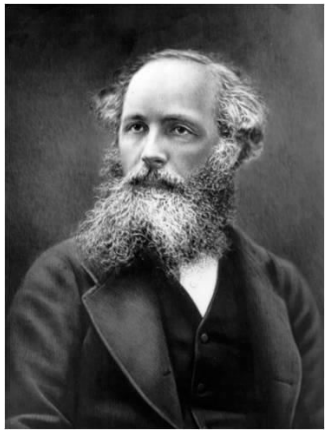
Maxwell-Ampere
Biot-Savart law

$$\vec{\nabla} \wedge \vec{B} = \mu_0 \vec{j} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$



Not seen yet

The synthesis: 1855-1864



James C. Maxwell
1831-1879

Connection with Optics ?
Light is known to be a wave.

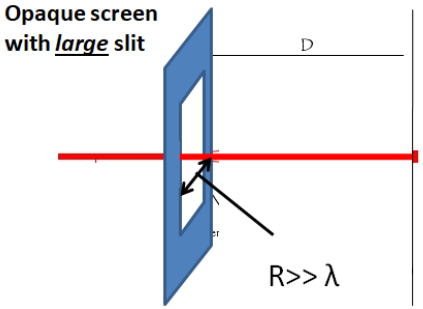
Maxwell predicted that Electric and Magnetic field are waves propagating at the speed of the light c !

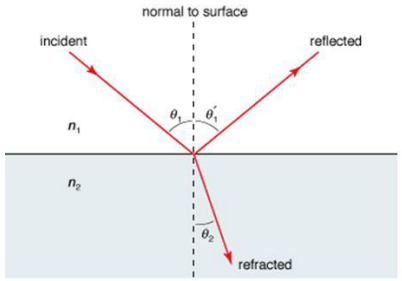
$$\vec{\nabla} \wedge \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \vec{\nabla} \wedge \vec{B} = \mu_0 \vec{j} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

From Maxwell equations one can obtain a 3D wave equation
Propagation of E-M waves (in the vaccum)

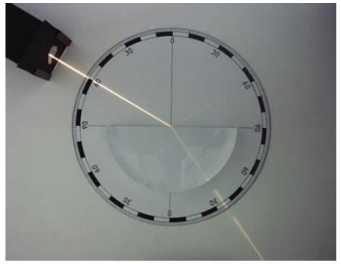
$$\Delta \vec{E} - \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = 0 \qquad c^2 = \frac{1}{\epsilon_0 \mu_0}$$

Optics: geometric optics and wave optics



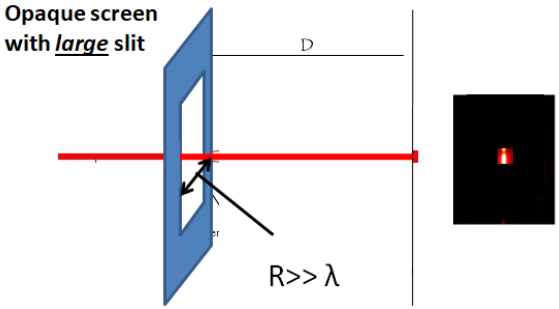


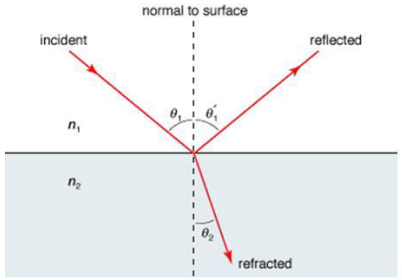
Here $n_1<n_2$!!



$n_1 \sin\theta 1 = n_2 \sin\theta 2$

Optics: geometric optics and wave optics





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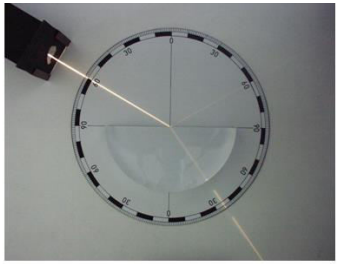

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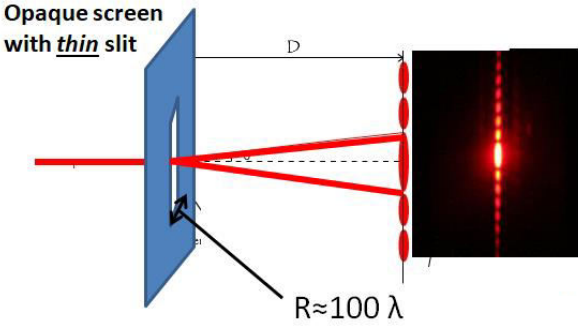
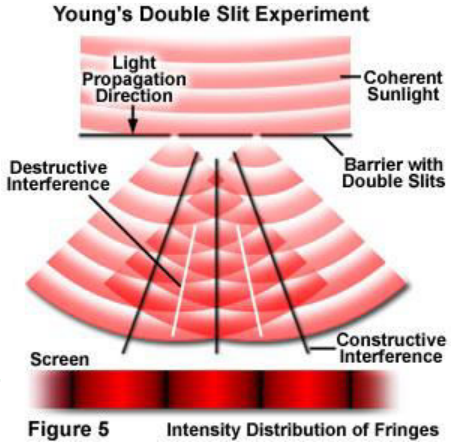
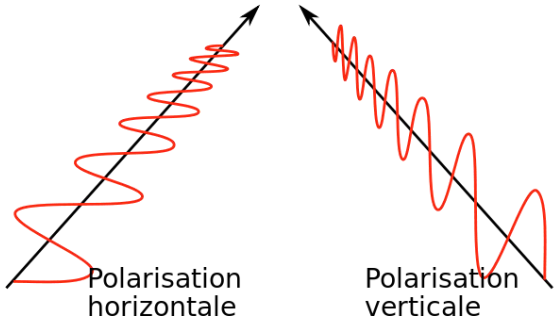
DIFFRACTION !!!!!



Interferences

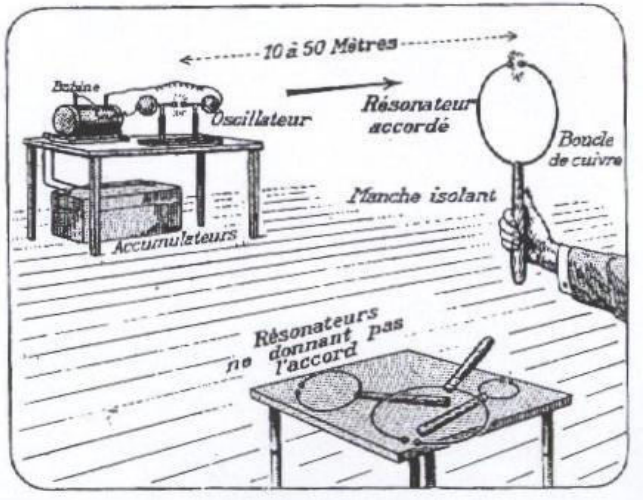


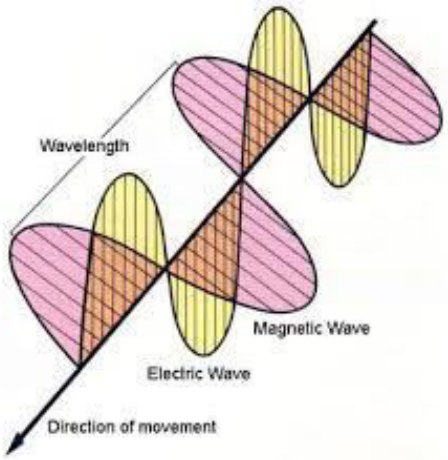
Polarisation



Further key-events

1887: Experimental Proof of Maxwell Theory by Heinrich Rudolf Hertz. Emission and reception of electromagnetic waves !





Heinrich. R Hertz
1857-1894

Further key-events

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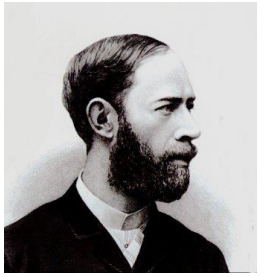

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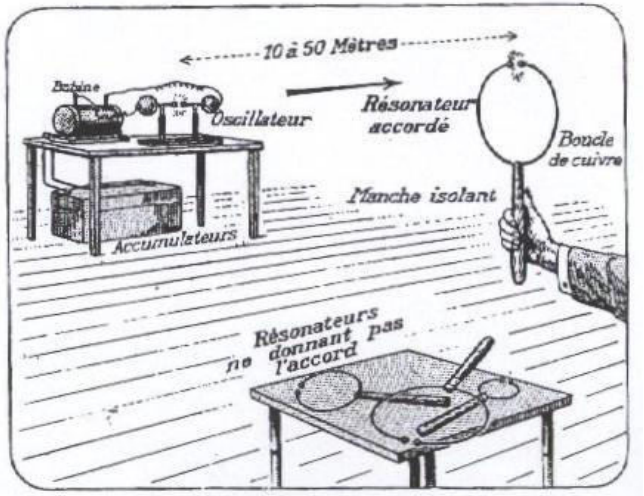
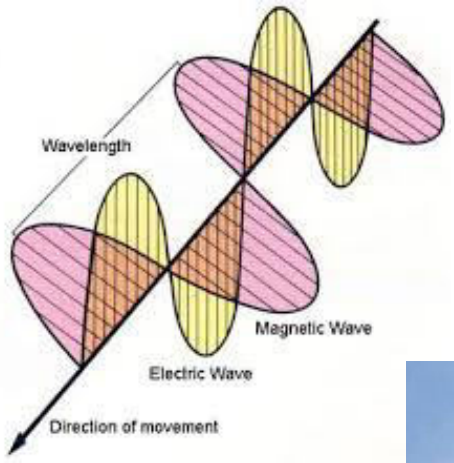
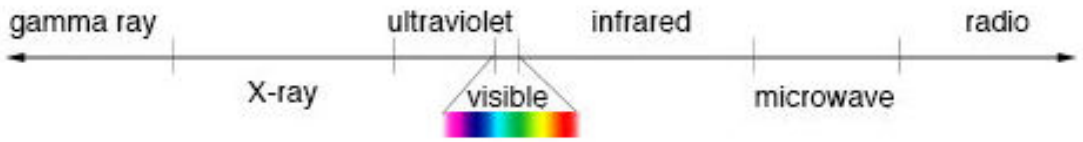
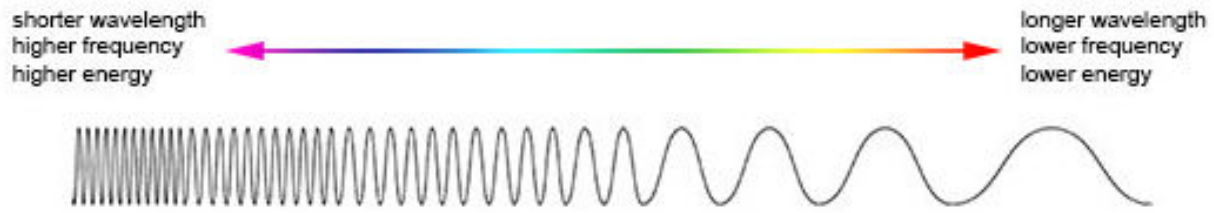


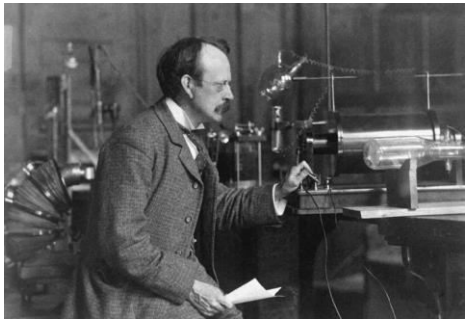




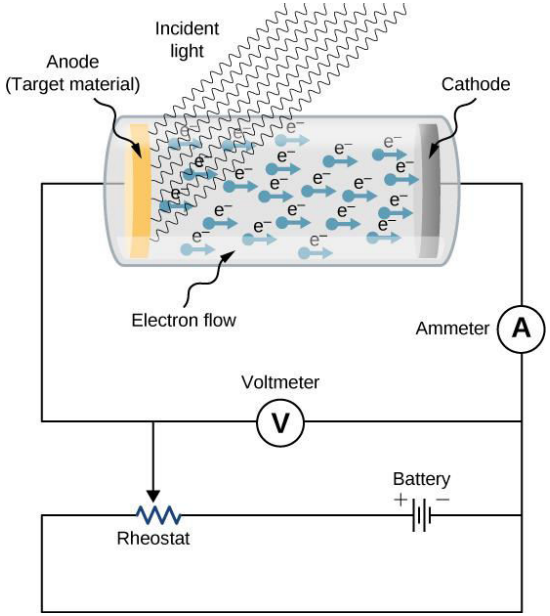


Further key-events

1897: Discovery of the electron by Thompson (1856-1940)



1905: Albert Einstein explains photoelectric effect (discovered by Hertz).
Light is **also a particule**: photon of energy E=hν where is the frequency of the light.



$E=h\nu$

Further key-events

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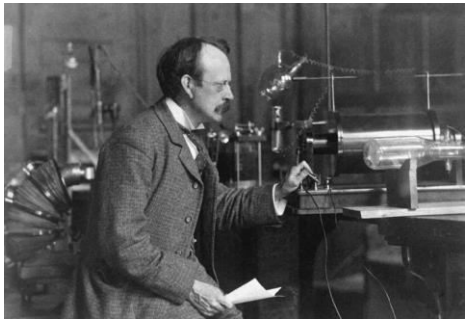

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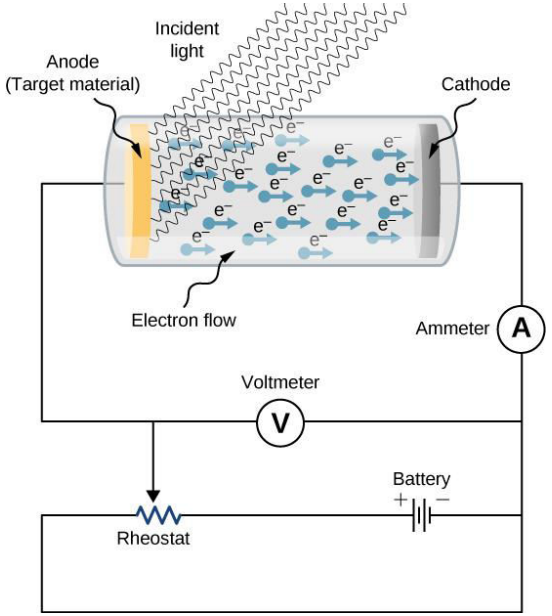
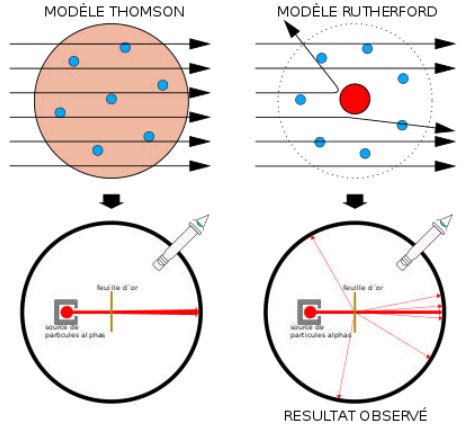
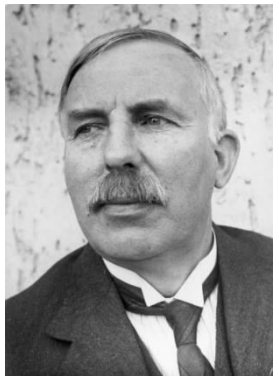
Light is **also a particule**: photon of energy E=hν where is the frequency of the light.

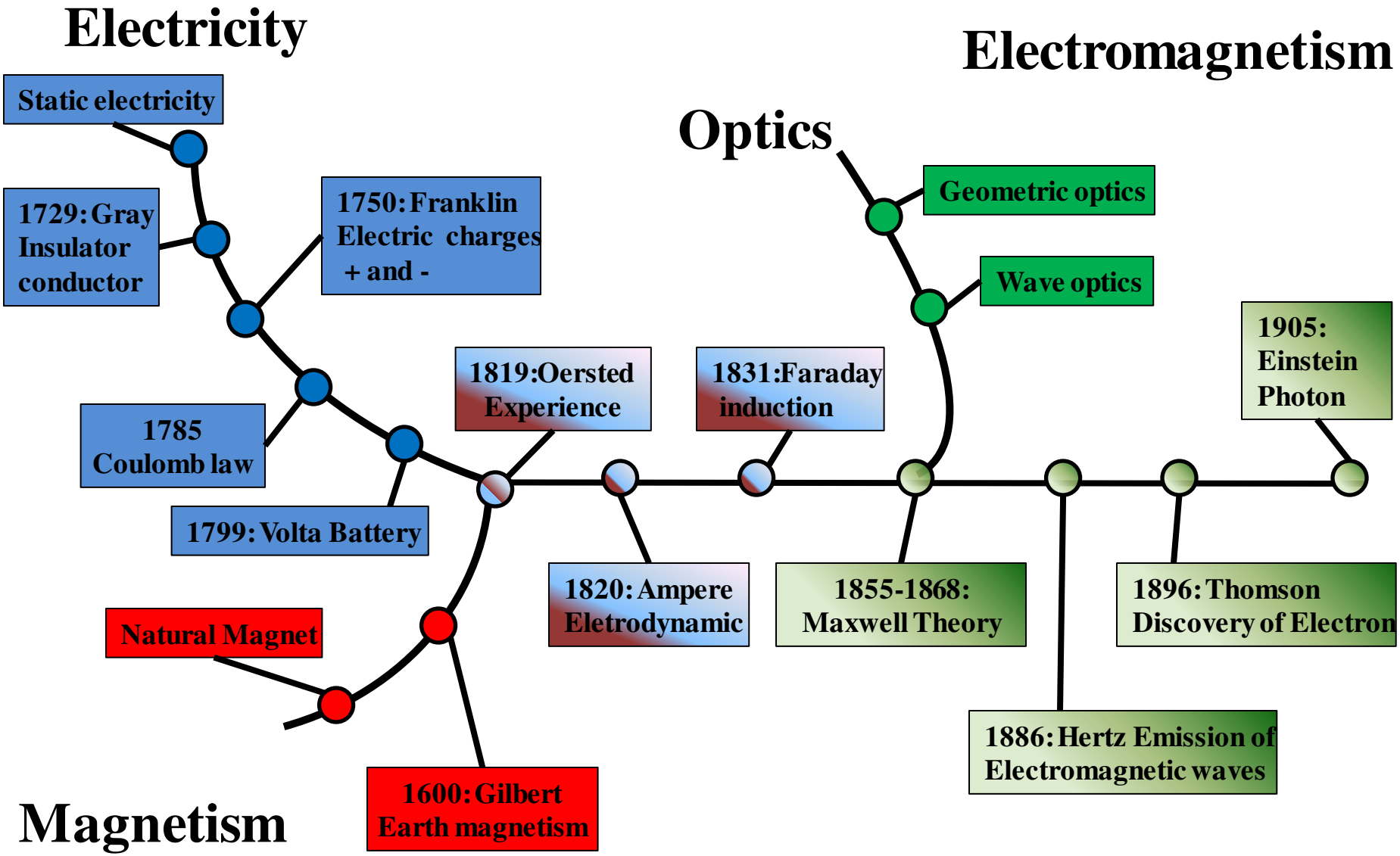


$$E=h\nu$$

1911: Discovery of the nucleus by Ernest Rutherford






Electricity
Electromagnetism
Optics
Magnetism
Static electricity
1729: Gray Insulator conductor
1750: Franklin Electric charges + and -
1785 Coulomb law
1799: Volta Battery
1819:Oersted Experience
1820: Ampere Eletrodynamic
1831:Faraday induction
1855-1868: Maxwell Theory
1886: Hertz Emission of Electromagnetic waves
1896: Thomson Discovery of Electron
1905: Einstein Photon
Geometric optics
Wave optics
Natural Magnet
1600: Gilbert Earth magnetism