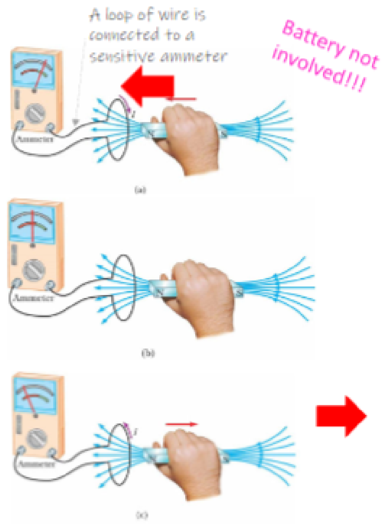
Chapter 30 Electromagnetic Induction

Introduction to Electromagnetic Induction

- **Electromagnetic induction**: The process of generating an electromotive force (emf) through the relative motion between a conductor and a magnetic field.
- **Key Principle**: An electric current is induced in a circuit if the magnetic flux through the circuit changes.



Faraday’s Law of Induction

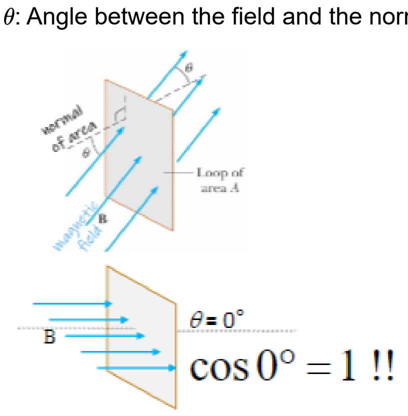
- **Faraday’s Law**:
  - The induced emf ϵ in a circuit is directly proportional to the rate of change of magnetic flux Φ_B through the circuit.

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

  - The negative sign follows Lenz’s Law, indicating that the induced emf opposes the change in flux.
- **Magnetic flux**:

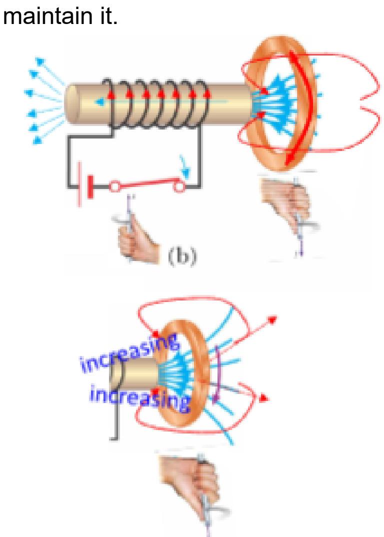
$$\Phi_B = B \cdot A \cdot \cos\theta$$

  - B: Magnetic field strength
  - A: Area through which the field lines pass
  - θ: Angle between the field and the normal to the area



Lenz’s Law

- **Statement**: The direction of the induced current is such that it opposes the change in magnetic flux that produced it.
- **Physical Interpretation**: If the magnetic flux increases, the induced current creates a magnetic field opposing the increase; if the flux decreases, the current acts to maintain it.



Ways of Inducing an E.M.F.

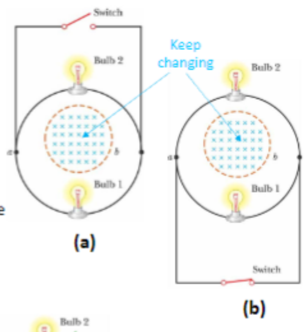
- **Methods**:
  - Change in the magnetic field B.
  - Change in the area A of the loop within the magnetic field.
  - Change in the orientation (angle θ) of the loop relative to the magnetic field.
- **General Formulation**:

$$\epsilon = -N\frac{d\Phi_B}{dt}$$

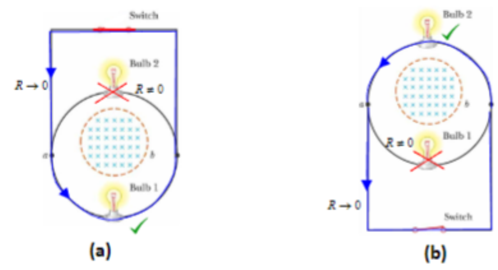
- N: Number of loops in the coil

Example. Two bulbs are connected to opposite sides of a circular loop of wire as shown in figure. A changing magnetic-field confined to the smaller circular area shown in the figure **(a)** induces an e.m.f. in the loop that causes the two bulbs to light. When the switch is connected, the inverted U-shape nearly-resistance-free wires connected to the switch short out Bulb 2 and only Bulb 1 remains lighted.

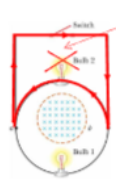
What happens if the wires containing the closed switch remain connected at points *a* and *b*, but the switch and the wires are lifted up and moved to the other side of the field, as in figure **(b)**? The wires are still connected to Bulb 2 as it was before, so does it continue to stay dark?



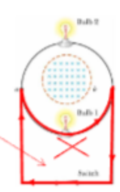
Answer:



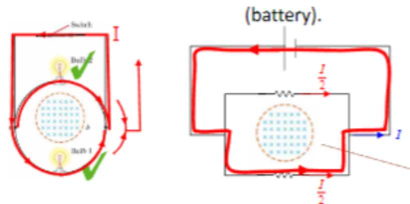
What if you **hard-connect** the red wire which has resistance?



The magnetic field in this enclosed area is 0 so there is no way to induce the current!!!



This is possible provided there is external e.m.f. (battery).



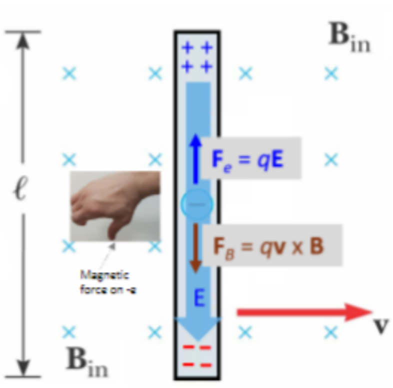
But in this example the source of e.m.f. is solely due to the changing magnetic flux. There is no battery.

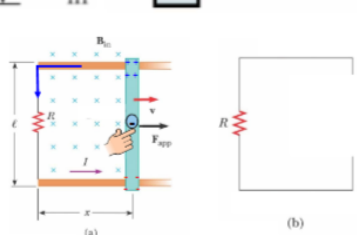
Motional E.M.F.

- **Concept**:
  - A conductor moving through a magnetic field experiences an induced emf.
- **Expression for motional emf**:

$$\epsilon = B \cdot v \cdot \ell$$

  - v: Velocity of the conductor
  - ℓ: Length of the conductor in the field
- **Direction of induced current**:
  - Determined by the right-hand rule (fingers in the direction of v, thumb in the direction of B, palm indicates the direction of force on positive charges).

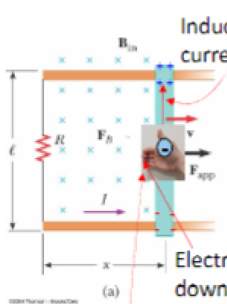




(a) A bar moving through a uniform field (by your finger!!)

(b) The equivalent circuit diagram

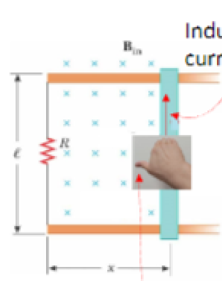
Conducting bar moves to the right.
Area increasing.
Magnetic flux increasing.
Apply Lenz's law.



Induced current

Electron is going downward ➔ induced current is going upward

Induced magnetic field is going out (.) of the page to oppose the increasing inward (x) magnetic flux (Lenz's Law)



Induced current

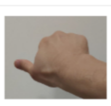
Direction of magnetic force on the conducting bar due to the **inward** magnetic field (x)

Applications of Induction

Induction Stoves

- **Mechanism**:
  - Uses a coil carrying an alternating current to create a changing magnetic field.
  - This field induces eddy currents in the metal pot, causing it to heat up due to the pot's resistance.

Application: Induction Stove



Magnetic Strip Readers

- **Mechanism**:
  - A magnetic strip passes over a coil, and the changing magnetic field induces a current.
  - This current is decoded to extract information.