Faraday's law

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Maxwell's equations describing Electrodynamics

- Gauss's law

$$\nabla \cdot E = \frac{\rho}{\varepsilon_0} \tag{1}$$

- Faraday's law

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{2}$$

- $$\nabla \cdot B = 0 \tag{3}$$

- $$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t} \tag{4}$$

where sources ρ and J are charge density and current density respectively.

Faraday's Law: Experimental observations

A current flows in a loop:

- When the loop of wire is pulled to the right through a magnet.
- When the magnet itself moved to left, holding the loop.
- With both the loop and the magnet at rest, but varying the strength of field.

A changing magnetic field induces an electric field.

- Mathematically, the above observations can be expressed as

$$\mathcal{E} = -\frac{d\phi}{dt}, \tag{5}$$

that says the induced emf $\mathcal{E}$ is equal to the rate change of the flux ϕ.

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- Whenever (and for whatever reason) the magnetic flux through a loop changes an emf

$$\mathcal{E} = -\frac{d\phi}{dt}, \tag{6}$$

will appear in the loop.

Integral & Differential form of the Faraday's law

- The induced electric field is given by the line integral

$$\mathcal{E} = -\oint E \cdot dl, \tag{7}$$

and then E is related to the change in B as

$$\oint E \cdot dl = -\oint \frac{\partial B}{\partial t} \cdot da, \tag{8}$$

- The Eq. (8) is the integral form of the Faraday's law.
- Using Stokes's theorem, this further reduces to differential form

$$\nabla \times E = -\frac{\partial B}{\partial t}. \tag{9}$$

Reference

- D. J. Griffiths, *Introduction to Electrodynamics*, Prentice Hall (1999).