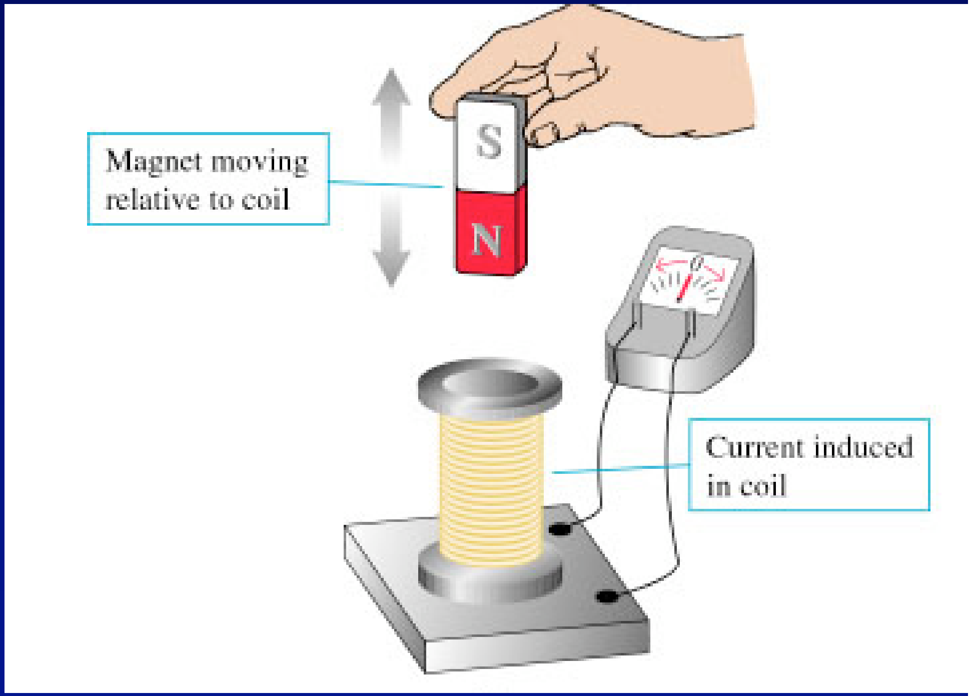
Chapter 29

Electromagnetic Induction

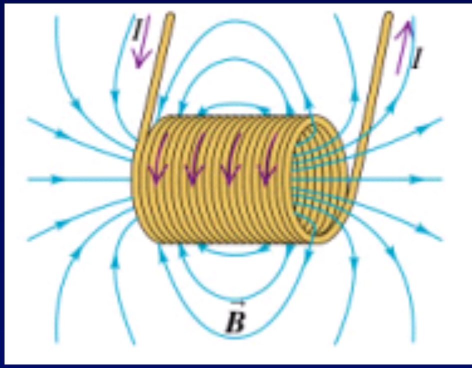
- Magnetic flux
- Induced emf
  - Faraday's Law
  - Lenz's Law
- Motional EMF



Magnetic Flux

New Topic

Electromagnetic Induction

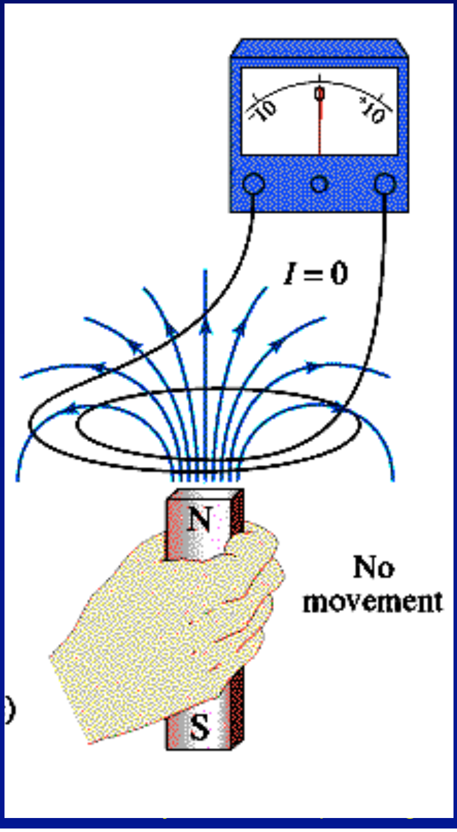


Fact: a current flowing through a coil produces a B field

current ⟶ **B field**

Question: Can a magnetic field produce an electric current?

B field ⟶ **current ?**



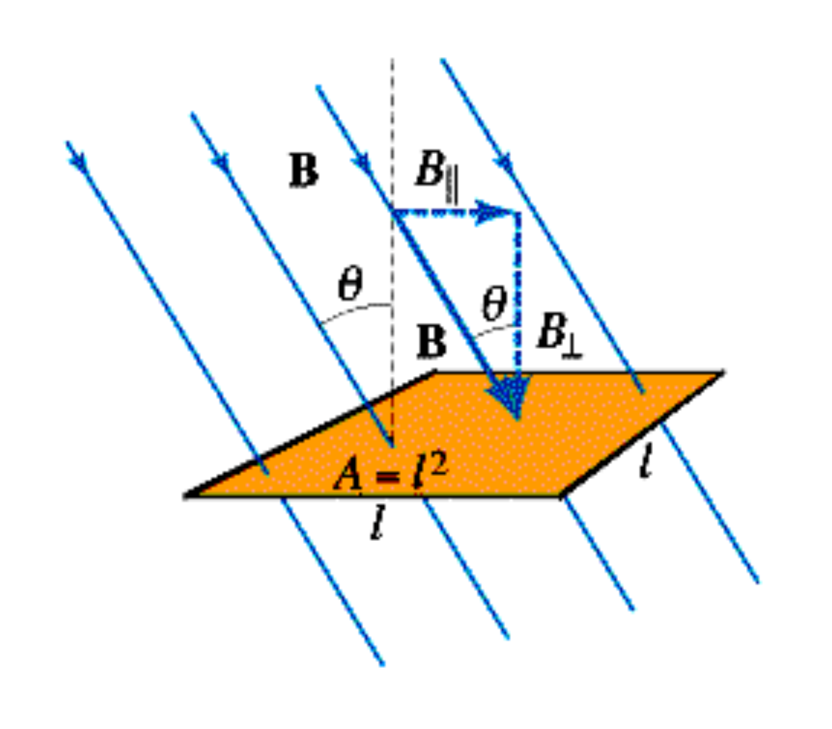
Yes, by magnetic induction. But with a condition.

Faraday discovered that B has to be *changing* to produce a current. More precisely the *Magnetic flux.*

Magnetic Flux

- Consider the B field lines that pass through a surface
  - define a quantity called the *magnetic flux* Φ

$$\boxed{\Phi \equiv B\, A \cos\theta}$$



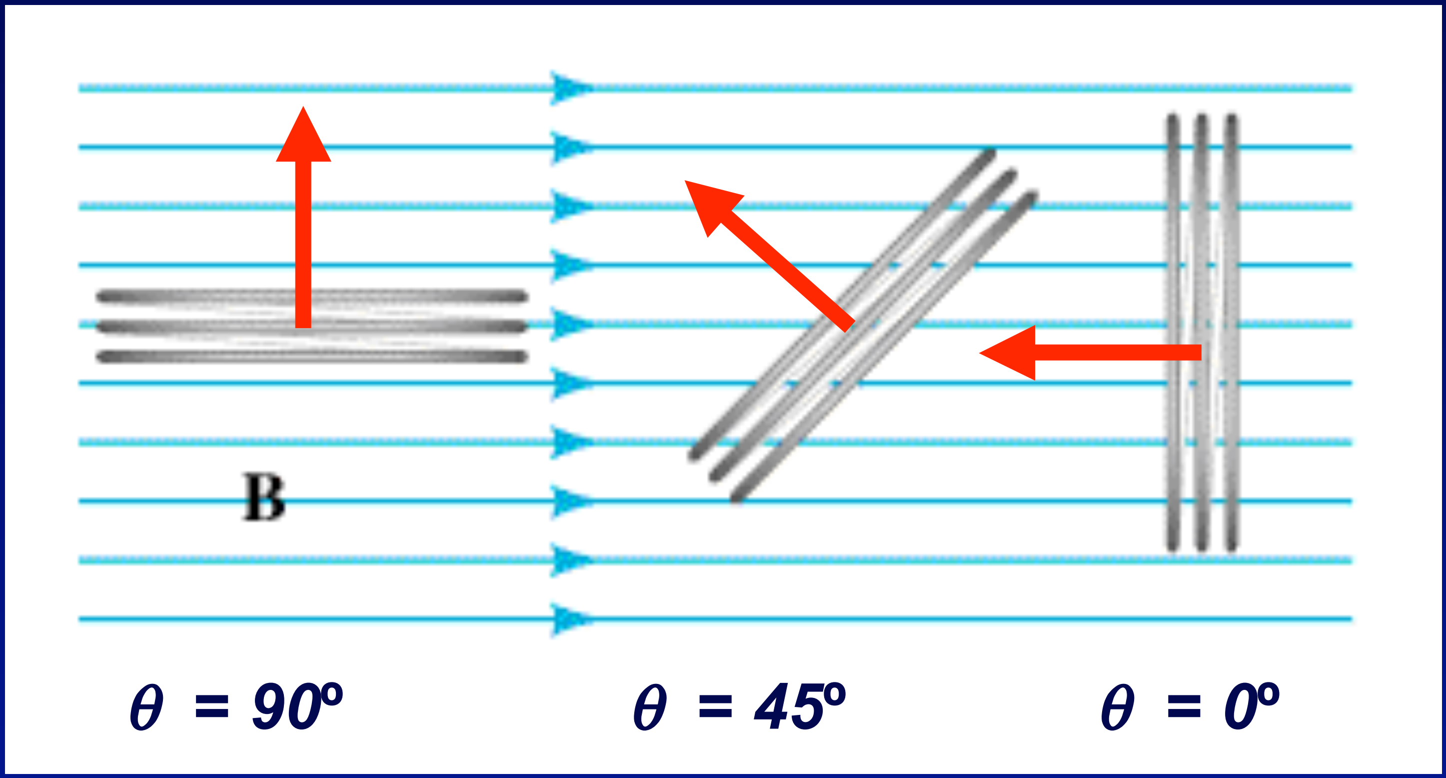
where θ is angle between *magnetic field B* and the *normal to the plane.*

- units of magnetic flux are $T.m^2$ = Weber (Wb)

- Scalar product $\Phi_B = \vec{B} \cdot \vec{A}$

Magnetic Flux

- Scalar product $$\Phi_B = \vec{B} \cdot \vec{A}$$

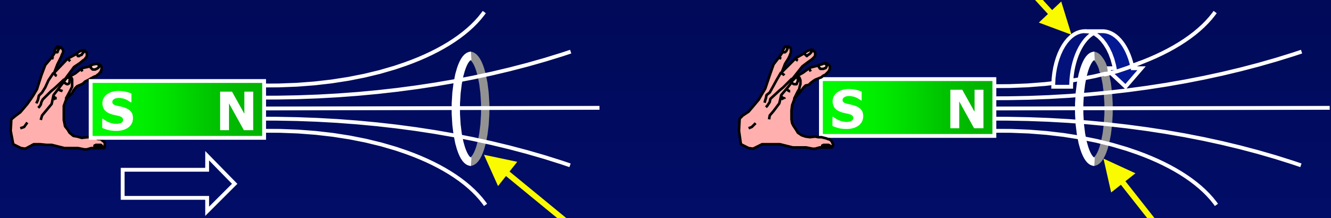


$\Phi = 0$ $\Phi = B\,A\cos\theta$ $\Phi = B\,A$

Changing the Magnetic Flux

Moving magnet

induced current

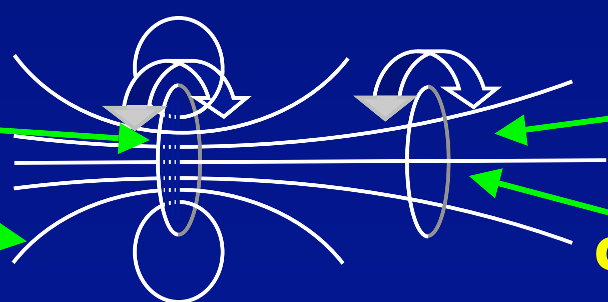


3 lines inside loop

5 lines inside loop
$\Rightarrow$ flux changed !

Changing current

changing current produces *changing* B field

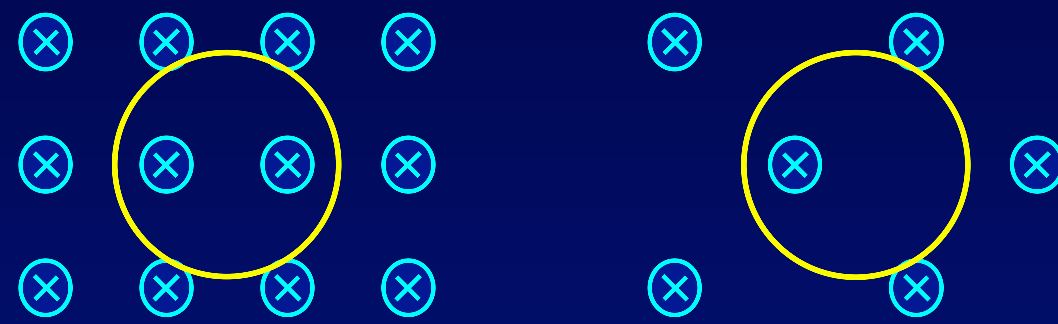


induced current produced by changing magnetic flux (inside loop)

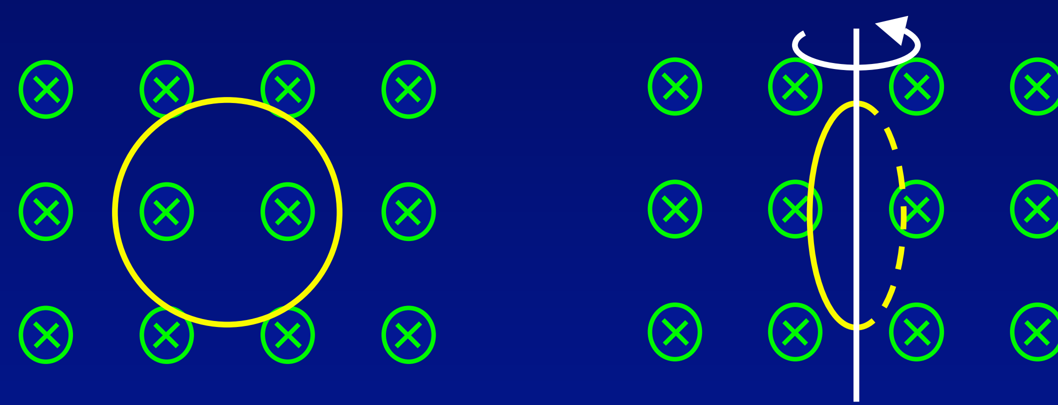
Changing the Flux

$$\Phi \equiv B\,A\cos\theta$$

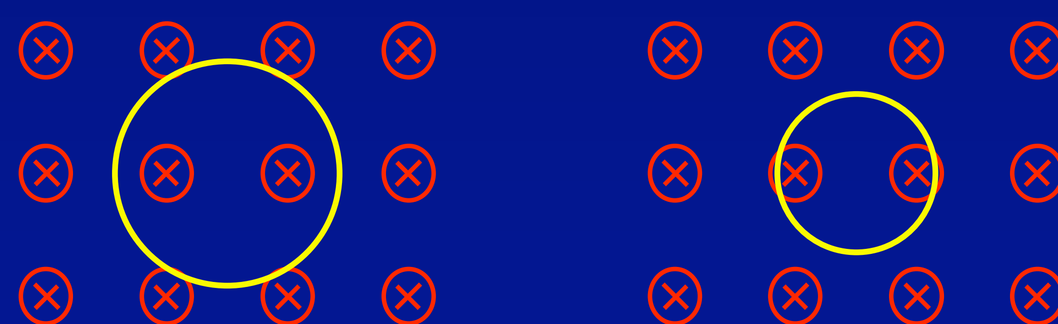
Change the B field



Change the angle



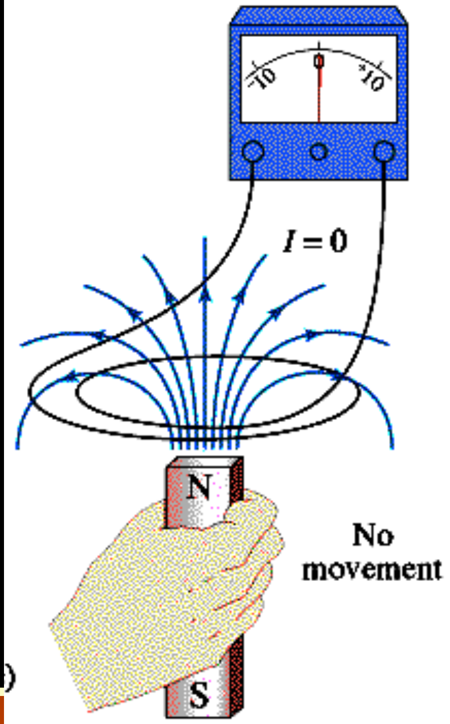
Change the area



ConcepTest 29.1 Induction

- If you want to change the magnetic flux through the loop what would you have to do?

(1) Drop the magnet
(2) Move the magnet upwards
(3) Move the magnet sideways
(4) Tilting the loops
(5) Reducing the loop area
(6) All of the above



Faraday's Law

New Topic

Faraday's Law of Induction

$$\mathcal{E} = -N \frac{\Delta \Phi_B}{\Delta t}$$

induced emf

number of loops

rate of change of flux with time

The faster the change, the larger the induced emf.

- **Remember:** the induced emf is a ***voltage*** !

Faraday's Law of Induction

Lenz's Law

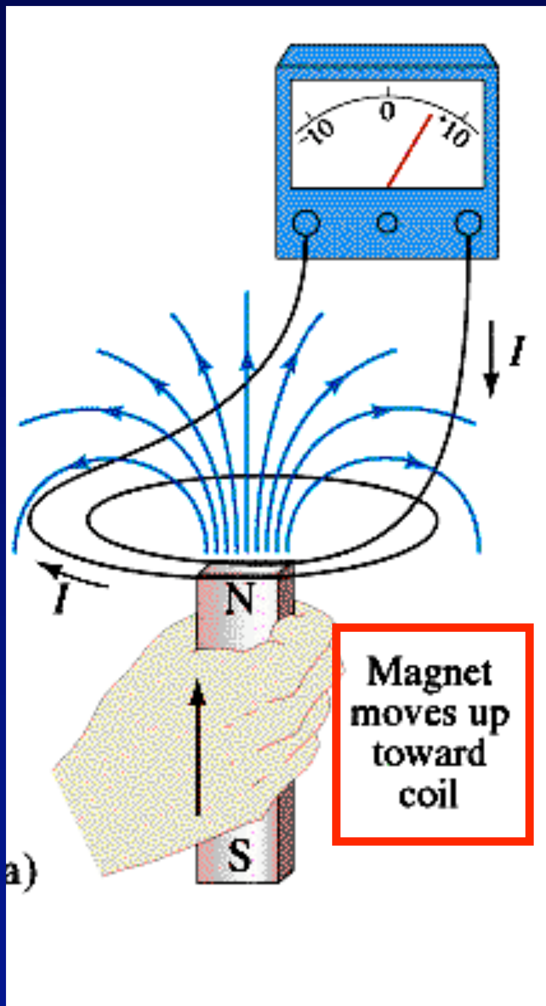
$$\boxed{\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t}}$$

induced emf

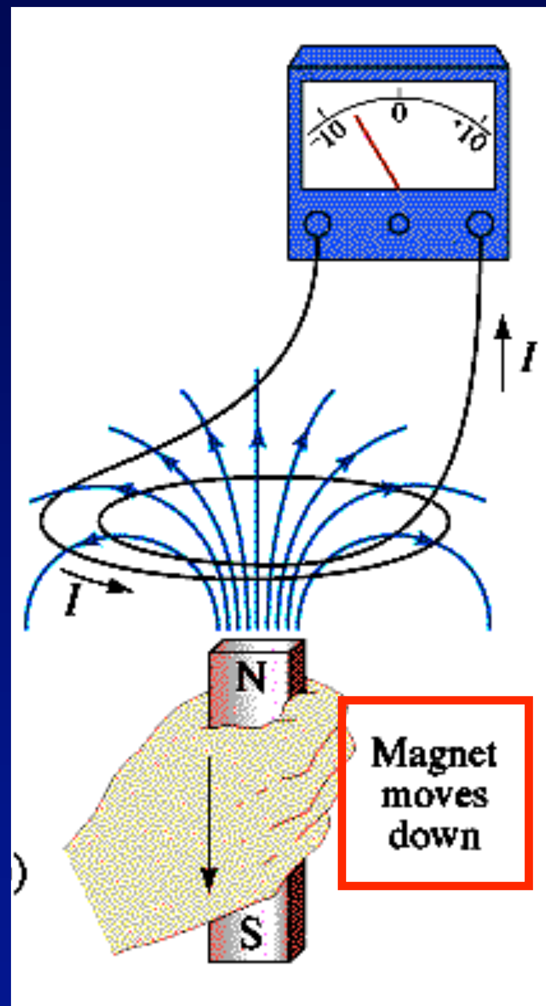
rate of change of flux with time

- **minus sign comes from Lenz's Law:**
  - **The induced emf gives rise to a current whose magnetic field *opposes* the original *change in flux.***

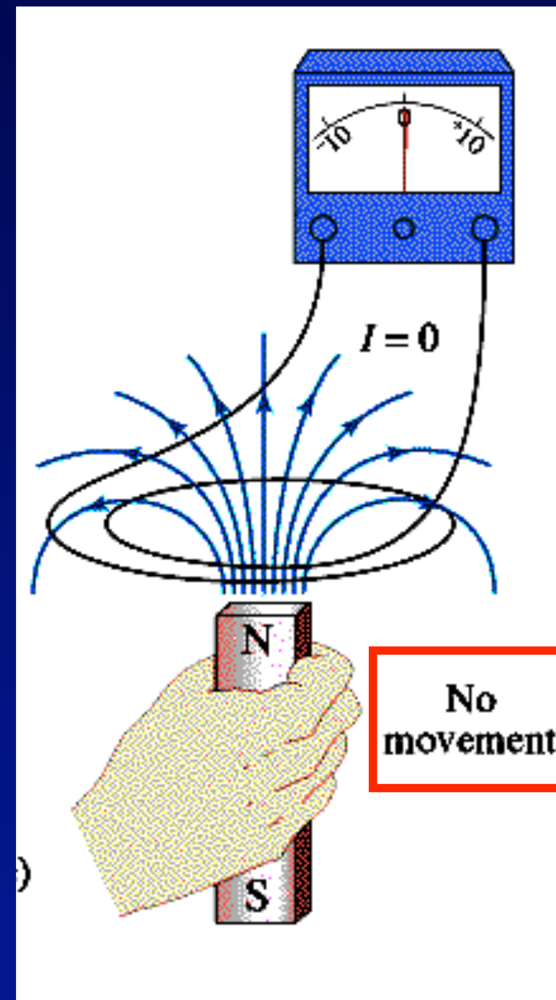
Lenz's Law



induced flux is **DOWN**



induced flux is **UP**



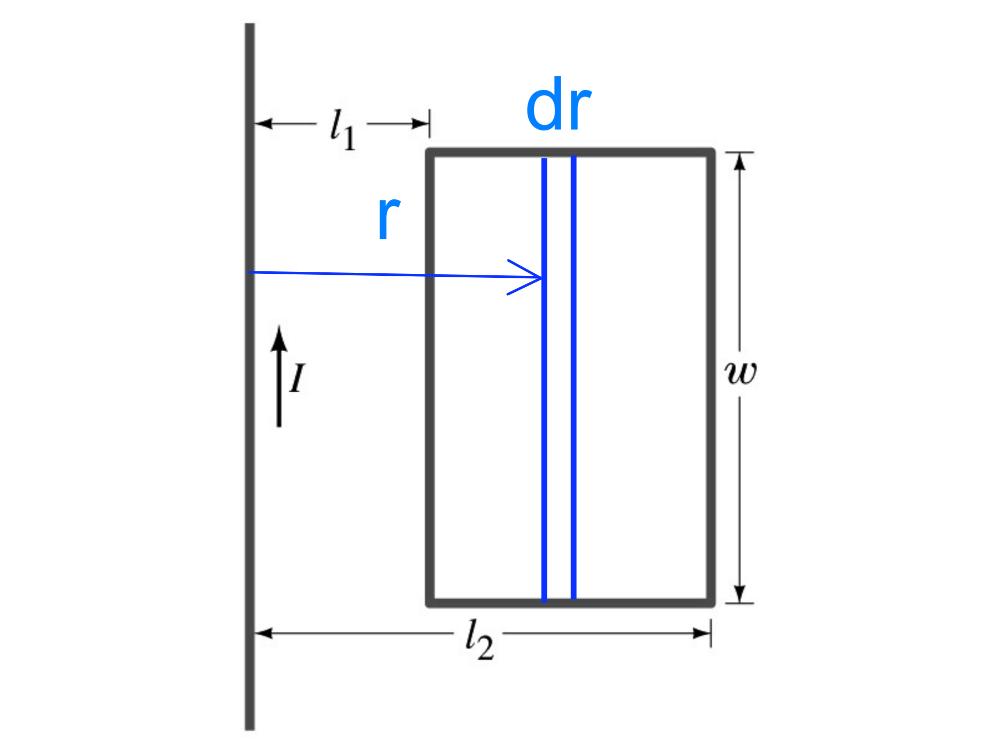
no induced flux

Example: **Determine the magnetic flux through a square loop near a long straight current-carrying wire as shown**

The B field around the wire is

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

going into the page.



The flux passing through the strip is

$$d\Phi_B = BdA = \frac{\mu_0 I}{2\pi r}(wdr)$$

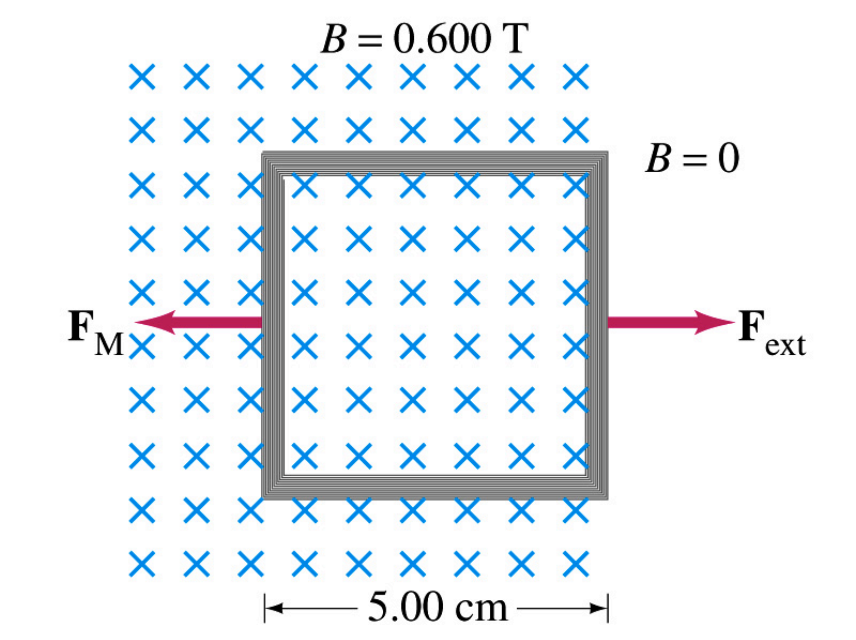
Integrate

$$\Phi_B = \frac{\mu_0 I w}{2\pi}\int_{l_1}^{l_2}\frac{dr}{r} = \frac{\mu_0 I w}{2\pi}\ln\frac{l_2}{l_1}$$

$$\boxed{\Phi_B = \frac{\mu_0 I w}{2\pi}\ln\frac{l_2}{l_1}}$$

Example (Giancoli 29-2): Puling a coil from a magnetic field

- A square coil of wire with side 5.00 cm contains 100 loops and is positioned perpendicular to an uniform 0.60-T magnetic field as shown. It is quickly and uniformly pulled from the field (moving perpendicular to B) to a region where B drops abruptly to zero. At t=0, the right edge of the coil is the edge of the field. It takes 0.100 s for the whole coil to reach the field-free region. The coil has a resistance of 100 ohm. Find
  - The rate of flux change through the coil
  - The emf and current induced
  - How much energy is dissipated in the coil?
  - What was the average force required?



ConcepTest 29.2 Induction

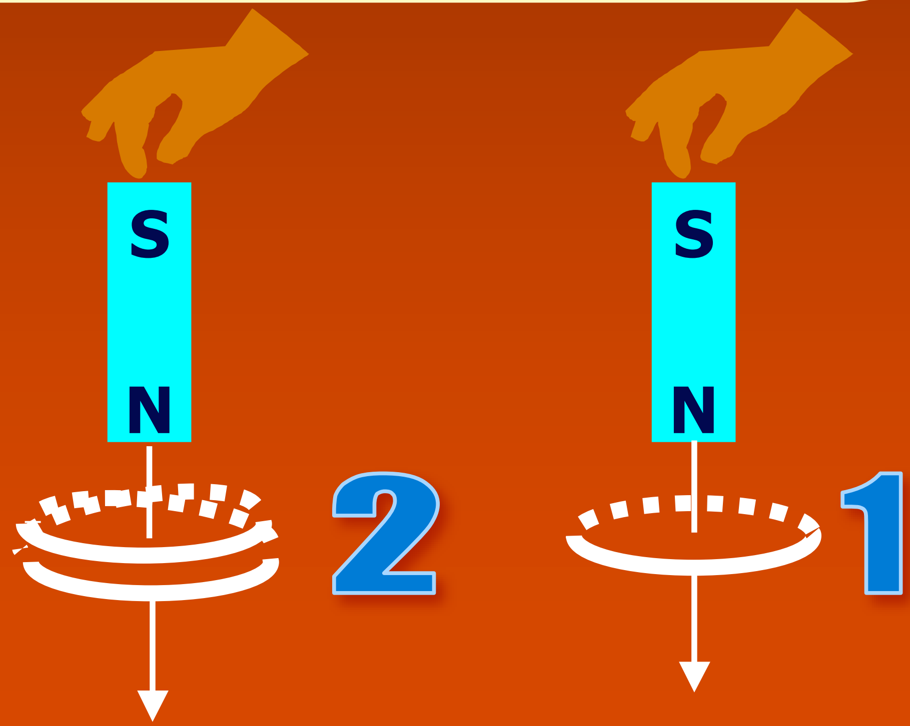
- Wire #1 (length L) forms a one-turn loop, and a bar magnet is dropped through. Wire #2 (length 2L) forms a two-turn loop, and the same magnet is dropped through. Compare the magnitude of the induced voltages in these two cases.

(1) $V_1 > V_2$

(2) $V_1 < V_2$

(3) $V_1 = V_2 \neq 0$

(4) $V_1 = V_2 = 0$



ConcepTest 29.3 Induction

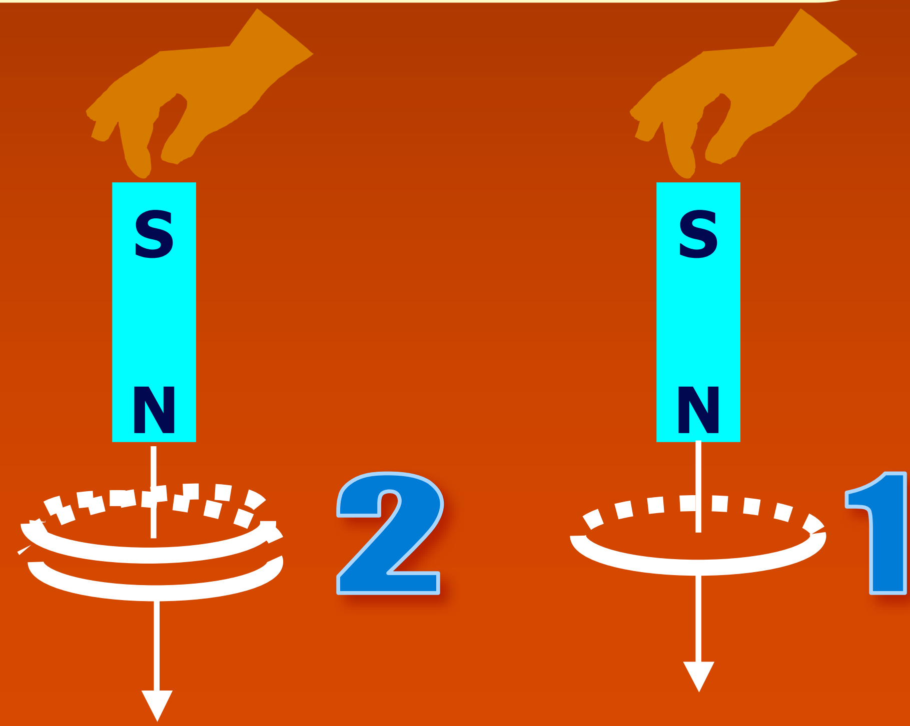
- Wire #1 (length L) forms a one-turn loop, and a bar magnet is dropped through. Wire #2 (length 2L) forms a two-turn loop, and the same magnet is dropped through. Compare the magnitude of the induced currents in these two cases.

(1) $I_1 > I_2$

(2) $I_1 < I_2$

(3) $I_1 = I_2 \neq 0$

(4) $I_1 = I_2 = 0$



Motional EMF

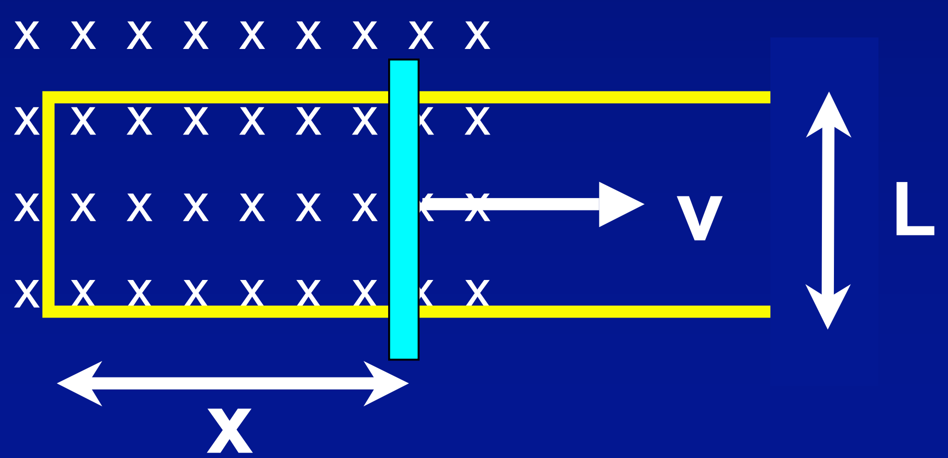
New Topic

Motional Emf (Examples 29.6, 29.7)

- Consider a conducting rod moving on metal rails in an uniform magnetic field:

$$|\mathcal{E}| = \frac{\Delta\Phi_B}{\Delta t} = \frac{\Delta(BA)}{\Delta t} = \frac{\Delta(BLx)}{\Delta t} = BL\frac{\Delta x}{\Delta t}$$

- Current will flow counter-clockwise in this “circuit”



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

ConcepTest 29.4 Induction

- If a coil is rotated from the position as shown, in a B field pointing to the left, in what direction is the induced current?

(1) clockwise
(2) counter-clockwise
(3) no induced current