

# PHYS 121H122-Lecture 12: Electromagnetic Induction

Today: Chap 29:

a) Faraday's Law

Maxwell's Laws [almost complete!]

b) Lenz's Law

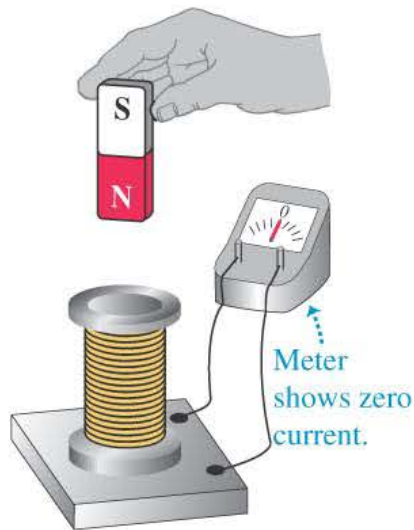
c) Examples

d) Correction to Ampere's Law

# Induced current

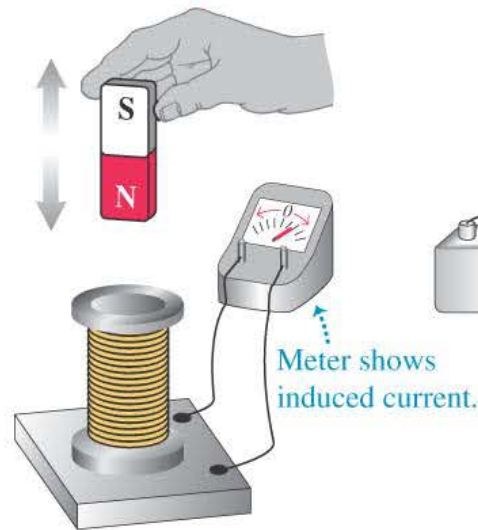
- A changing magnetic flux causes an *induced current*. See Figure 29.1 below.
- The *induced emf* is the corresponding emf causing the current.

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

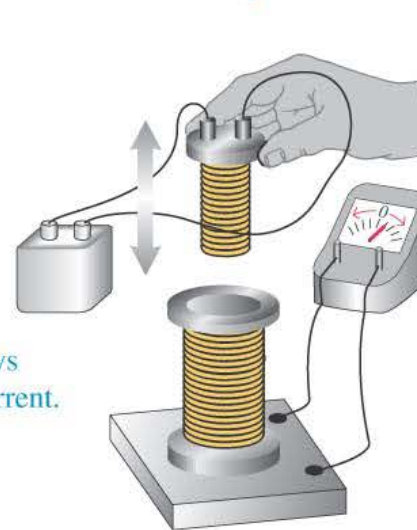


All these actions DO induce a current in the coil. What do they have in common?\*

(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*.

## Faraday's Law

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with  $\int \vec{B} \cdot d\vec{A} = \Phi_B$

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$$\nabla \times \vec{E} = -\frac{\delta \vec{B}}{\delta t}$$

## Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$$

Gauss' Law

$$\oint \vec{B} \cdot d\vec{A} = 0$$

"No Name Law"

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{enc}$$

Ampere's Law

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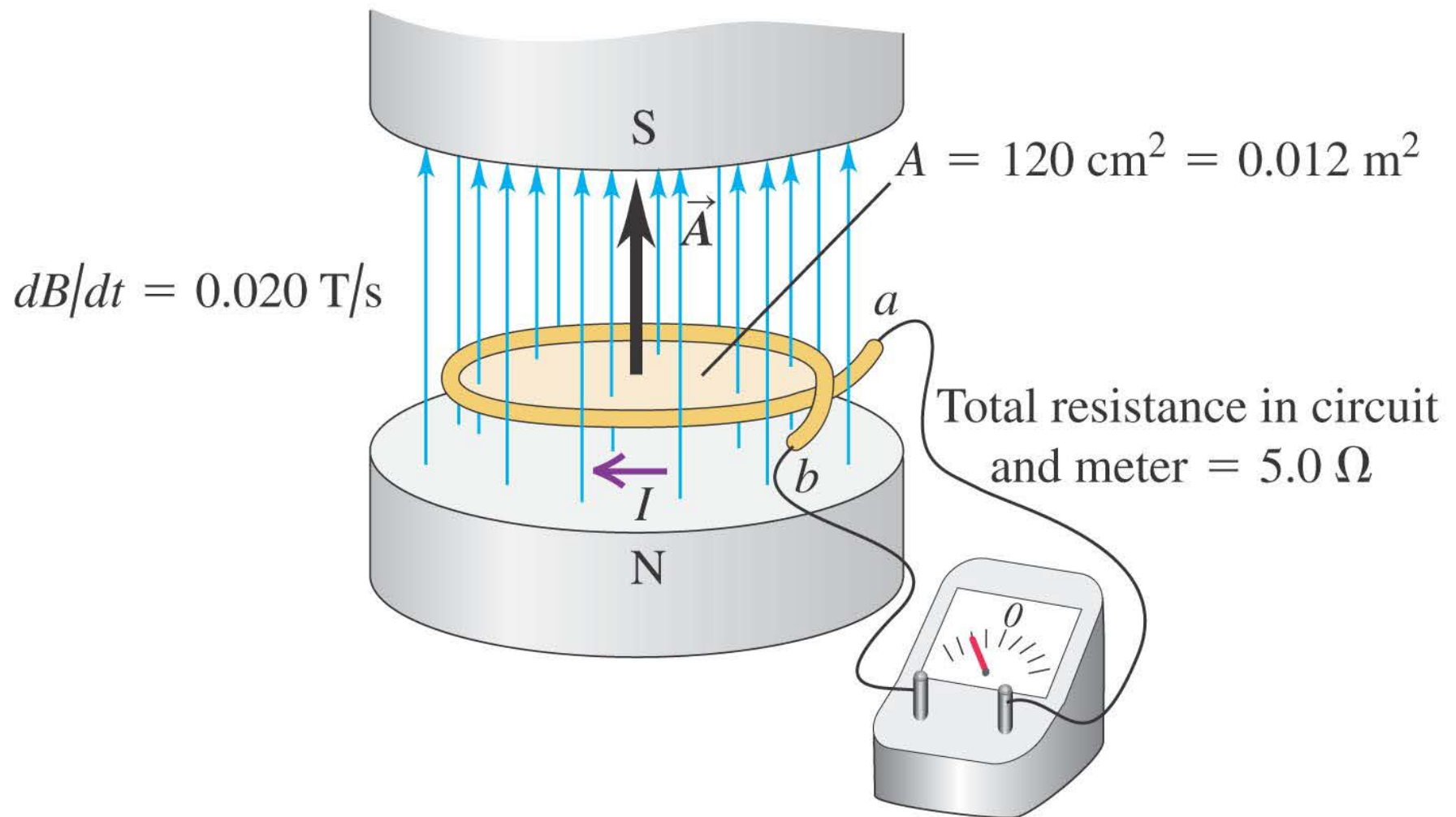
Ampere's Law

$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{\delta}{\delta t} \int \vec{B} \cdot d\vec{A}$$

Faraday's Law

# Emf and the current induced in a loop

- Follow Example 29.1 using Figure 29.5 below.



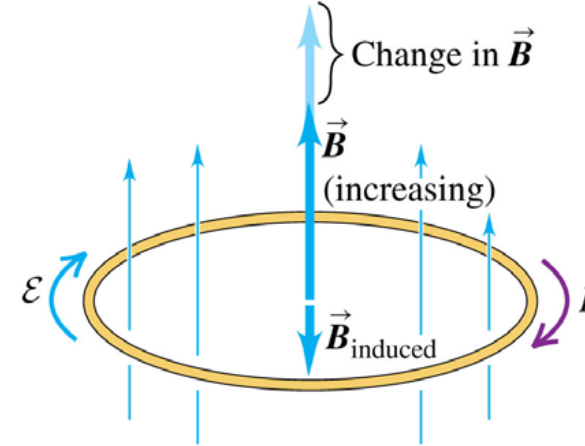
# Lenz's law

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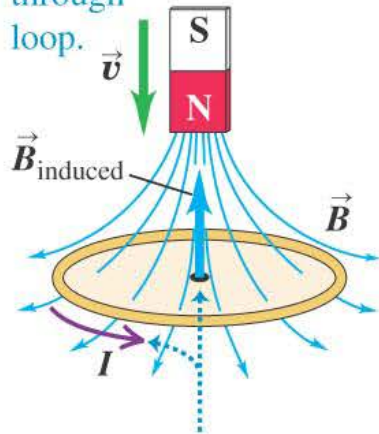
- *Lenz's law*: The direction of any magnetic induction effect is such as to oppose the cause of the effect.
- Follow Conceptual Example 29.7.

# Lenz's law and the direction of induced current

- Follow Example 29.8 using Figures 29.13 (right) and 29.14 (below).

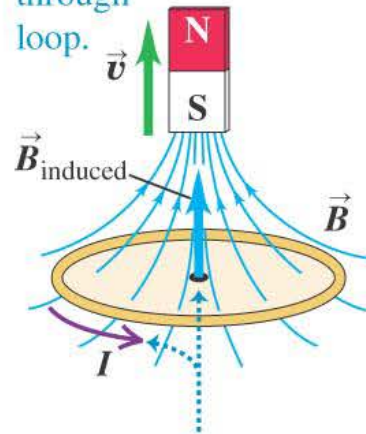


- (a) Motion of magnet causes increasing downward flux through loop.

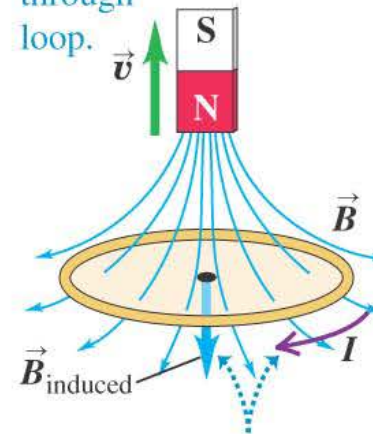


The induced magnetic field is *upward* to oppose the flux change. To produce this induced field, the induced current must be *counterclockwise* as seen from above the loop.

- (b) Motion of magnet causes decreasing upward flux through loop.

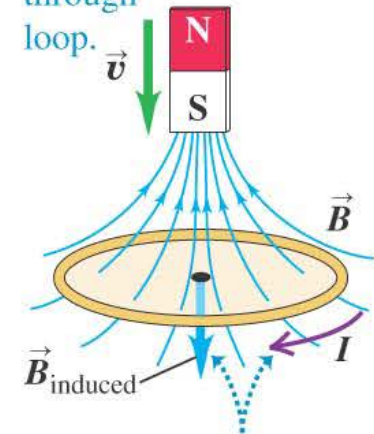


- (c) Motion of magnet causes decreasing downward flux through loop.



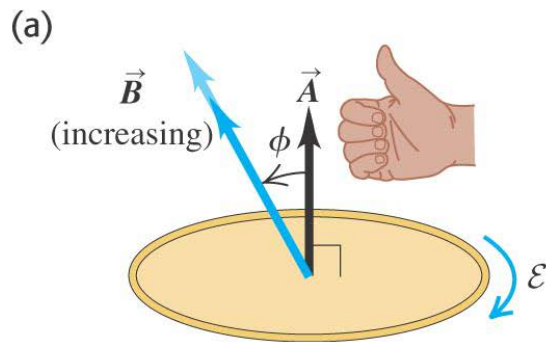
The induced magnetic field is *downward* to oppose the flux change. To produce this induced field, the induced current must be *clockwise* as seen from above the loop.

- (d) Motion of magnet causes increasing upward flux through loop.

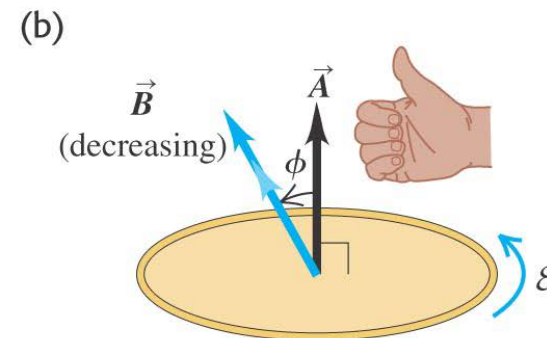


# Direction of the induced emf

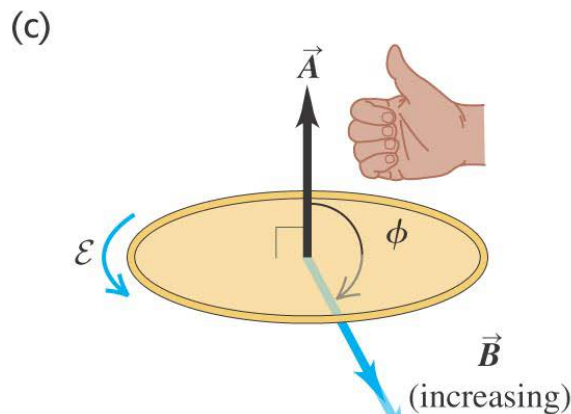
- Follow the text discussion on the direction of the induced emf, using Figure 29.6 below.



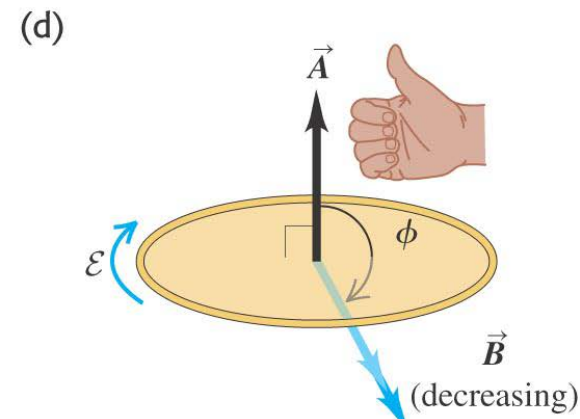
- Flux is positive ( $\Phi_B > 0$ ) ...
- ... and becoming more positive ( $d\Phi_B/dt > 0$ ).
- Induced emf is negative ( $\mathcal{E} < 0$ ).



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



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

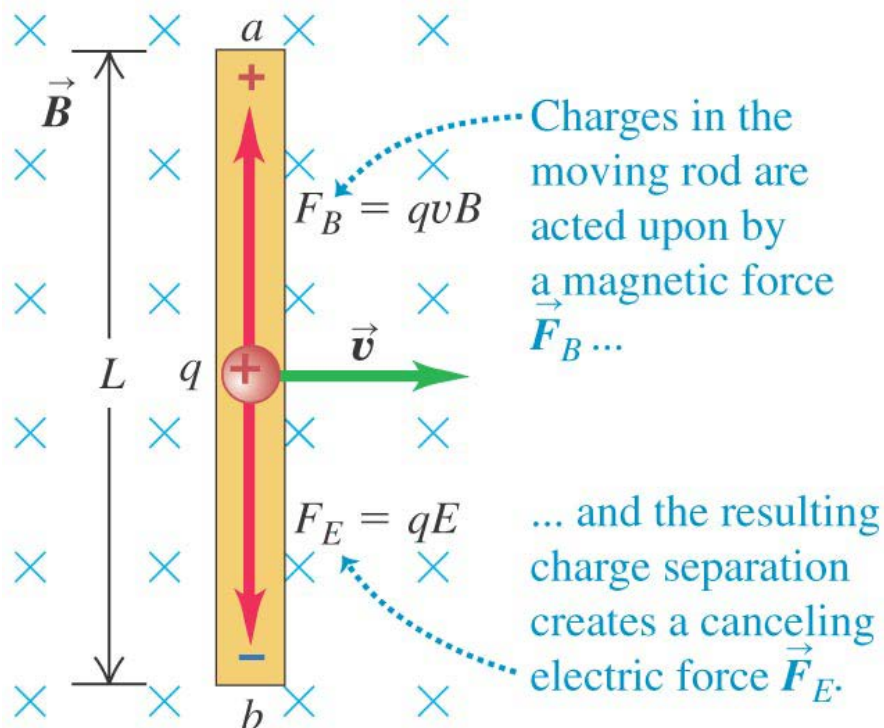


- Flux is negative ( $\Phi_B < 0$ ) ...
- ... and becoming less negative ( $d\Phi_B/dt > 0$ ).
- Induced emf is negative ( $\mathcal{E} < 0$ ).

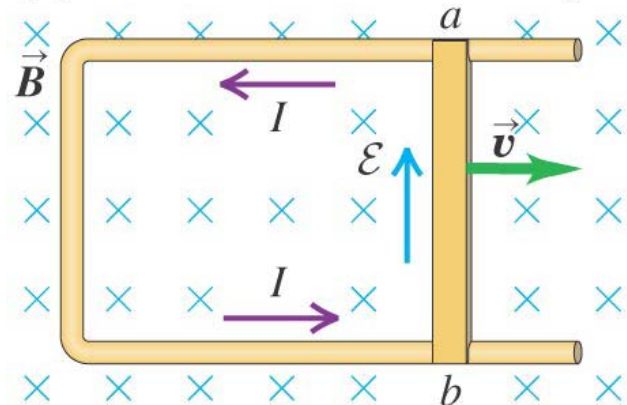
# Motional electromotive force

- The *motional electromotive force* across the ends of a rod moving perpendicular to a magnetic field is  $\xi = vBL$ . Figure 29.15 below shows the direction of the induced current.
- Follow the general form of motional emf in the text.

(a) Isolated moving rod



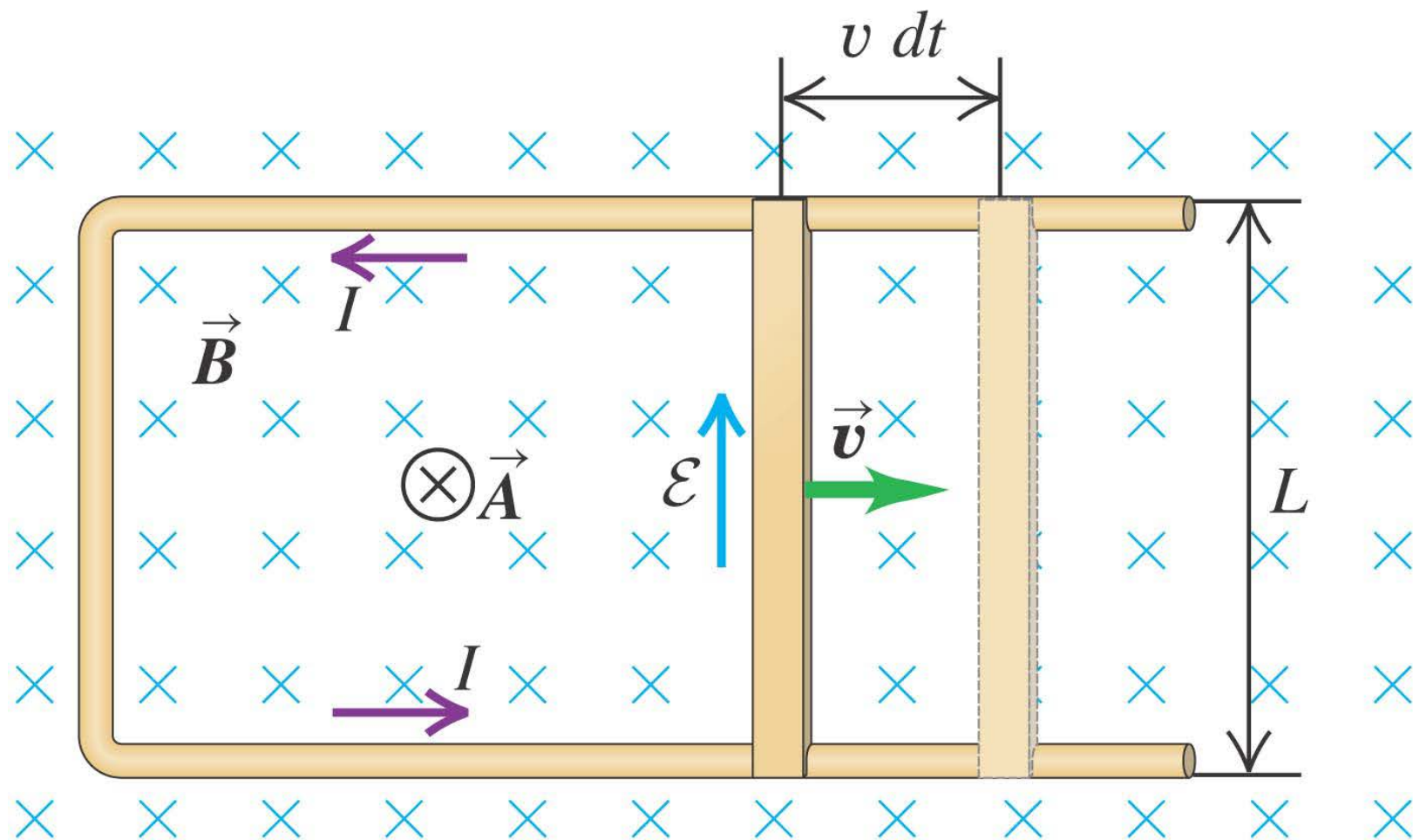
(b) Rod connected to stationary conductor



The motional emf  $\mathcal{E}$  in the moving rod creates an electric field in the stationary conductor.

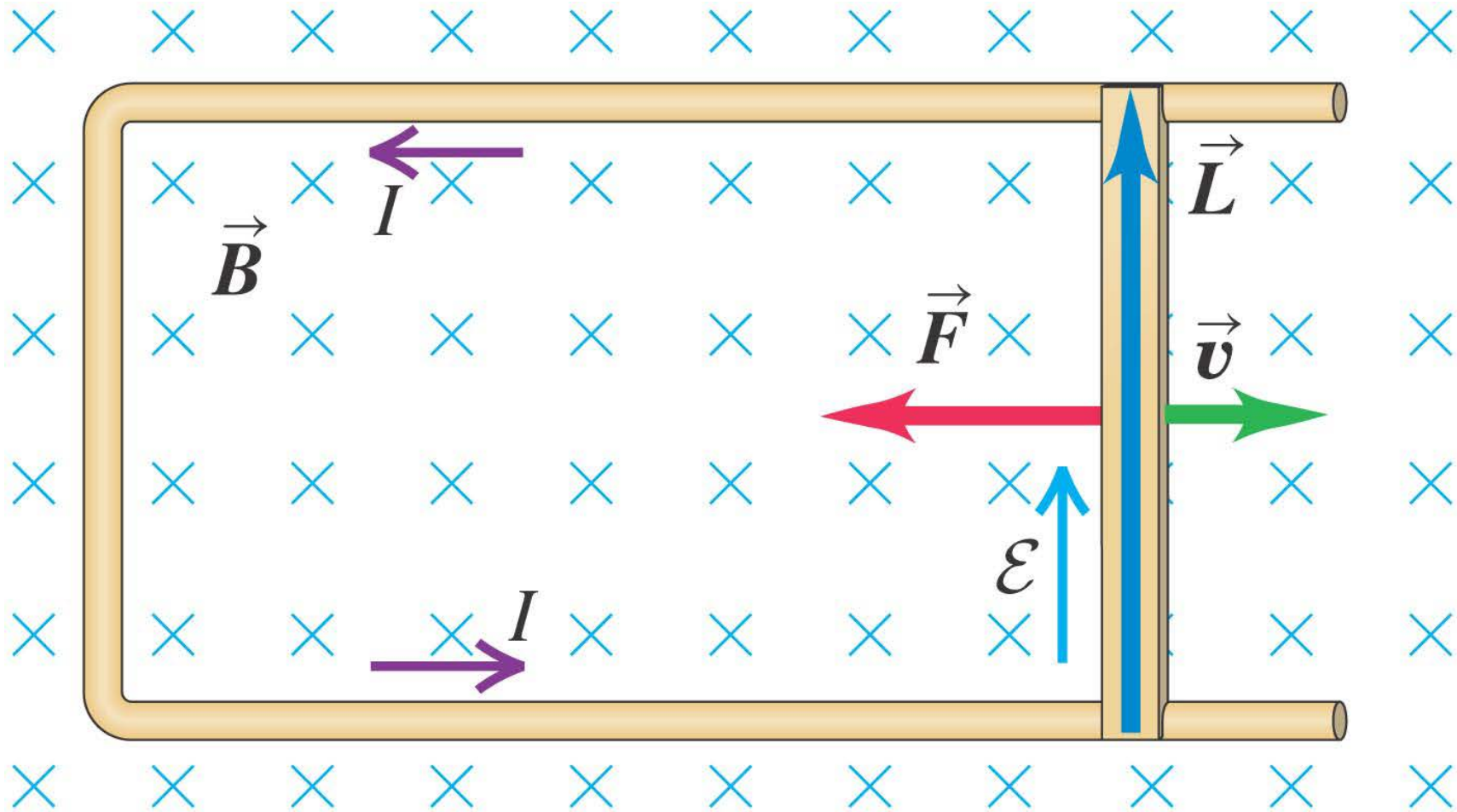
# Slidewire generator

- Follow Example 29.5 using Figure 29.11 below.



## Work and power in the slidewire generator

- Follow Example 29.6 using Figure 29.12 below.





## Maxwell's Equations To Date

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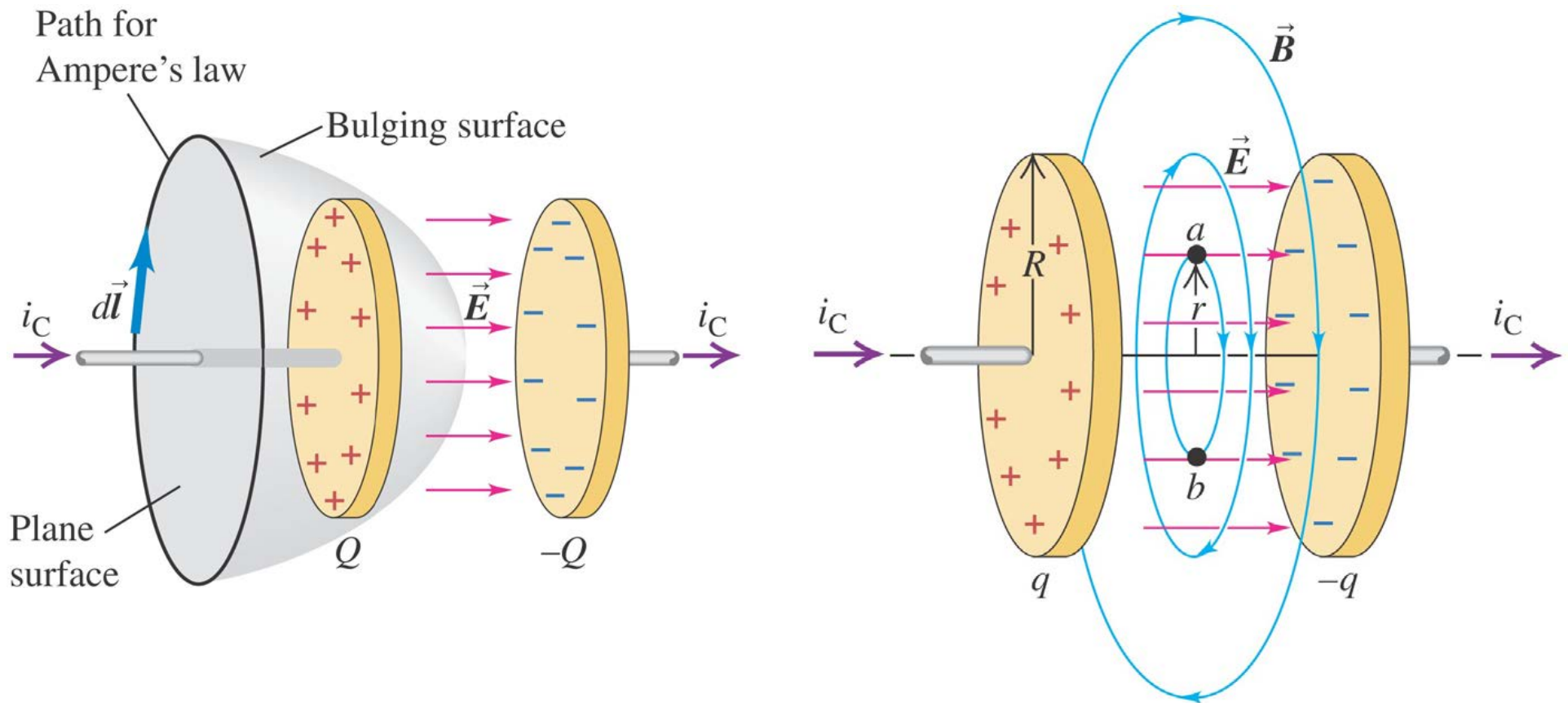
Ampere's Law

$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{\delta}{\delta t} \int \vec{B} \cdot d\vec{A}$$

Faraday's Law

# Displacement current

- Follow the text discussion displacement current using Figures 29.21 and 29.22 below.



## Maxwell's Equations To Date

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## Maxwell's Equations To Date

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Faraday's Law

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Gauss' Law

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$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{e\_enc} + \frac{\delta}{\delta t} \int \vec{E} \cdot d\vec{A}$$

Ampere's Law

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Faraday's Law

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**But no magnetic monopoles have been found!  
So no magnetic current!**

## Maxwell's Equations To Date

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Ampere's Law  
w/ Maxwell's Correction

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Faraday's Law

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