Electromagnetic Fields

Lecture 10

Induction

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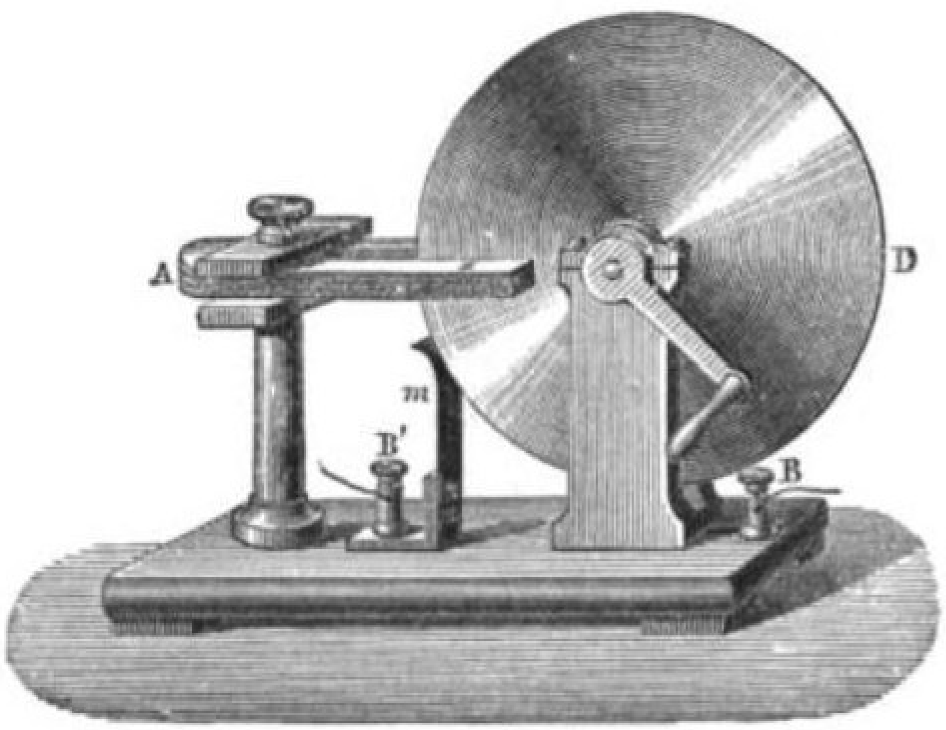
History

- 1831 - Michael Faraday



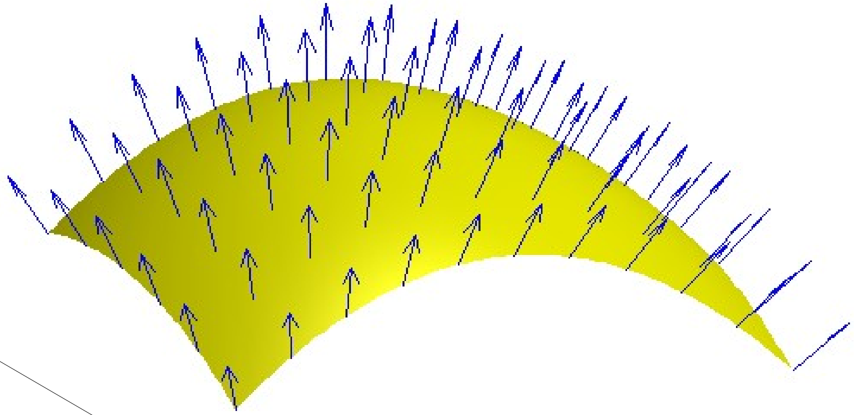
Faraday's disk - Rotating a copper disk near a bar magnet with a sliding electrical lead generates DC current.

Magnetic flux

The magnetic flux

Amount of magnetic field passing through a given surface

$$\iint \mathbf{B} \cdot d\,\mathbf{S} = \Phi_m$$



Magnetic flux density (vector field)

Dot product

Surface normal vector

Magnetic flux is measured in Webers [Wb].

Induction

- Faraday's law of induction

The induced electromotive force (EMF) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit.

$$|\varepsilon| = \left| \frac{d\Phi_m}{dt} \right|$$

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Lenz's law

Lenz's law:

- "An induced current is always in such a direction as to oppose the motion or change causing it."

$$\varepsilon = -\frac{d\Phi_m}{dt}$$

Two EMFs

- **Motional EMF** - generated by magnetic force on a moving wire

$$\varepsilon = B v l$$

- **Transformer EMF** - generated by electric force due to a changing magnetic field

$$\varepsilon = B S \omega \cos(\omega t)$$

EMF

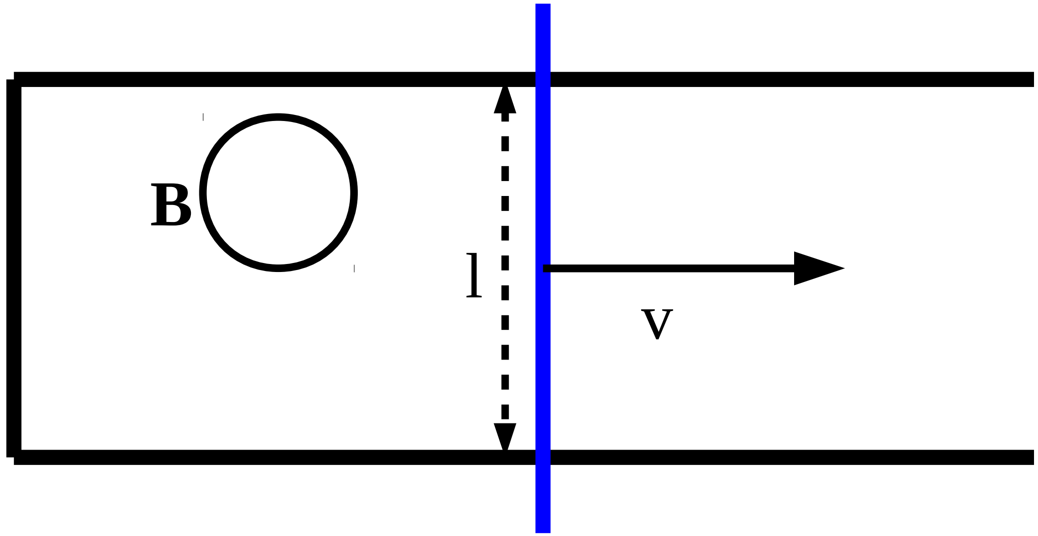
$$\varepsilon = -\frac{d\Phi}{dt} + \oint (\boldsymbol{v} \times \boldsymbol{B}) \cdot d\boldsymbol{l}$$

$$\varepsilon = -\iint \frac{d\boldsymbol{B}}{dt} \cdot d\boldsymbol{S} + \oint (\boldsymbol{v} \times \boldsymbol{B}) \cdot d\boldsymbol{l}$$

transformer EMF

motional EMF

Case 1: Sliding bar



$$\varepsilon = \oint (\boldsymbol{v} \times \boldsymbol{B}) \cdot d\,\boldsymbol{l} = B v l$$

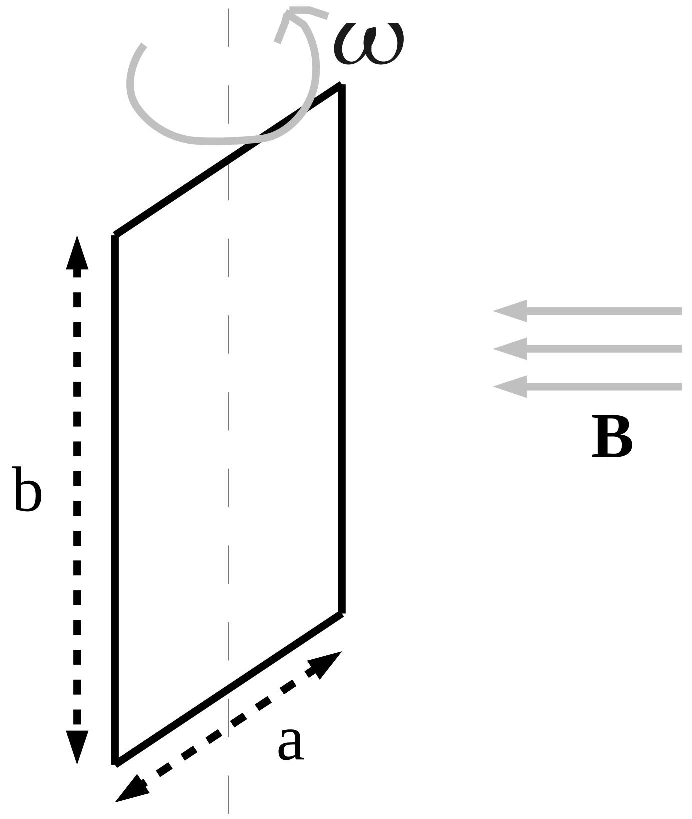
Case 2: Rotating frame

$$\varepsilon = -\frac{d\Phi_m}{dt}$$

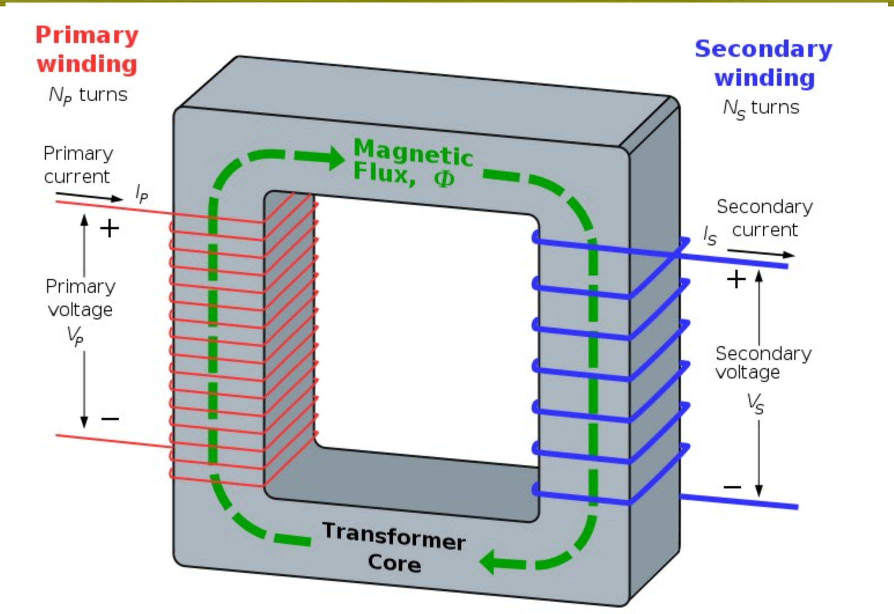
$$\varepsilon = -\frac{d}{dt}\iint \boldsymbol{B}\cdot d\boldsymbol{S}$$

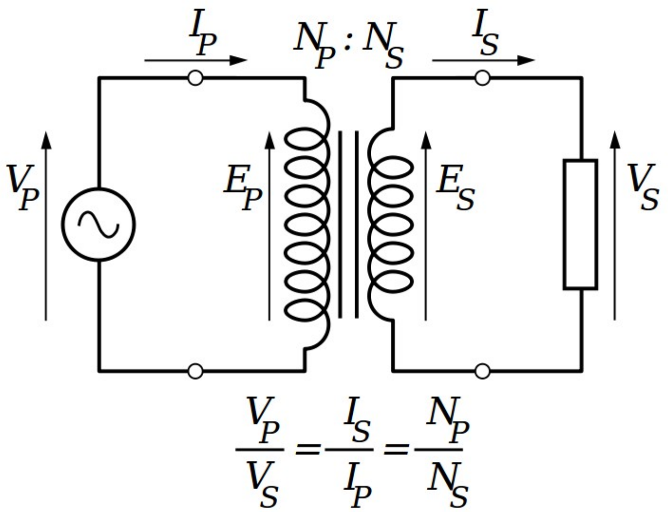
$$\varepsilon = -\frac{d}{dt} B\,a\,b\sin(\omega t)$$

$$\varepsilon = -B\,a\,b\,\omega\cos(\omega t)$$



Case 3: Transformer





$$V_p = -N_p \frac{d\Phi}{dt}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = -N_s \frac{d\Phi}{dt}$$

References

References:

Deventra K. Mistra: Practical Electromagnetics, From Biomedical Science to Wireless Communication, Wiley-Interscience, 2007

Joseph F. Becker: Physics 51 - Electricity & Magnetis, Califonia State University http://www.physics.sjsu.edu/becker/physics51/

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