Module 7

Shaping electromagnetism

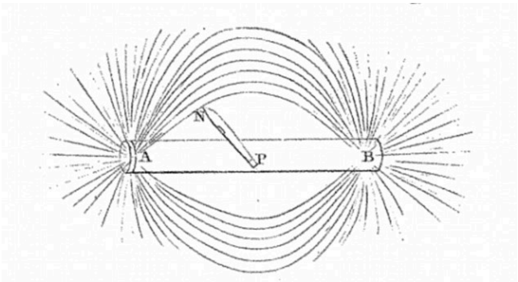
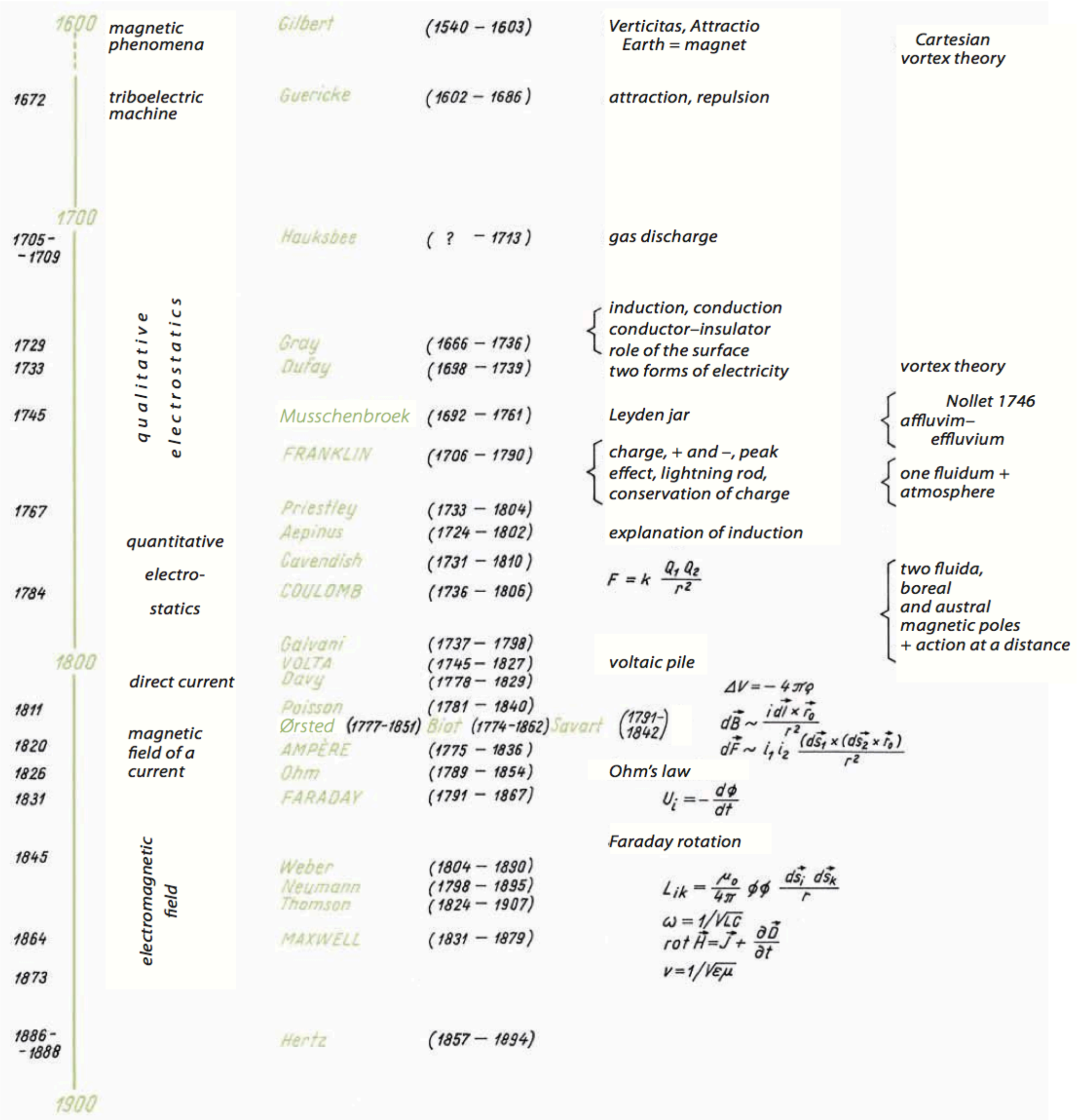
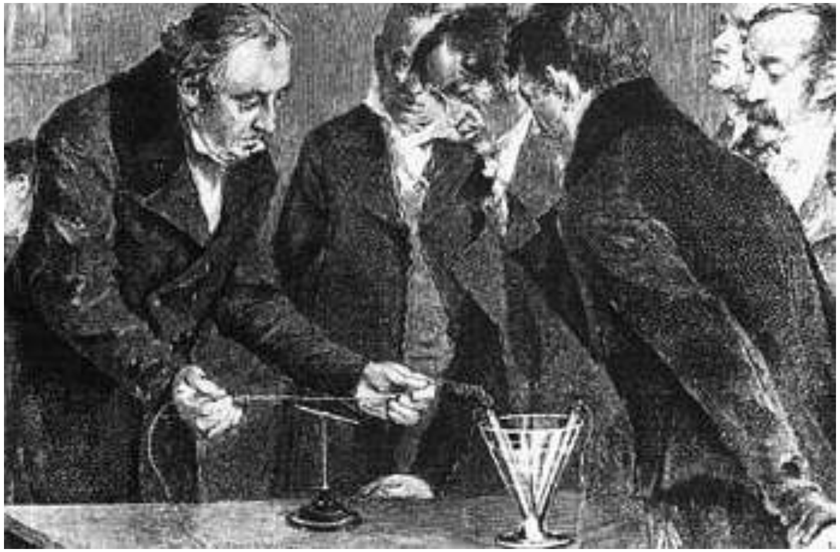


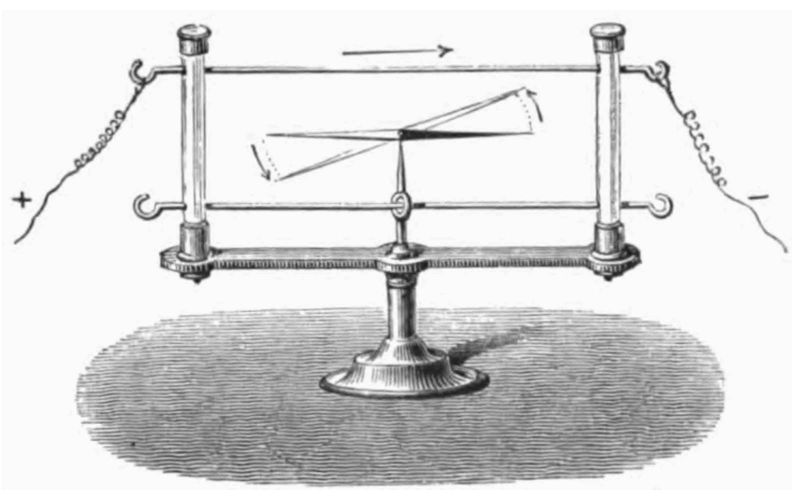
Fig. 25.

300 years of history



Ørsted experiment (1820)

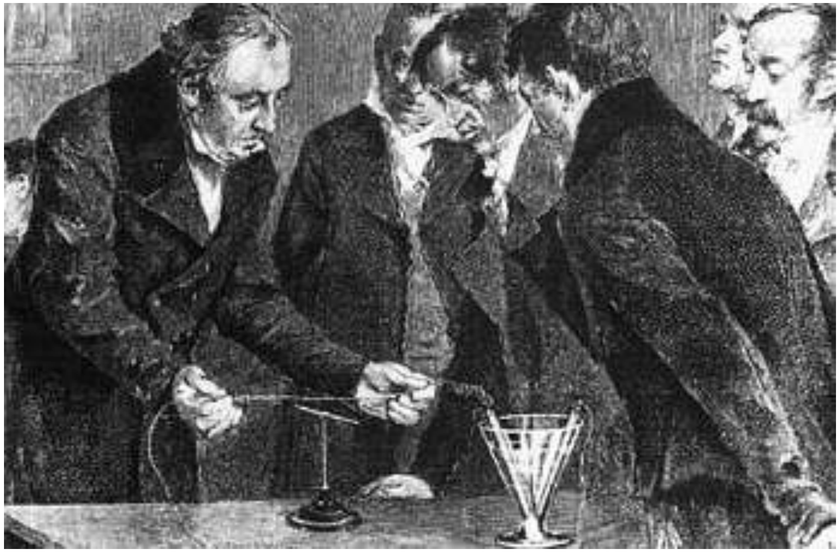


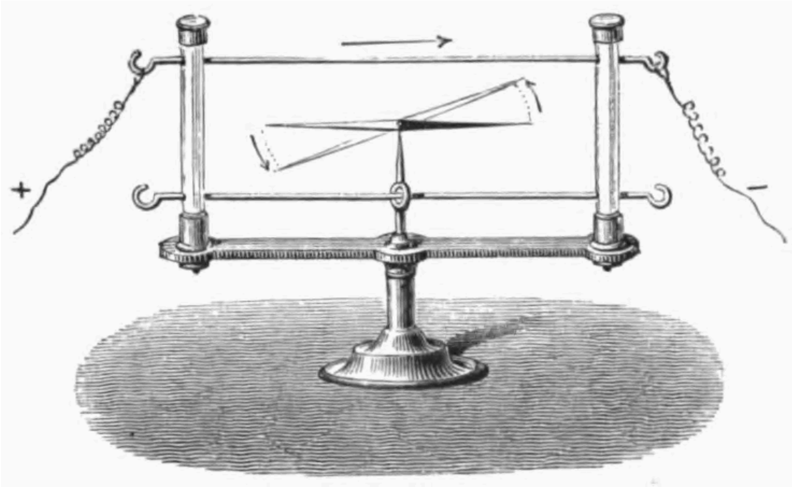


Some observations

- The declination of the needle makes an angle of about 45°; $> d\ < \theta$ and $> I\ > \theta$
- If needle above the wire, *opposite direction*
- The effect *cannot be ascribed to attraction*
- Nature of metal does not alter the effect
- The effect passes through glass, metals, wood, water, resin, etc (inc. all together)*; such transmission was never observed*
- When needle and wire in the same horizontal plane, *inclination* takes place
- When wire *perpendicular* to magnetic meridian, *needle at rest*
- Brass, glass gum lac needles: no effect

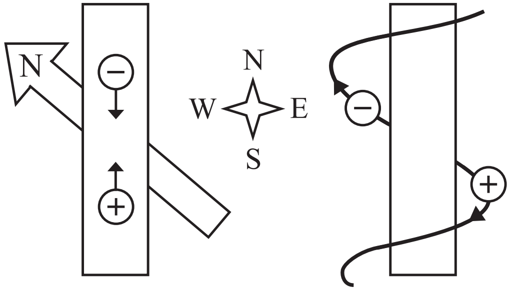
Ørsted experiment (1820)





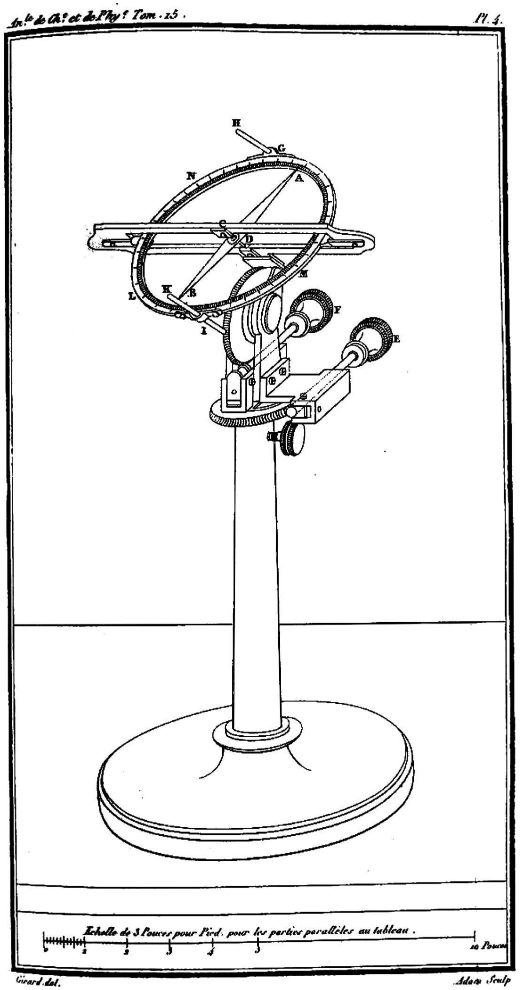
Some explanations

The electric conflict
- acts on magnetic poles
- is not confined within the conductor
- performs circles around the wire
  (nature of circle: motions in opposite parts have opposite directions)



negative electricity moves in a spiral line bent towards the right, and propels the north pole

Ampère's important modification



astatic needle

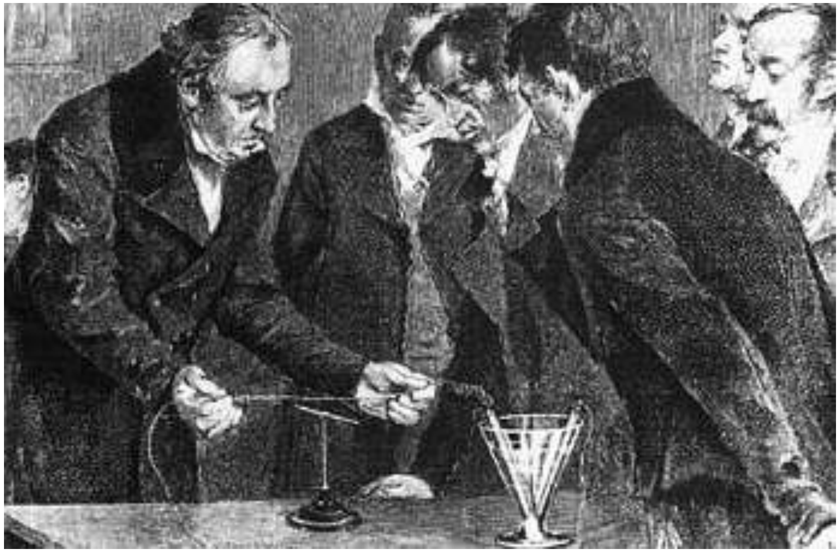
By placing the [rotation] axis of the astatic needle parallel to the resultants of the actions of the [terrestrial] globe, the needle will only be able to move in the plane perpendicular to these resultants. In this way the *action of the globe will be destroyed* and the needle will remain indifferent in all its orientations.

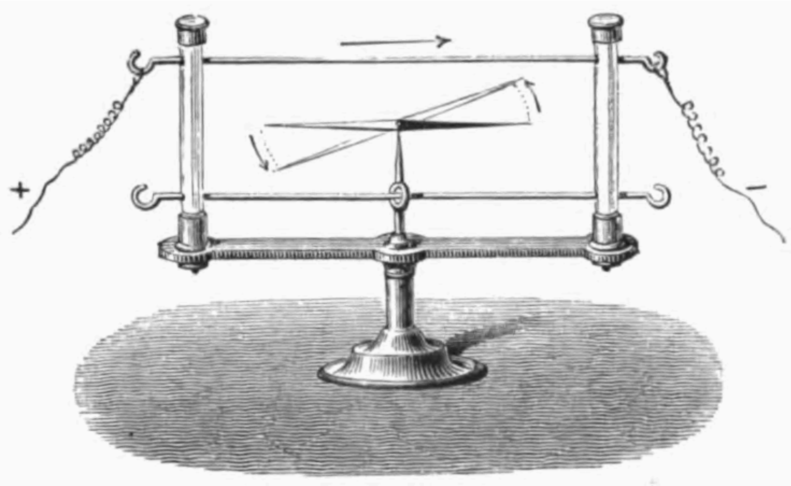
When a galvanic current is close [to an astatic needle], its directive action will be the only one affecting the needle, and *experiment shows that the needle always becomes exactly perpendicular to the direction of the current*.

Other important contributions

- Closed circuit: Current inside the battery
- Magnetic needle: universal current detector (galvanometer)

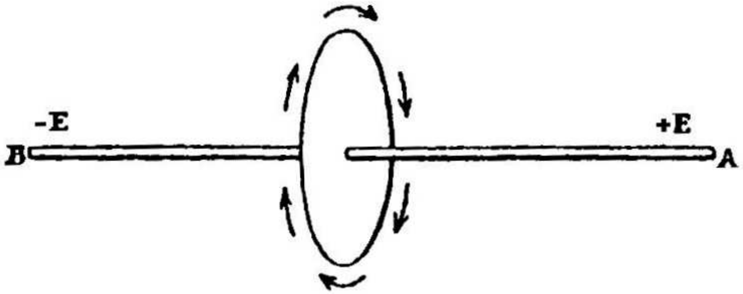
Ørsted (1821)





Some explanations

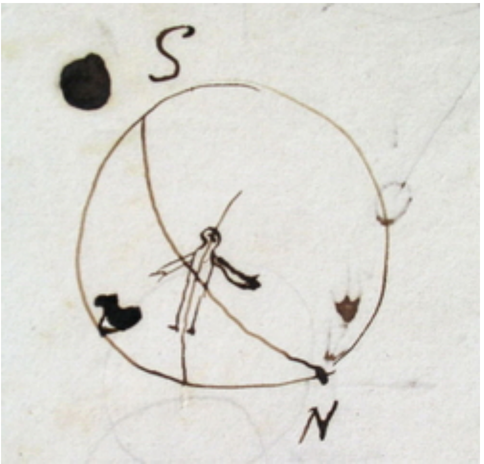
- the north pole of a magnetic needle is *repelled* by the negative electricity and *attracted* by the positive.



The little arrows show the direction of the austral magnetism.

Ampère's conception of magnetism

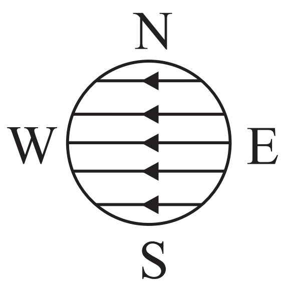
Since the order in which two facts are discovered in no way affects any conclusions which can be drawn from their analogies, we could suppose that before we knew about the South-North orientation of a magnetic needle, we already knew the needle's property of taking a perpendicular position to an electric current […] Then, for one who tries to explain the South-North orientation, would not it be the simplest idea **to assume an electric current in the Earth**?



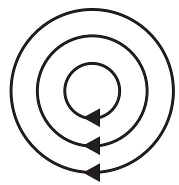
Ampère's observer

Ampère’s conception of magnetism

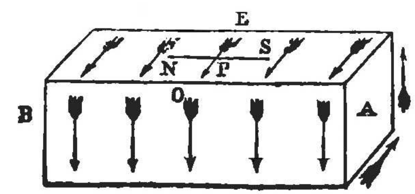
Basic principle: Magnetism is due to currents flowing



Earth’s Surface

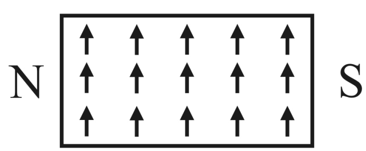


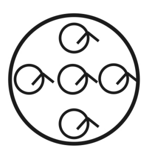
Earth’s Interior



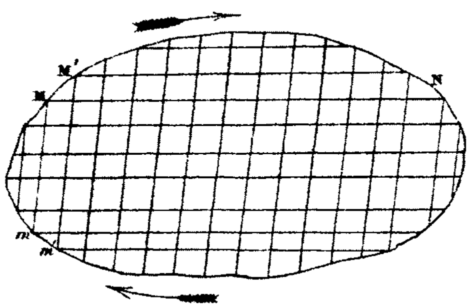
Objections: a) No Joule effect b) Cut the magnet, pieces are still magnets

Solution (suggested by Fresnel): Molecular currents





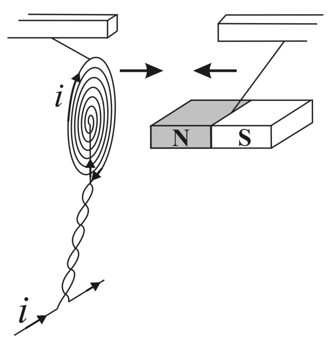
Cylindrical magnet

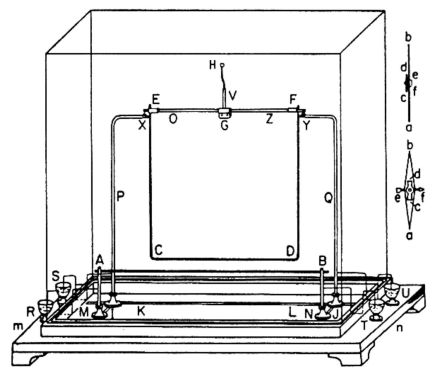


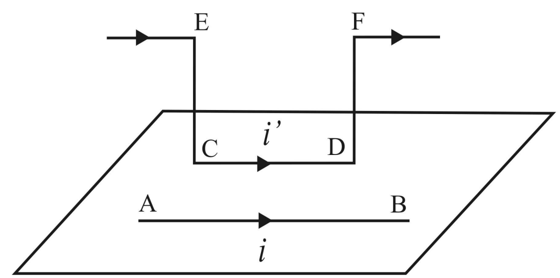
Details in Assis & Chaib (2015)

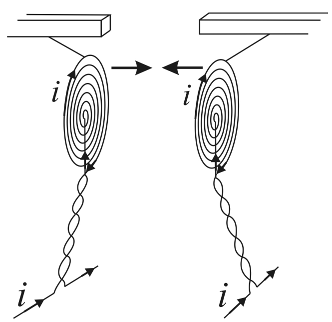
Ampère’s experiments

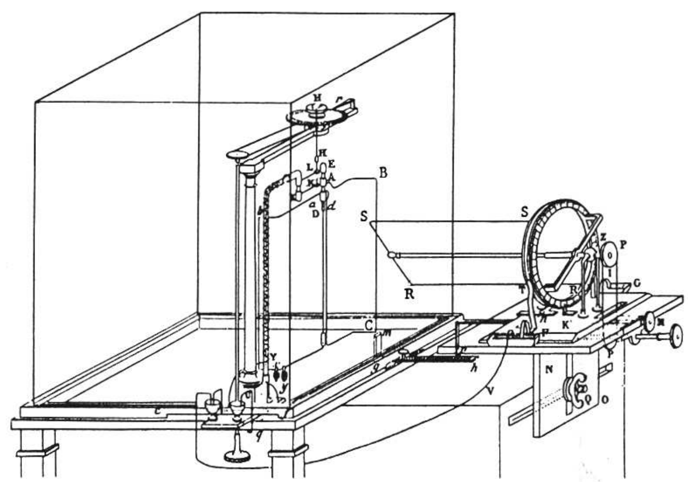
Basic principle: Interaction between currents

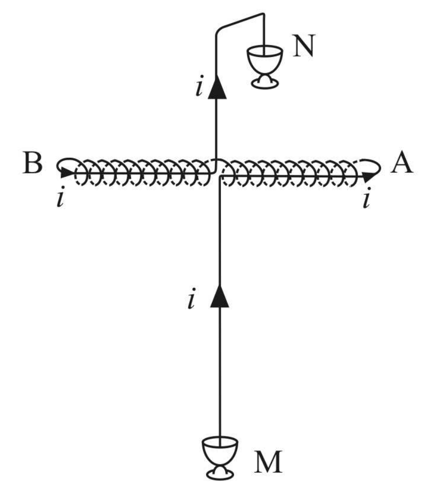






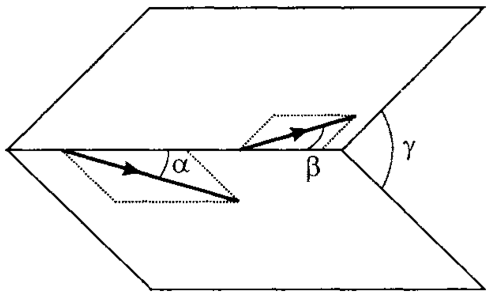




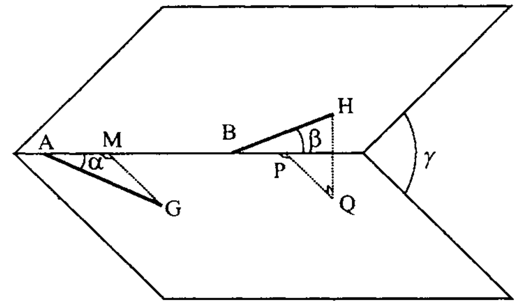


Details in Assis & Chaib (2015)

Ampère's Force between 2 current elements



$$F \propto \frac{\cos\gamma \sin\alpha \sin\beta}{r^2}$$

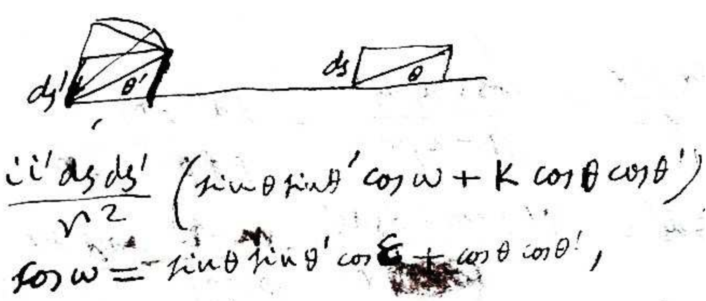


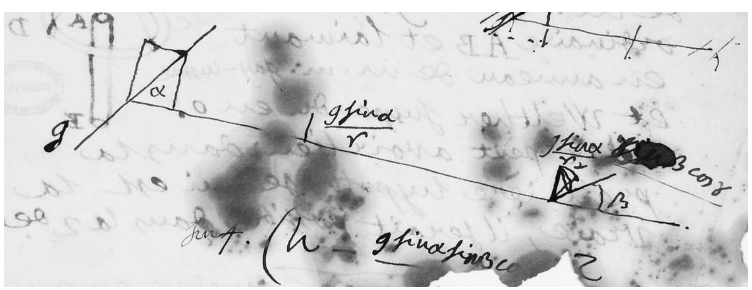
Force decomposition

$$\cos\gamma \sin\alpha \sin\beta + k \cos\alpha \cos\beta$$

- Analogy with gravitation $1/r^2$
- Experiments on rectilinear currents
- Need to retrieve properties of magnets

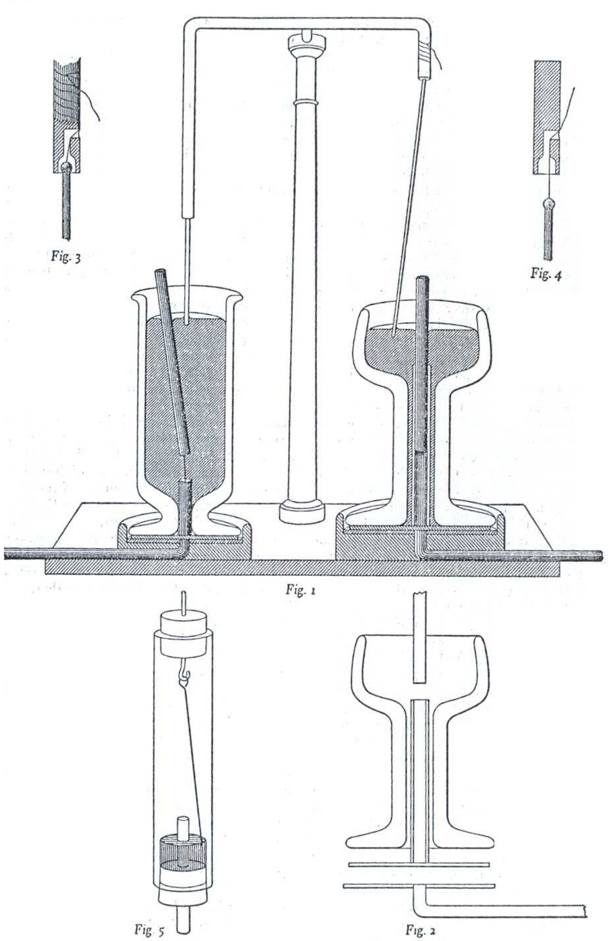
k = 0 "without inconvenience"



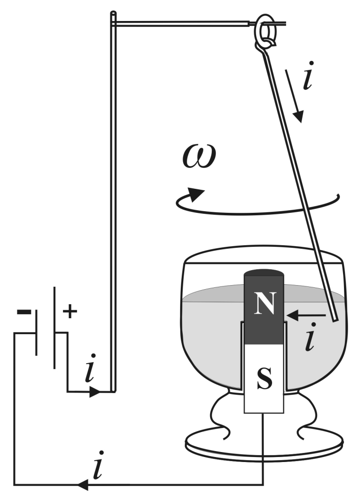


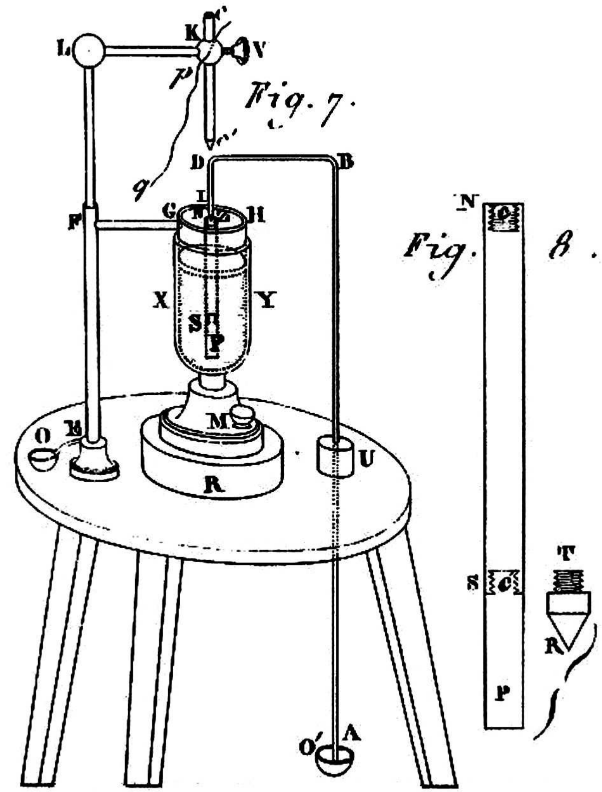
Details in Assis & Chaib (2015)
http://www.ifi.unicamp.br/~assis/Amperes-Electrodynamics.pdf

Faraday's rotations



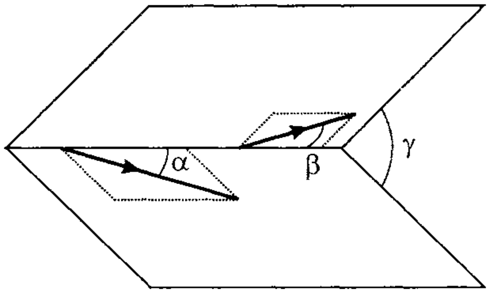
Faraday (1822)





Ampère (1822)
Rotation of a magnet
around its axis

Ampère's Force between 2 current elements

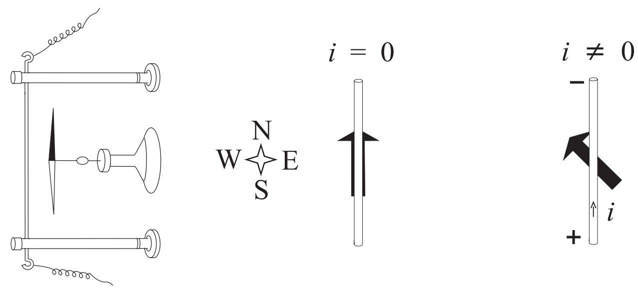


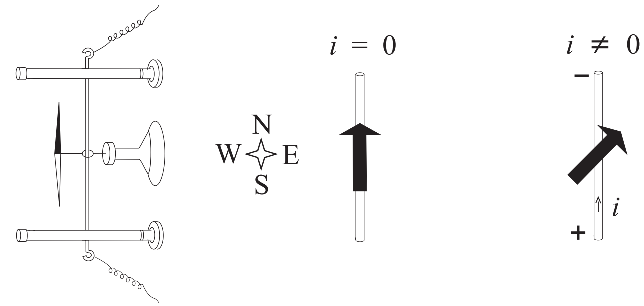
$$d^2 f = ii' \frac{ds ds'}{r^2} \left(\sin\alpha \sin\beta \cos\gamma - \frac{1}{2} \cos\alpha \cos\beta \right)$$

$$d^2 f = ii' \frac{ds ds'}{r^2} \left(r \frac{\partial^2 r}{\partial s \partial s'} - \frac{1}{2} \frac{\partial r}{\partial s} \frac{\partial r}{\partial s'} \right)$$

Details in Assis & Chaib (2015)

Interpreting Ørsted experiment

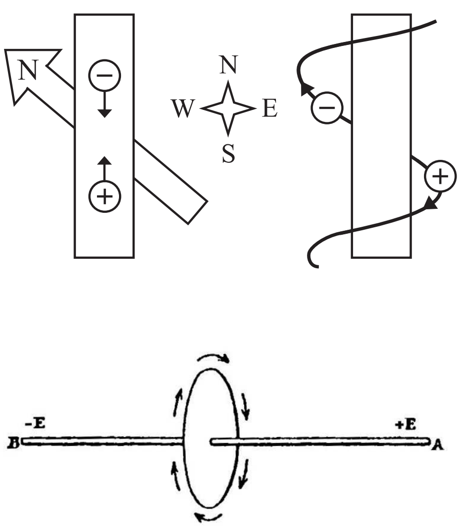


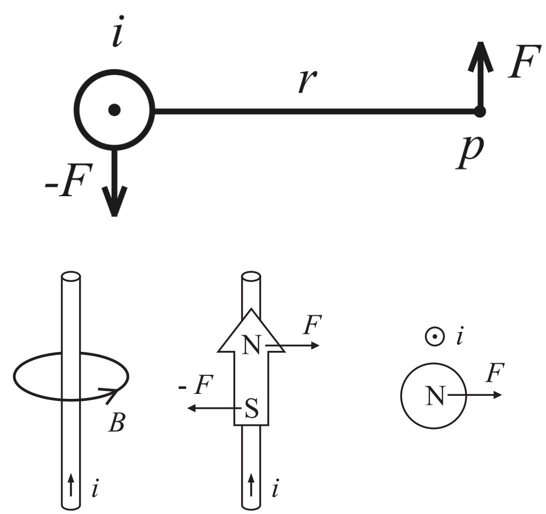


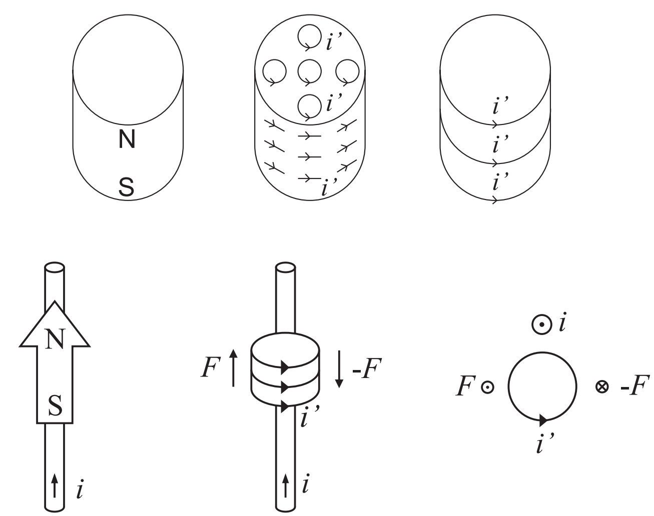
Ørsted

Faraday

Ampère







Details in Assis & Chaib (2015)

Ørsted  vs. Ampère 

- Magnetism is due to a distribution of magnetic particles inside a magnet or the Earth
- Ampère's theory is based on complicated mathematics
- There is no a direct interaction between two current-carrying wires, without the intermediation of a flux of charges circulating around the wire

- There are no magnetic poles;
- There is no vortex of electric charges around a current-carrying wire;
- There cannot be interaction between distinct magnitudes (magnetic pole with an electric charge);
- Ørsted gives no explanation for the interaction between two current-carrying wires

Details in Assis & Chaib (2015)

Faraday  vs. Ampère 

- I am skeptical about the idea that an electric current is due to the motion of electric charges;
- Magnetic properties are not due to electric currents flowing in the Earth or in magnets;
- The simplest cases are circular motions of a magnetic pole around a current carrying wire and vice-versa. One should explain interactions between current-carrying wires on this basis;

- There are no real magnetic poles;
- We should always fight against rotational actions (central force);
- There cannot be interaction between distinct magnitudes (magnetic pole with an electric charge);
- I showed the rotation of a magnet around its own axis of symmetry (something you thought was not possible);
- And your own explanation to this phenomenon violates Newton's 3rd law

Details in Assis & Chaib (2015)

Appraisal: Ampère is the "Newton of Electricity"

Of these different assumptions that of Ampère is undoubtedly the best, since it is the only one which makes the forces on the two elements not only equal and opposite but in the straight line which joins them.

[…]

The experimental investigation by which Ampère established the law of the mechanical action between electric currents is one of the most brilliant achievements in science. The whole, theory and experiment, seems as if it had leaped, full grown and full armed, from the brain of the "Newton of Electricity". It is perfect in form, and unassailable in accuracy, and it is summed up in a formula from which all the phenomena may be deduced, and which must always remain the cardinal formula of electro-dynamics. (Maxwell, 1873)

Questions for discussion (Ørsted)

- Why isn't there a single diagram of the setup? Is this normal or is Ørsted being unprofessional?

- What does he mean by "vexelkamp" (electric conflict)? And has this "vexelkamp" anything to do with the later notion that Maxwell had of the two interacting fields that can generate disturbances in each other?

- Are there any historical accounts of electromagnetics effects of this kind or was Ørsted's experiment truly the first?

Questions for discussion (Ørsted)

- Ørsted only mentions the strength of the field and the connection to the radius as ”men forøges frastanden, så formindskes afvigelsesvinklen i samme forhold, som afstandende vokse”. When is this transformed into an actual $1/r^2$ relationship?

- Did Ørsted’s experiments actually help in getting to know more about the polarization of light or was this first later?

Questions for discussion (Ampère)

- What does he mean by “electrodynamical action” and how does he define it? Does he mean some kind of inertial motion?

- Is he motivated by theory or experiment in this derivation?

- What is his notion of the “voltaic current” does he imagine it as a flow of charges or it as a flow of something else?

- What is known today as Ampère’s law? How faithful it is to Ampère’s work?

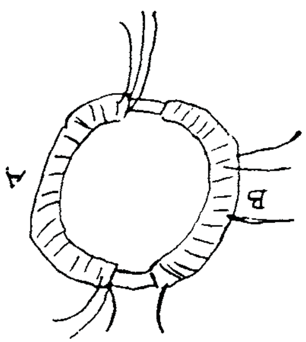
Faraday’s discovery of induction

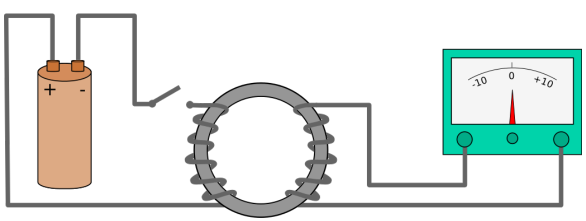
Faraday‘s diary (1822)

Convert magnetism into electricity

29.8.1831

Induction ring





3. [...] Then connected the ends of one of the pieces on A side with battery; immediately a sensible effect on needle. It oscillated and settled at last in original position. On *breaking* connection of A side with Battery again a disturbance of the needle.

4. Made all the wires on A side one coil and sent current from battery through the whole. Effect on needle much stronger than before.

5. The effect on the needle then but a very small part of that which the wire communicating directly with the battery could produce.

8. Hence effect evident but transient; but its recurrence on breaking the connection shows an equilibrium somewhere that must be capable of being rendered more distinct (electro-tonic state).

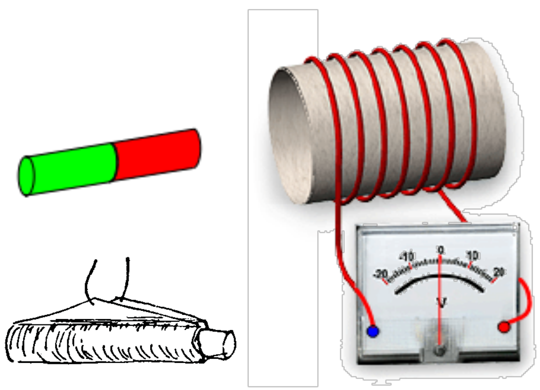
Faraday’s discovery of induction

Faraday‘s diary (1822)

Convert magnetism into electricity

17.10.1831

Moving a magnet through a coil



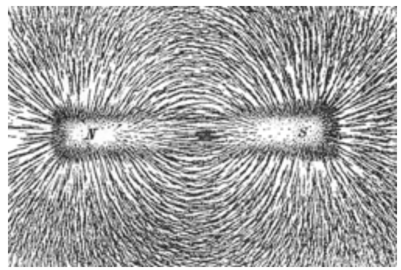
57. The 8 ends of the helices at one end of the cylinder were cleaned and fastened together as a bundle. These compound ends were then connected with the Galvanometer by long copper wires then a cylindrical bar magnet 3/4 inch in diameter and 81⁄2 inches in length had one end just inserted into the end of the helix cylinder—then it was quickly thrust in the whole length and the galvanometer needle moved—then pulled out and again the needle moved but in the opposite direction. This effect was repeated every time the magnet was put in or out and therefore a wave of Electricity was so produced from mere approximation of a magnet and not from its formation *in situ*.

Magnetic lines of force

IMAGInation: Continuous curved patterns

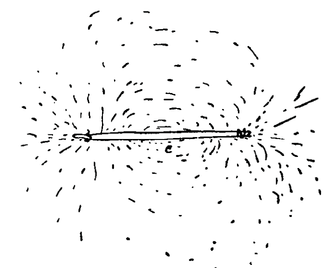
- Place a bar magnet beneath a sheet of paper

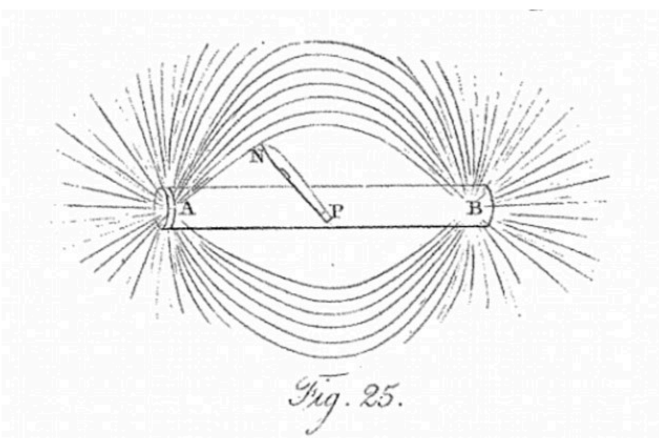
- Spread iron fillings



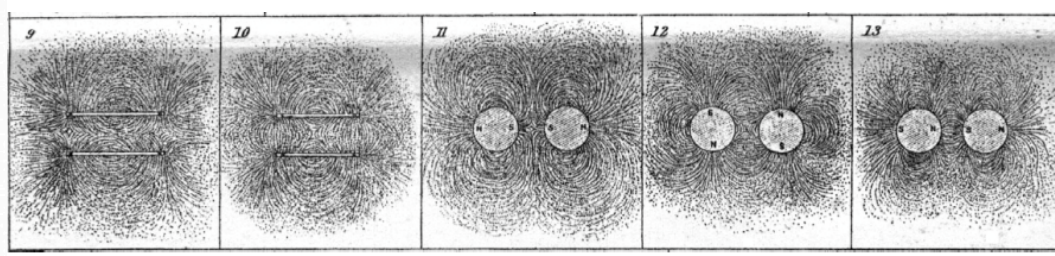
- Continuous curves from pole to pole

Diary (1851)





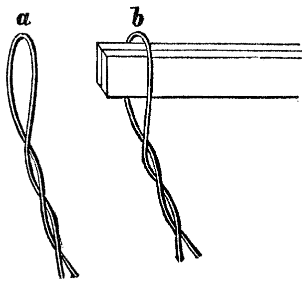
1st series (1831)



29th series (1852)

Magnetic lines of force

Moving wire
28th series (1852)

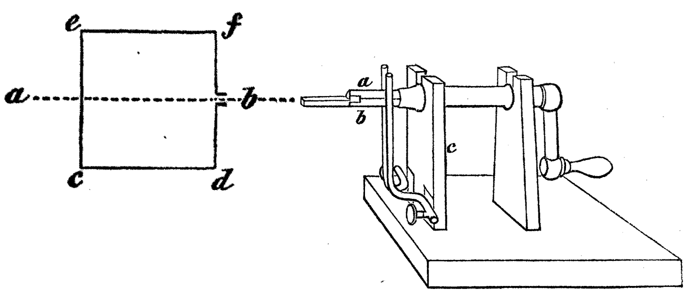


When the bend of the wires was formed into a loop and carried from *a* to *b*, the galvanometer needle was deflected two degrees or more. The vibration of the needle was slow, and it was easy to reiterate this action five or six times, breaking and making contact with the galvanometer at right intervals, so as to combine the effect of induced currents; and then a deflection of 10° or 15° could be readily obtained.

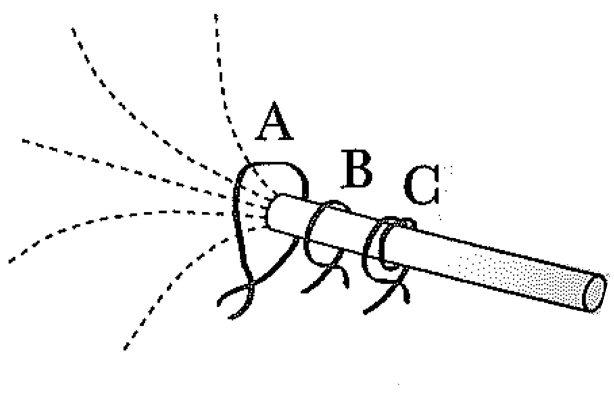
- Deflection is proportional to number of times, i.e. “number of lines of force that cut the loop” (Counting principle)
- The “moving wire” undergoes a profound transformation: from a *phenomenon* to a [reasoning?] *instrument* to interpret other phenomena (Fisher, 2001)

Magnetic lines of force

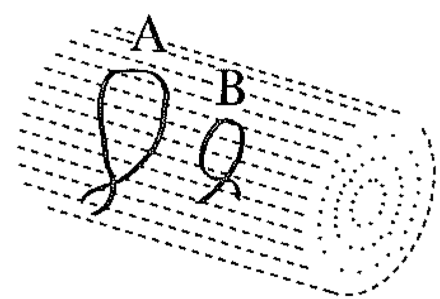
Revolving rectangles
29^{th} series (1852)



3195. When a given length of wire is to be disposed of in the form best suited to produce the maximum effect, then the circumstances to be considered are contrary for the case of a loop to be employed with a small magnet (39. 3184.), and a rectangle or other formed loop to be employed with the lines of terrestrial force. In the case of the small magnet, *all* the lines of force belonging to it are inclosed by the loop; and if the wire is so long that it can be formed into a loop of two or more convolutions, and yet pass over the pole, then twice or many times the electricity will be evolved that a single loop can produce (36.). In the case of the earth's force, the contrary result is true; for as in circles, squares, similar rectangles, &c. the areas inclosed are as the squares of the periphery, and the lines of force intersected are as the areas, it is much better to arrange a given wire in one simple circuit than in two or more convolutions. Twelve feet of wire in one square inter-



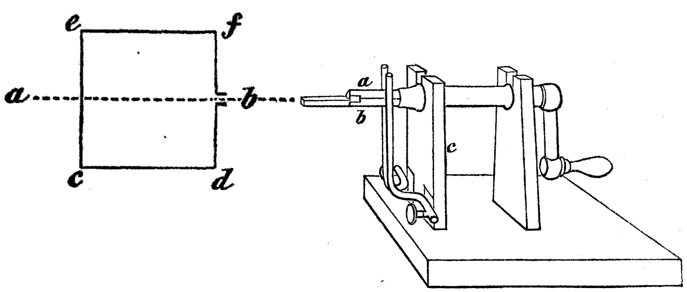
Loop in a small magnet



Loop in “lines of terrestrial force”

Magnetic lines of force

Revolving rectangles
29th series (1852)



Now 144 square inches is to 128 square inches as 2,61° is to 2,32° proving that the electric current induced is directly as the lines of magnetic force intersected by the moving wire [...] no alterations are caused by changing the velocity of motion, provided the amount of lines of force intersected remains the same. [...] "thrice as advantageous to intersect the lines within nine square feet once, as to intersect those of one square foot three times"

On the physical character of the lines of magnetic force (Faraday, 1852, Philosophical Magazine)

Reading for Module 8

- On Faraday's Lines of Force (Maxwell 1855)
- On Physical Lines of Force (Maxwell 1862)
- A Treatise on Electricity and Magnetism (Maxwell 1873)

Questions for discussion (Faraday)

- Why does Faraday assume that he is looking to an equilibrium somewhere as the needle turns the other way when breaking the connection?

- How was his new concept of curved “lines of force” received in the community at the time?

- What did his Galvanometer look like and how was it build? Did the needle of the galvanometer swing freely like a pendulum or did it swing and stayed at the maximum value?

- What is known today as Faraday’s law? How faithful it is to Faraday´s work?

End of module feedback

- Please go to b.socrative.com (student login)
- Enter the HISPHYSKU room
- Fill out the short (anonymous) survey
- Tak skal du have!