

Chapter 29

Electromagnetic Induction

PowerPoint® Lectures for
University Physics, Thirteenth Edition
– *Hugh D. Young and Roger A. Freedman*

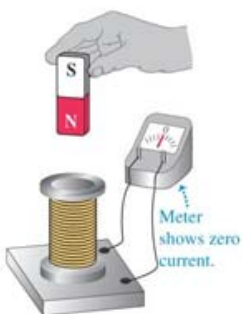
Lectures by **Wayne Anderson**

Copyright © 2012 Pearson Education Inc.

Induced current

- Moving charges and currents create magnetic fields
- Changing magnetic fields can create or *induce* a current

(a) A stationary magnet does NOT induce a current in a coil.



All these actions DO induce a current in the coil. What do they have in common?*

(b) Moving the magnet toward or away from the coil



(c) Moving a second, current-carrying coil toward or away from the coil

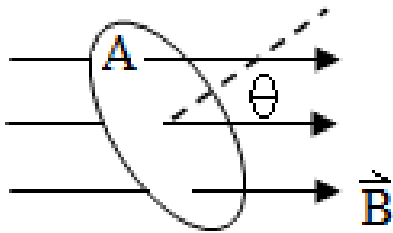


(d) Varying the current in the second coil (by closing or opening a switch)



*They cause the magnetic field through the coil to *change*.

Magnetic flux



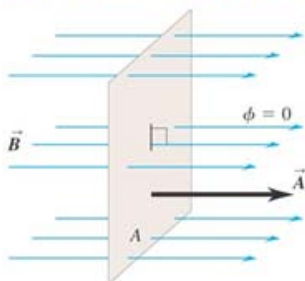
$$\Phi_B = \int \mathbf{B} \cdot d\mathbf{A}$$

Unit of magnetic flux : $T \cdot m^2 = \text{Weber (Wb)}$

- Magnetic flux depends on 3 things
 - o Magnetic field strength
 - o Loop area
 - o Orientation of the loop with respect to the field

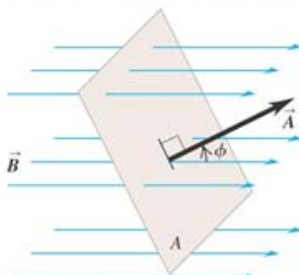
Surface is face-on to magnetic field:

- \vec{B} and \vec{A} are parallel (the angle between \vec{B} and \vec{A} is $\phi = 0$).
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA$.



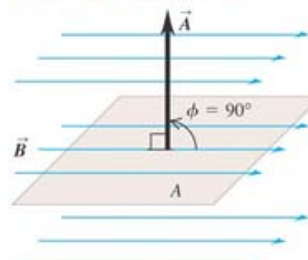
Surface is tilted from a face-on orientation by an angle ϕ :

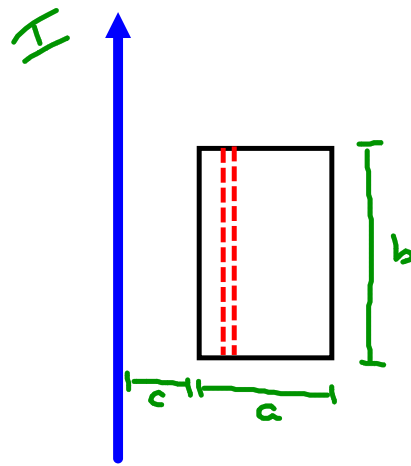
- The angle between \vec{B} and \vec{A} is ϕ .
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos \phi$.



Surface is edge-on to magnetic field:

- \vec{B} and \vec{A} are perpendicular (the angle between \vec{B} and \vec{A} is $\phi = 90^\circ$).
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos 90^\circ = 0$.





A rectangular loop with width a and length b is located near a wire carrying a current I . The distance from the wire to the closest side of the loop is c . The wire and loop are parallel. Calculate the total magnetic flux through the loop.

$$\Phi_B = \int \mathbf{B} \cdot d\mathbf{A}$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$\Phi_B = \int_c^{c+a} \frac{\mu_0 I}{2\pi r} b dr$$

$$= \frac{\mu_0 I b}{2\pi} \int_c^{c+a} \frac{1}{r} dr$$

$$\Phi_B = \frac{\mu_0 I b}{2\pi} \ln\left(\frac{c+a}{c}\right)$$

Faraday's law

- *Faraday's law*: The induced emf in a closed loop equals the negative of the time rate of change of magnetic flux through the loop

$$\mathcal{E} = - \frac{d\Phi_B}{dt}$$

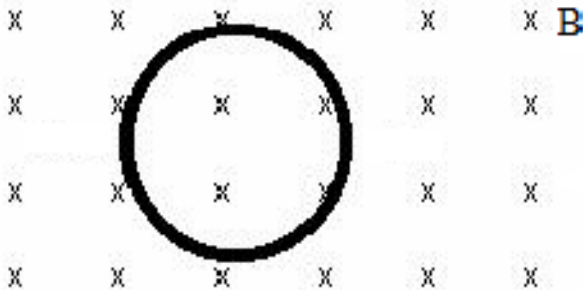
If the loop has multiple coils

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$

From Lenz's Law

Example:

How can an EMF be induced in the loop below?

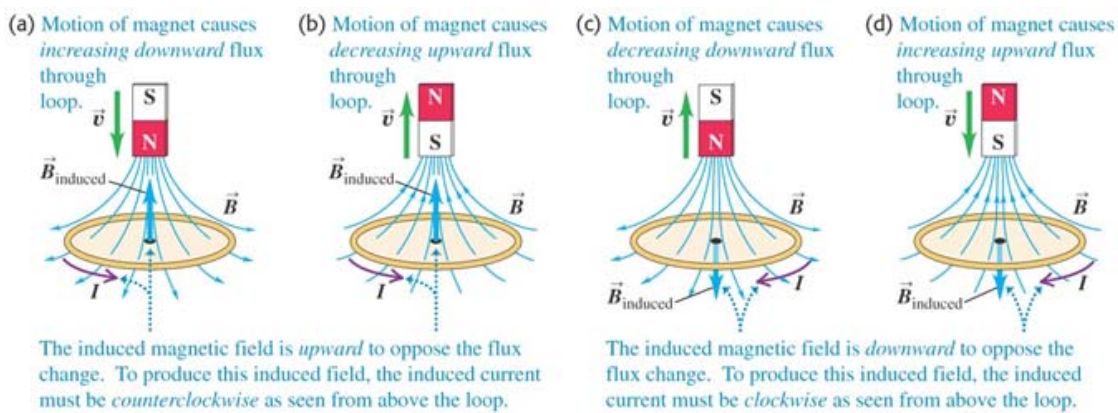


Lenz's law

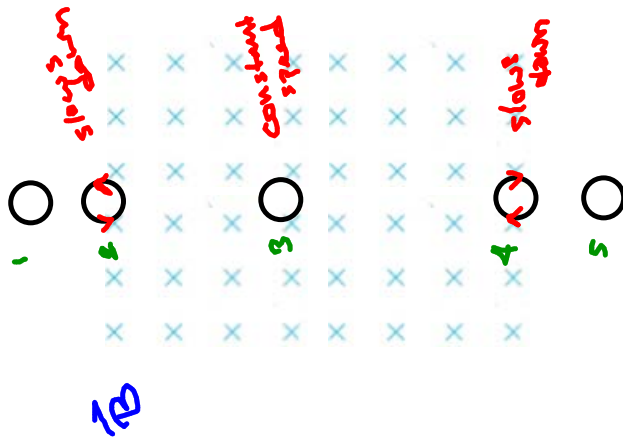
- *Lenz's law*: The magnetic field created by an induced current (due to the induced emf) will always *oppose* the change in magnetic flux through the loop

consequence of conservation of energy

Dropping a bar magnet through a loop



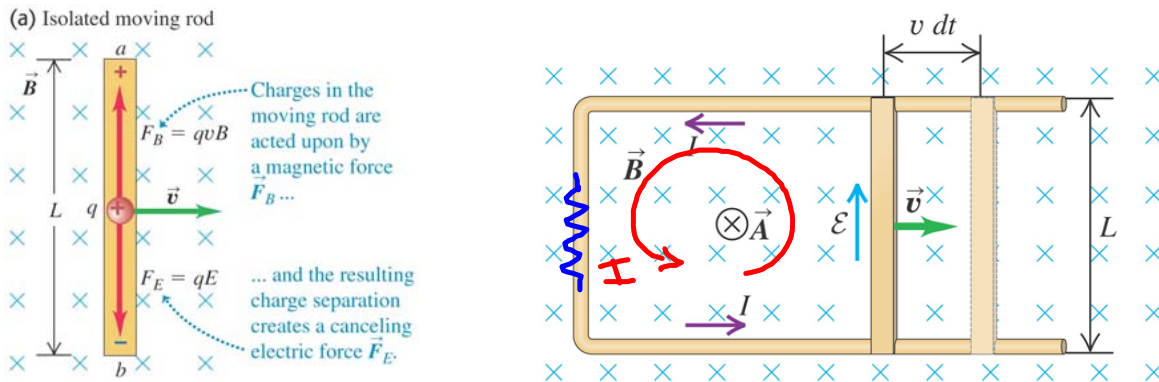
Dropping a loop through a magnetic field



- 1) No induced current
- 2) Flux into page increasing
loop creates a field pointing
out of page
→ current flows (CW)
- 3) No induced current
no change in flux
- 4) flux into page decreasing
loop creates field pointing
into page
→ current flows (CCW)
- 5) no induced current

Motional emf

- Move a conductor of length L through a magnetic field B at a speed v , perpendicular to the field



$$\mathcal{E} = - \frac{d\Phi_B}{dt}$$

$$\Phi_B = BA \cos\theta$$

Copyright © 2012 Pearson Education Inc.

$$\mathcal{E} = B \frac{dA}{dt}$$

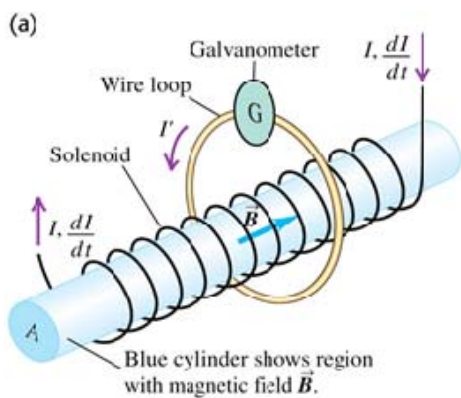
$$dA = Lv dt$$

$$\mathcal{E} = B \frac{Lv dt}{dt}$$

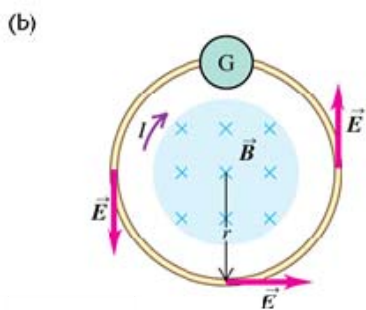
$$\boxed{\mathcal{E} = BLv}$$

$$I = \frac{\mathcal{E}}{R}$$

Induced electric fields



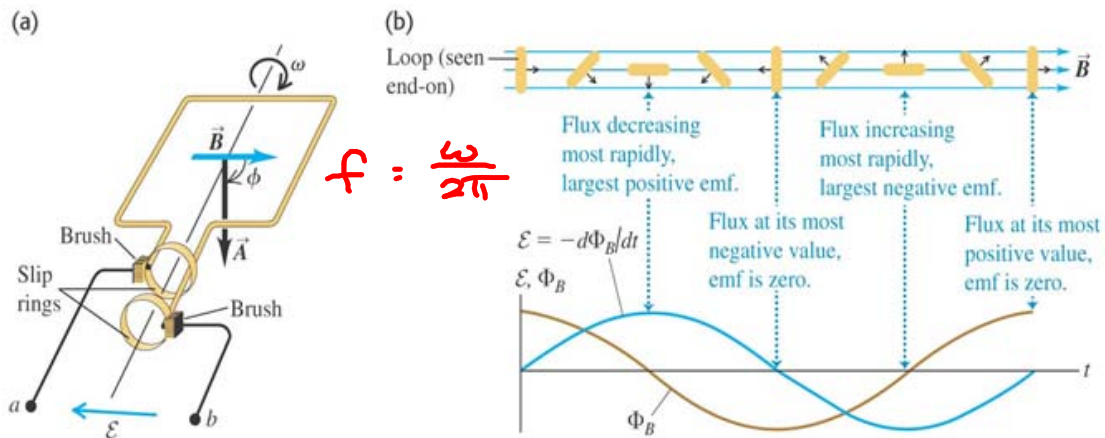
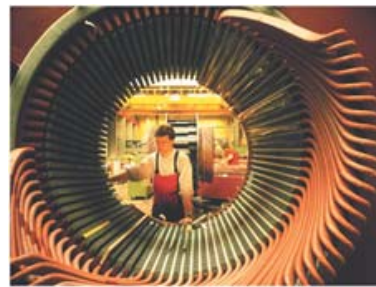
$$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell}$$



$$\mathcal{E} = - \frac{d\Phi_B}{dt} = \oint \vec{E} \cdot d\vec{\ell}$$

A simple alternator

- Follow Example 29.3 using Figures 29.8 (below) and 29.9 (right).



Maxwell's equations

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q_{enc}}{\epsilon_0} \quad \text{Gauss's Law}$$

$$\oint \mathbf{B} \cdot d\mathbf{A} = 0 \quad \text{Gauss's Law for Magnetism}$$

→ no magnetic monopoles

$$\mathcal{E} = \oint \mathbf{E} \cdot d\mathbf{l} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt} \int \mathbf{B} \cdot d\mathbf{A} \quad \text{Faraday's Law}$$

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_{enc} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} \quad \text{Ampere's Law}$$