PHYS 1220, Engineering Physics, Chapter 29 – Electromagnetic Induction

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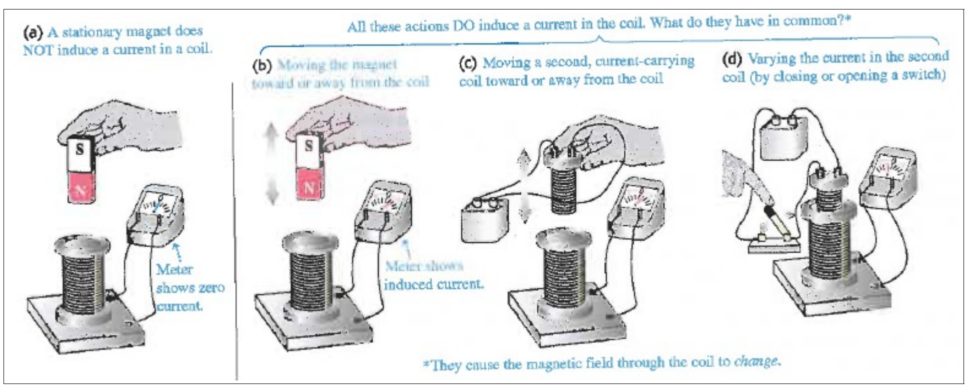
Goal of this chapter is to learn how the changing magnetic flux induces emf

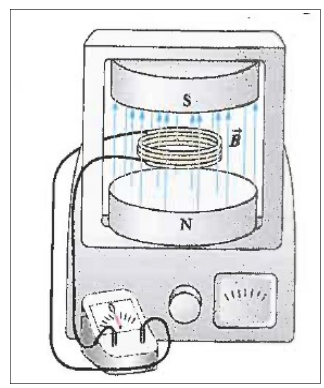
- Induction: Consider a conducting loop placed in a magnetic field, when the magnetic field is **varying** as function of **time**, there will be a **induced current** in the loop. The corresponding emf responsible for the induced current is the **induced emf**.

- The relationship between the induced emf in the closed conducting loop and the magnetic field is made through the change of the magnetic flux as:

$$\epsilon = \frac{-d\Phi_B}{dt} \qquad \text{(Faraday's law of induction)}$$

- The change of the magnetic flux could be achieved by either (1) rotating the conducting loop in static magnetic field; or (2) changing varying the strength of the magnetic field while the conducting loop is stationary.



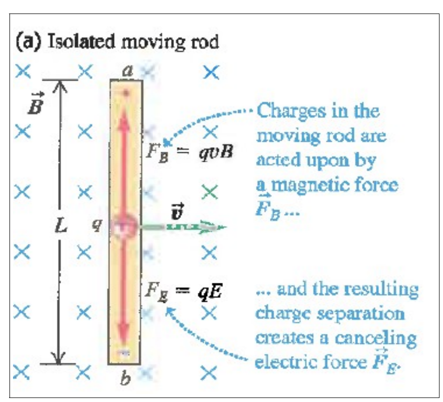


- The direction of the induced emf (or induced current) could be determined **Lenz's Law**. (**the direction of the induced current is as if the system is trying to maintain the original magnetic status**; **or equivalently**, **the direction of any magnetic induction effect is such as to oppose the cause of the effect**.)

Do Example 29.3 on page 963.
Do Example 29.6 on page 966.

- Induced emf in a conducting rod moving across a magnetic field (perpendicular to the velocity):

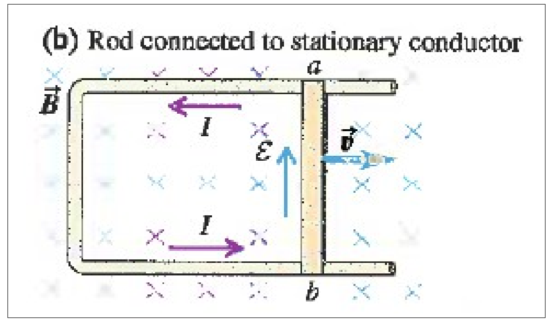
$$\epsilon = vBL$$



- For a closed conducting loop moving (with velocity $\vec{v}$) in a magnetic field, $\vec{B}$, the induced emf could be calculated as

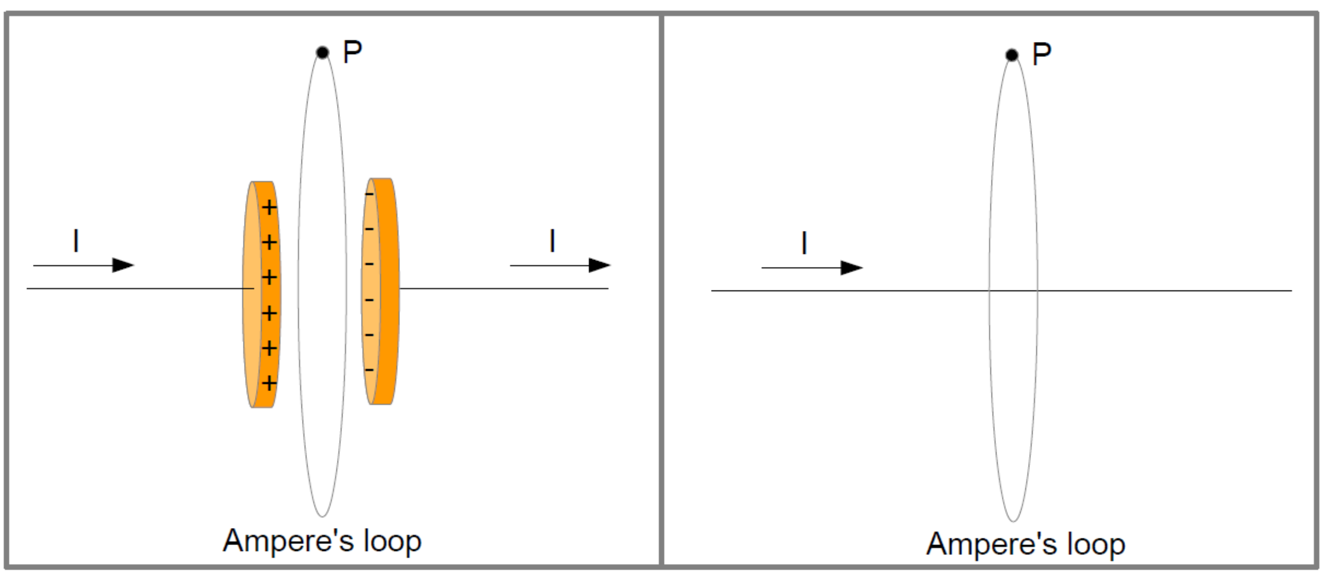
$\epsilon = \oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$ (this is equivalent to $\epsilon = \frac{-d\Phi_B}{dt}$)

Do Example 29.10 on page 971



- Let's look at Ampere's law ($\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$) again closely. Consider a capacitor under charging process (left panel of the figure below). At a particular moment, there is a current *I* flowing in the wires that connect tot he plates in capacitor. The current-carrying wires could produce magnetic field at point P. If the gap between the plates in capacitor is very small, the calculation of the magnetic field is very close to the case of just single current-carrying wire (the right panel of the figure below). My choice of the Ampere's loop is as plotted.

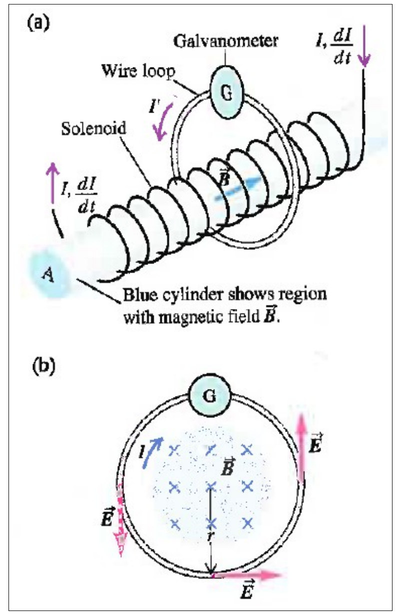
- $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$ (Ampere's law in the right panel of the figure below)
- In left panel, the magnetic field along the ampere's loop is the same as the one in the right panel of the figures, but there is no I_{encl}. But there is electric field in the gap of the capacitor.
- $I_{encl} = I = \frac{dq}{dt} = \frac{d(CV)}{dt} = \frac{d(\epsilon_0 \frac{A}{D} \cdot ED)}{dt} = \frac{d(\epsilon_0 AE)}{dt} = \frac{d(\epsilon_0 \Phi_E)}{dt} = \epsilon_0 \frac{d\Phi_E}{dt}$
- The generalized Ampere's law becomes: $\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_{encl} + \epsilon_0 \frac{d\Phi_E}{dt})$
- In other words, in addition to **moving charge** (or **current**), **time-dependent electric field** (or electric flux) could produce magnetic field.



- Let's look at Faraday's Law ($\epsilon = \frac{-d\Phi_B}{dt}$) again closely.

Look at the induced emf in a closed conducting wire (as the figure to the right). The emf is the driving force to move charges in the conducting wire. The emf is closely related to the electric field in the conducting wire as:

$$\epsilon = \oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$



- Summery of all these "laws" together:

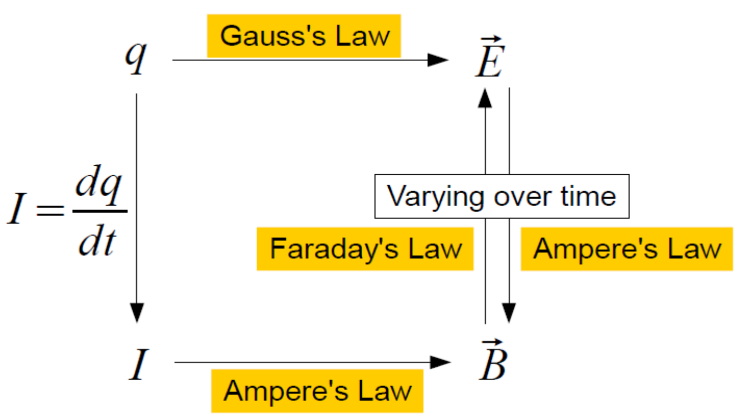
$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0}$$ (Gauss's Law for $\vec{E}$)

$$\oint \vec{B} \cdot d\vec{A} = 0$$ (Gauss's Law for $\vec{B}$)

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_{encl} + \epsilon_0 \frac{d\Phi_E}{dt})$$ (Ampere's Law)

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$ (Faraday's Law)

The above four equations are the famous Maxwell's Equations!



Math Preview for Chapter 30:

- vector integration
- differential equations

Questions to think about for Chapter 30:

- Now you know current-carrying wire could produce magnetic field, also, you know that the change of magnetic field could induce efm. If a conducting wire is made into coil shape, will it work just like a regular conducting wire? Or the magnetic field and magnetic induction will have effects on the circuit behavior? If so, how?