Level UGI- Semester 2

Magnetism Theory

PHY-1209-C-7 ECTS

Prerequisite Module Code (PHY-1102)

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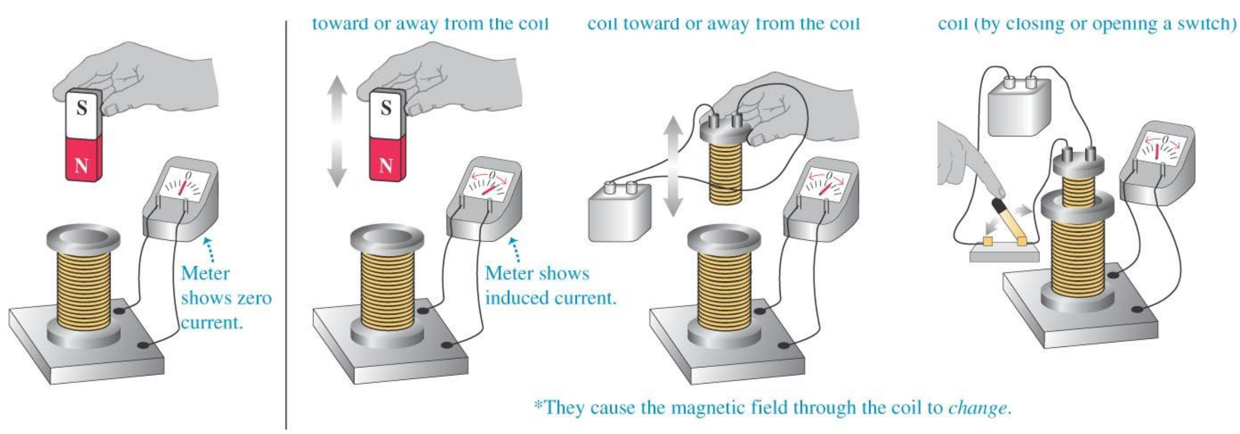
Chapter Two - Electromagnetic Induction

Induction Experiments

- An induced current (and emf) is generated when: (a) we move a magnet around a coil, (b) move a second coil toward/away another coil, (c) change the current in the second coil by opening/closing a switch.



- Magnetically induced emfs are always the result of the action of nonelectrostatic forces. The electric fields caused by those forces are E_n (nonCoulomb, non conservative).

Electromagnetic Induction

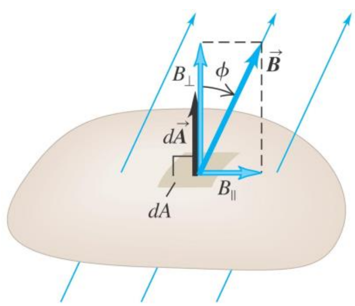
The central principle of electromagnetic inducts is Faraday's Law. This low relates induced emf to changing magnetic flux in any loop, including a closes circuit.

Faraday's Law

The Common element in all induction effects is changing magnetic flux through a circuit.

For an infinitesimal- area element $d\vec{A}$ in magnetic field B, the magnetic flux $d\emptyset_B$ through the area is:-

$$d\emptyset_B = \vec{B} \,.\, d\vec{A} = B_\perp \, dA = BdA \, Cos \, \emptyset$$



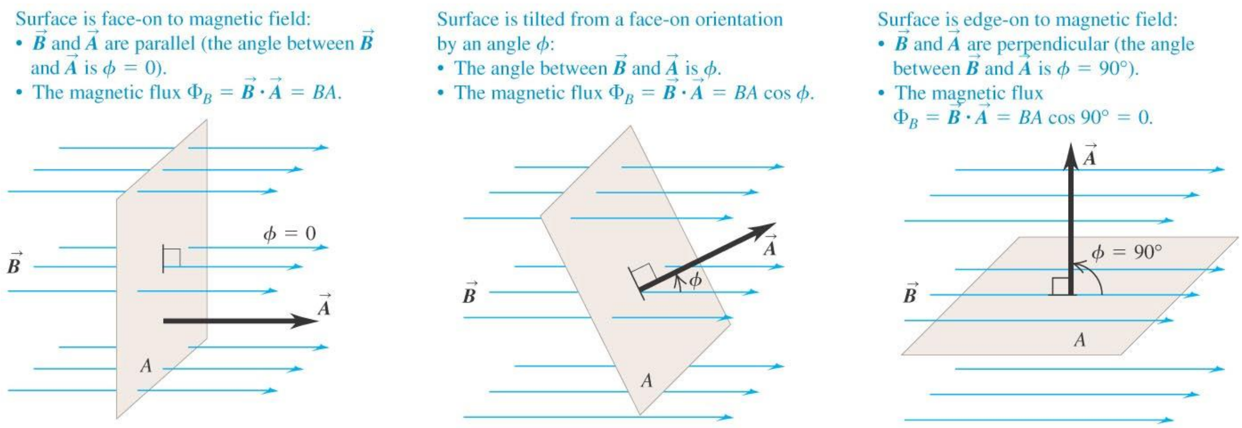
Where $B_\perp$ is the component to $\vec{B}$ perpendicular to the surface of the area element and $\emptyset$ is the angle between $\vec{B}$ and $d\vec{A}$.

The total magnetic flux $\emptyset_B$ through a finite area is the integral of this expression over the area.

$$\Phi_B = \int \vec{B} \cdot d\vec{A} = \int B \cos\varphi \cdot dA$$

If $\vec{B}$ is uniform over a flat area $\vec{A}$, then:

$$\Phi_B = \vec{B} \cdot \vec{A} = B \cdot A \cdot \cos\varphi$$



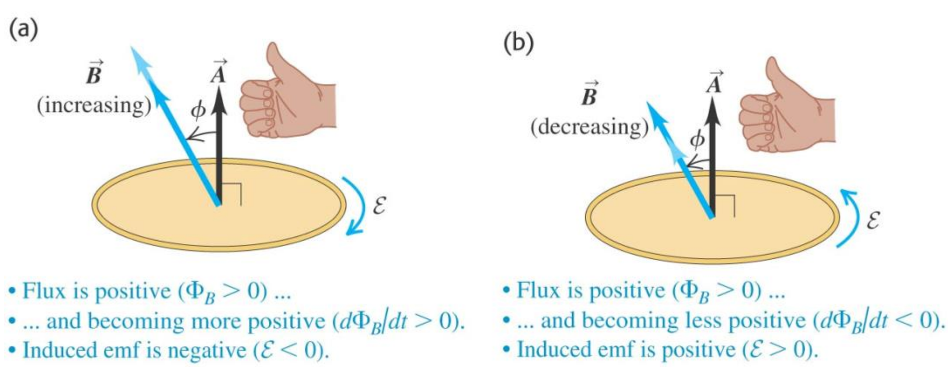
Faraday's Law of Induction states:

"The induced emf in a closed loop equals the negative of the time rate of Change of the magnetic flux through the loop.

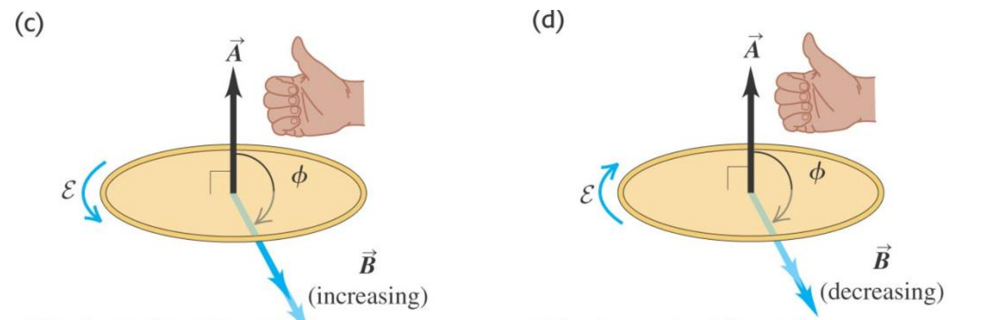
$$\varepsilon = -\frac{d\Phi_B}{dt}$$

- Increasing flux → $\varepsilon < 0$;   Decreasing flux → $\varepsilon > 0$

- Direction: curl fingers of right hand around A, if $\varepsilon > 0$ is in same direction of fingers (counter-clockwise), if $\varepsilon < 0$ contrary direction (clockwise).



- Only a change in the flux through a circuit (not flux itself) can induce emf. If flux is constant → no induced emf.



• Flux is negative ($\Phi_B < 0$) ...
• ... and becoming more negative ($d\Phi_B/dt < 0$).
• Induced emf is positive ($\mathcal{E} > 0$).

• Flux is negative ($\Phi_B < 0$) ...
• ... and becoming less negative ($d\Phi_B/dt > 0$).
• Induced emf is negative ($\mathcal{E} < 0$).

Coil: $$\varepsilon = -N\frac{d\Phi_B}{dt}$$

N = number of turns

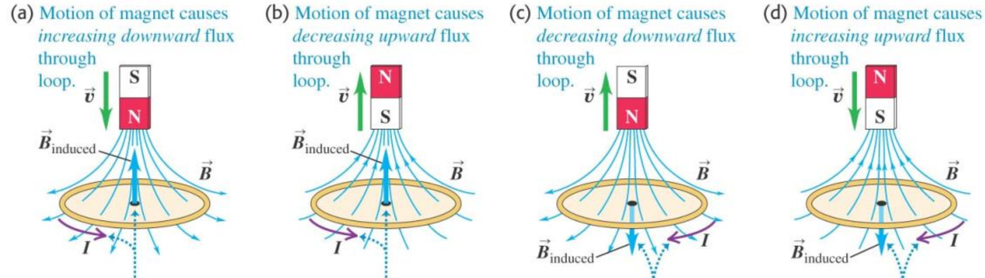
- If the loop is a conductor, an induced current results from emf. This current produces an additional magnetic field through loop. From right hand rule, that field is opposite in direction to the increasing field produced by electromagnet.

Lenz's Law

- Alternative method for determining the direction of induced current or emf.

"The direction of any magnetic induction effect is such as to oppose the cause of the effect".

-The "cause" can be changing the flux through a stationary circuit due to varying B, changing flux due to motion of conductors, or both.



The induced magnetic field is *upward* to oppose the flux change. To produce this induced field, the induced current must be *counterclockwise* as seen from above the loop.

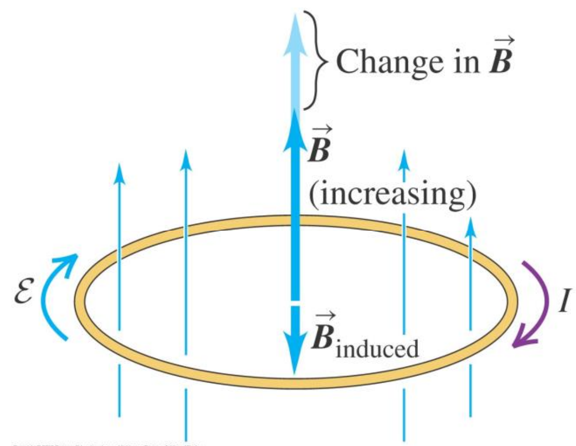
The induced magnetic field is *downward* to oppose the flux change. To produce this induced field, the induced current must be *clockwise* as seen from above the loop.

- If the flux in an stationary circuit changes, the induced current sets up a magnetic field opposite to the original field if original B increases, but in the same direction as original B if B decreases.

- The induced current opposes the change in the flux through a circuit (not the flux itself).

- If the change in flux is due to the motion of a conductor, the direction of the induced current in the moving conductor is such that the direction of the magnetic force on the conductor is opposite in direction to its motion (e.g. slide-wire generator). The induced current tries to preserve the "status quo" by opposing motion or a change of flux.

B induced downward opposing the change in flux ($d\Phi/dt$). This leads to induced current clockwise.



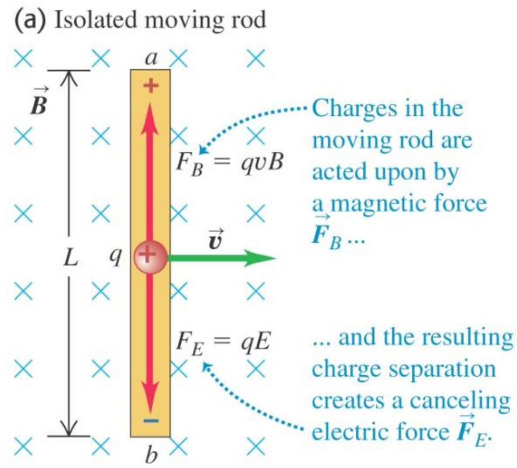
Lenz's Law and the Response to Flux Changes

- Lenz's Law gives only the direction of an induced current. The magnitude depends on the circuit's resistance. Large R → small induced I → easier to change flux through circuit.

- If loop is a good conductor → I induced present as long as magnet moves with respect to loop. When relative motion stops → I = 0 quickly (due to circuit's resistance).

- If R = 0 (superconductor) → I induced (persistent current) flows even after induced emf has disappeared (after magnet stopped moving relative to loop). The flux through loop is the same as before the magnet started to move → flux through loop of R =0 does not change.

Motional Electromotive Force



- A charged particle in rod experiences a magnetic force $\vec{F} = q\vec{v} \times \vec{B}$ that causes free charges in rod to move, creating excess charges at opposite ends.

- The excess charges generate an electric field (from a to b) and electric force ($F = q\,E$) opposite to magnetic force.