Motional emf & Induced emf

(Electric flux, and motional emf)

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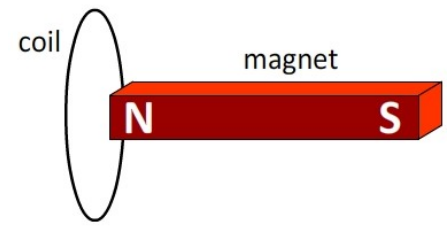
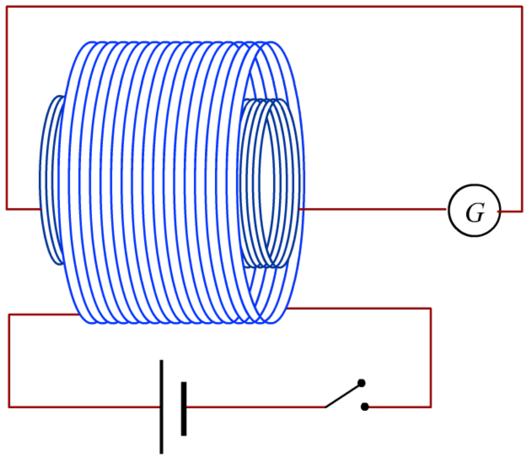
Experiments of Faraday and Henry

Faraday demonstrated that an electric current could be induced in a coil of wire by changing the magnetic field around it. In his experiment, moving a magnet towards or away from a coil caused a deflection in a galvanometer connected to the coil, showing the presence of induced current. This established the principle that a changing magnetic flux induces an electromotive force (emf) in a conductor.



Joseph Henry independently discovered electromagnetic induction by demonstrating that a current in one coil could induce a current in a nearby coil. His work also led to the discovery of self-induction, where a changing current in a coil induces emf in the same coil, and mutual induction, where one coil induces emf in another.



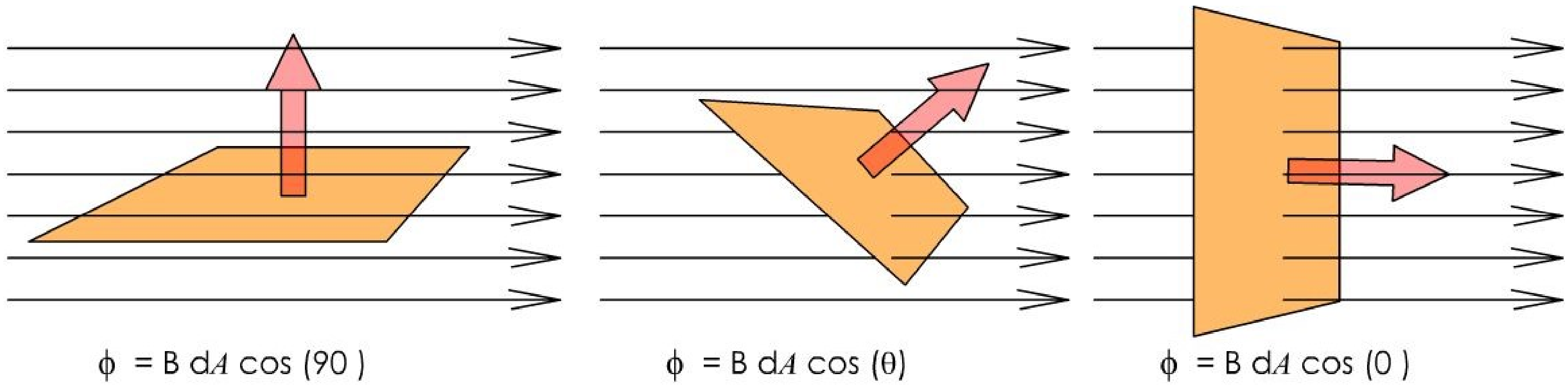
The unit of inductance, the henry (H), is named after him, reflecting his contributions.
Experiments of Faraday and Henry demonstrated that phenomena of electricity and magnetism are related to each other.

Magnetic flux

Magnetic flux associated with an area is defined as the dot product of area and the magnetic field in that region.

$$\phi = \bar{B} \bullet \mathrm{d}\bar{A}$$

SI unit : weber (Wb)



Total magnetic flux associated with a surface is the sum of individual magnetic fluxes

$$\phi_{\text{total}} = \phi_1 + \phi_2 + \phi_3 + \ldots$$

Faraday's law of electromagnetic induction

The magnitude of induced emf in a coil is equal to the time rate change of magnetic flux through the coil.

$$\boxed{\mathcal{E} = -\frac{\mathrm{d}\phi}{\mathrm{d}t}}$$

In case of N turns in a coil

$$\boxed{\mathcal{E} = -N\frac{\mathrm{d}\phi}{\mathrm{d}t}}$$

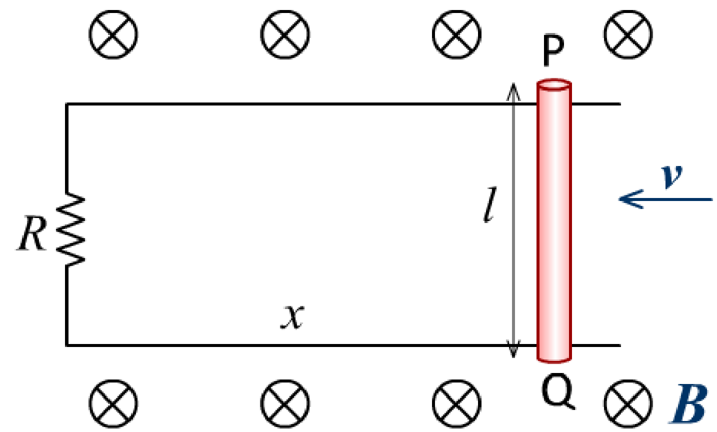
Negative sign is due to Lenz law.

Lenz law : Polarity of induced emf is such that it tends to produce a current which *opposes* the change in magnetic flux producing it.

It is based on the law of conservation of energy.

Induced (motional) emf

Consider a rod PQ of length l placed on U shaped frame. The rod is made to move uniform velocity v in a region of uniform magnetic field of induction B. Let the resistance of the system be R.



Magnetic flux associated with the area enclosed is

$$\phi = B\,l\,x$$

Change in magnetic flux due to movement of the rod is

$$\frac{\mathrm{d}\phi}{\mathrm{d}t} = B\,l\,\frac{\mathrm{d}x}{\mathrm{d}t}$$

$$\boxed{\mathcal{E} = B\,l\,v}$$

Induced emf exists only as long as there motion of the conductor

Induced current

Motional emf induced across the ends of the rod is

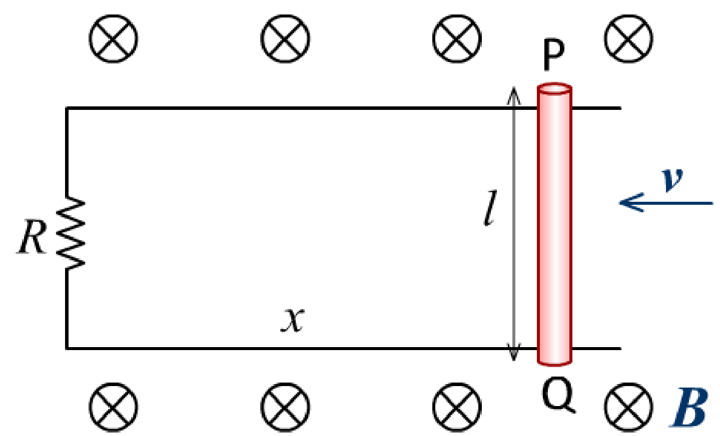
$$\mathcal{E} = B\,l\,v$$

This induced emf results in a current through resistance R. Using Ohm's law we get

$$\mathcal{E} = i\,R$$

$$B\,l\,v = i\,R$$

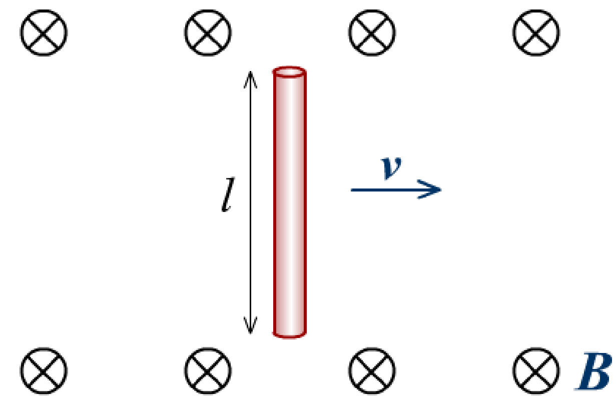
$$\boxed{i = \frac{B\,l\,v}{R}}$$



Induced current is present as long as there is emf induced due to motion of the conductor

Motional emf (alternate analysis)

It is the emf induced across the ends of a rod moving in a region of magnetic field.



A rod PQ of length l is made to move with uniform velocity v in a region of uniform magnetic field of induction B.

Force acting on each free charge q in the rod due to its motion is

$$F_B = q\,v\,B \quad \text{(i)}$$

Rearrangement of charges develops a potential difference across the ends of the rod. This P.D. results in an electric field which exerts a force opposing movement of charges.

$$F_E = q\,E \quad \text{(ii)}$$

Under equilibrium force on charges due to $\boldsymbol{E}$ is balanced by that due to $\boldsymbol{B}$.

$$qE = q\,v\,B$$

Representing electric field in terms of induced emf (P.D.)

$$q\frac{\mathcal{E}}{l} = q\,v\,B$$

$$\boxed{\mathcal{E} = B\,l\,v} \quad \text{(iii)}$$

$\mathcal{E}$ exists as long as there is motion (v)

Energy considerations

Force acting on rod carrying current i , moving in a region of uniform magnetic field of induction B with velocity v is given by

$$F = B\,i\,l$$

Induced current in the rod is given by

$$i = \frac{B\,l\,v}{R}$$

Using this in the above relation we get

$$F = B\,\frac{B\,l\,v}{R}\,l$$

$$F = \frac{B^2\,l^2 v}{R}$$

Mechanical power delivered by the agent moving the rod is

$$P = F\,v$$

$$\boxed{P = \frac{B^2 l^2 v^2}{R}}$$

Power dissipated in a resistor is given by

$$P = V\,i$$

Using induced emf and current

$$P = Blv\frac{Blv}{R}$$

$$\boxed{P = \frac{B^2 l^2 v^2}{R}}$$

<u>Power dissipated in R is at the expense of power delivered by external agent moving the rod.</u>

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