PHYS 122-Lecture 12: Electromagnetic Induction

Today: Chap 29:

a) Faraday's Law

Maxwell's Laws [almost complete!]

b) Lenz's Law

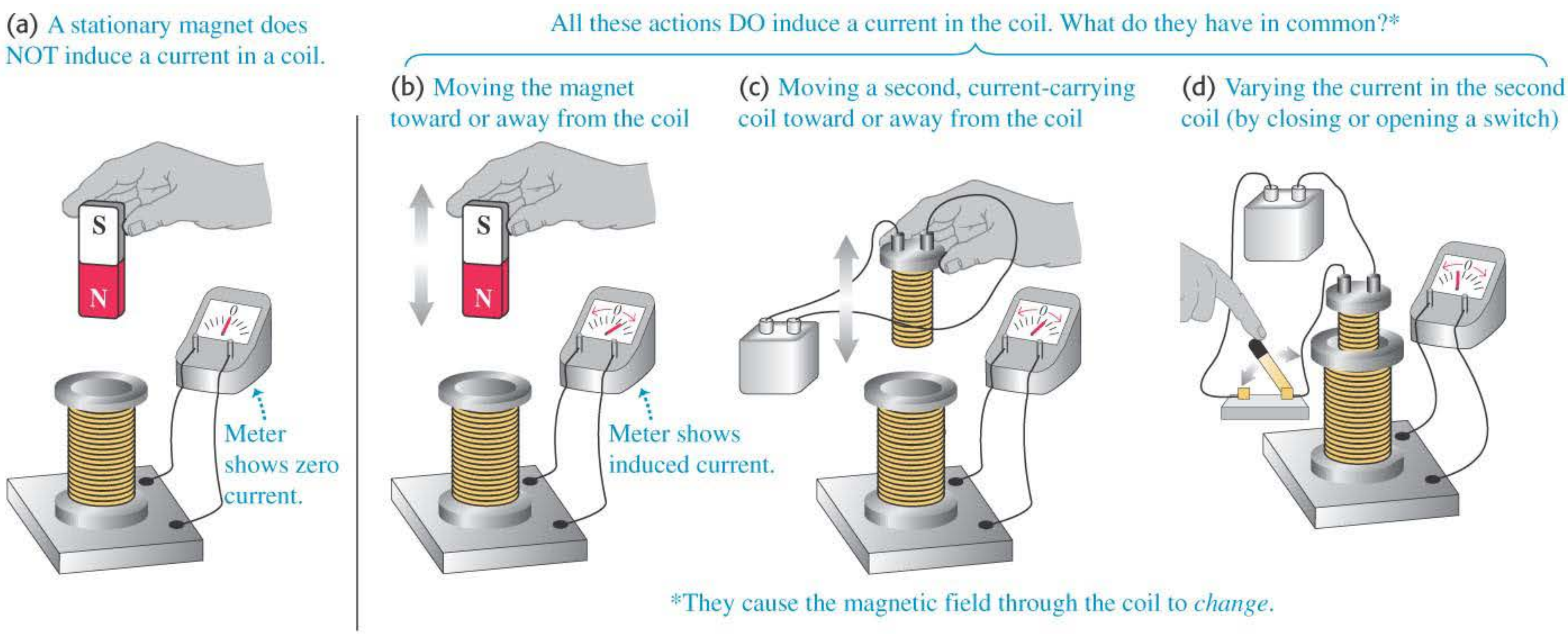
c) Examples

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.



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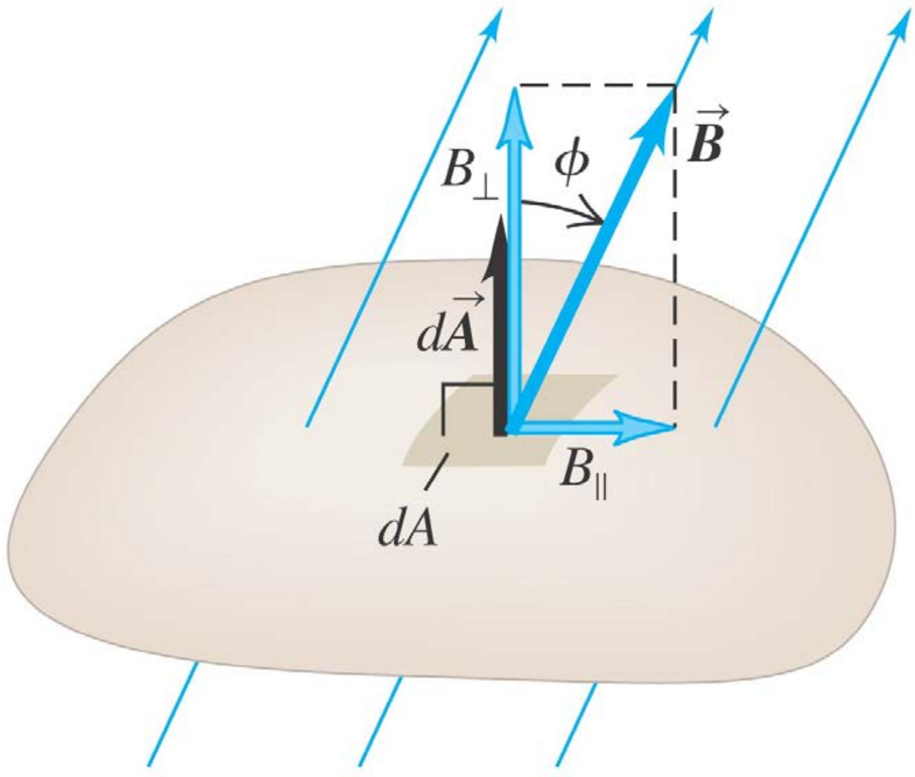
Magnetic flux through an area element

- Figure 29.3 below shows how to calculate the magnetic flux through an element of area.



Magnetic flux through element of area $d\vec{A}$:
$$d\Phi_B = \vec{B} \cdot d\vec{A} = B_\perp dA = B\, dA \cos\phi$$

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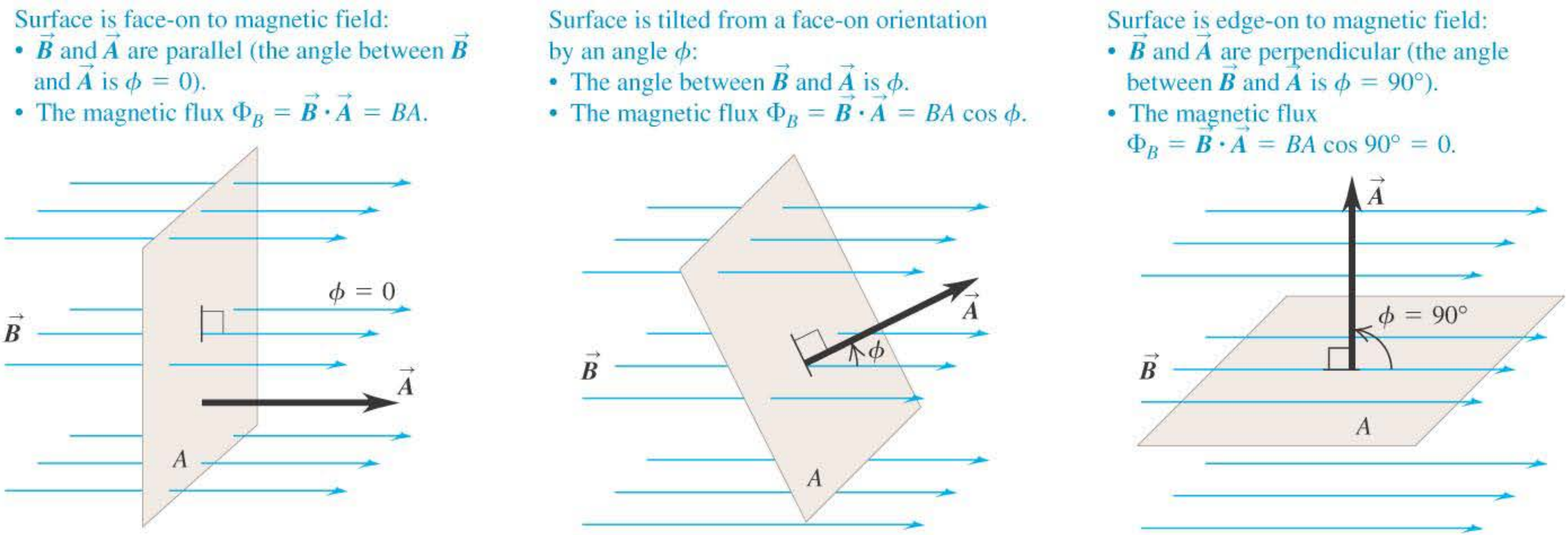
Faraday's law

- The flux depends on the orientation of the surface with respect to the magnetic field. See Figure 29.4 below.
- *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, or $\xi = -d\Phi_B/dt$.



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Faraday's Law

$$V = -\frac{\delta}{\delta t}\Phi$$

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

Faraday's Law

$$\text{V} = -\frac{\delta}{\delta t}\Phi$$

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

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

Faraday's Law

$$V = -\frac{\delta}{\delta t}\Phi$$

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

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

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

Faraday's Law

$$V = -\frac{\delta}{\delta t}\Phi$$

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

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

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

$$\oint (\nabla \times \vec{E}) \cdot d\vec{A} = -\frac{\delta}{\delta t}\int \vec{B} \cdot d\vec{A}$$

Faraday's Law

$$\boxed{V = -\frac{\delta}{\delta t}\Phi}$$

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

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

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

$$\oint (\nabla \times \vec{E}) \cdot d\vec{A} = -\frac{\delta}{\delta t}\int \vec{B} \cdot d\vec{A}$$

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

Maxwell's Equations To Date

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

Gauss' Law

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

"No Name Law"

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

Ampere's Law

$$V = -\frac{\delta}{\delta t}\Phi$$

Faraday's Law

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

Maxwell's Equations To Date

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

Gauss' Law

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

"No Name Law"

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

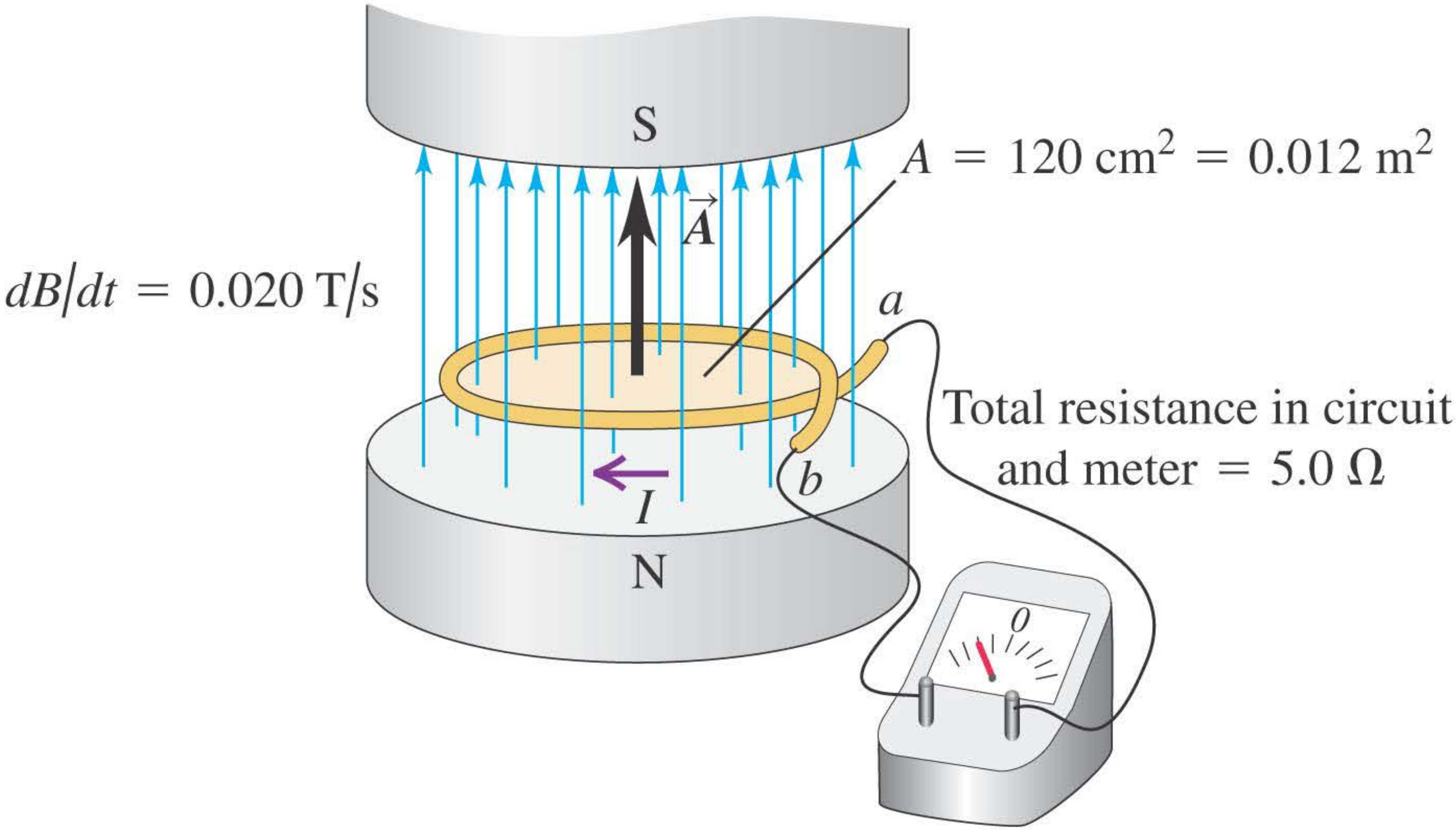
Ampere's Law

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

Faraday's Law

Emf and the current induced in a loop

- Follow Example 29.1 using Figure 29.5 below.



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Lenz's law

- *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.

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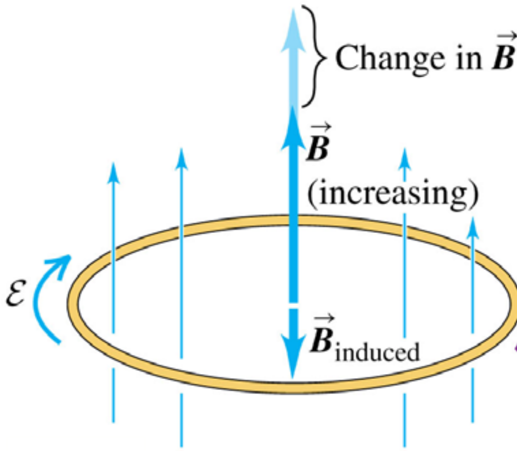
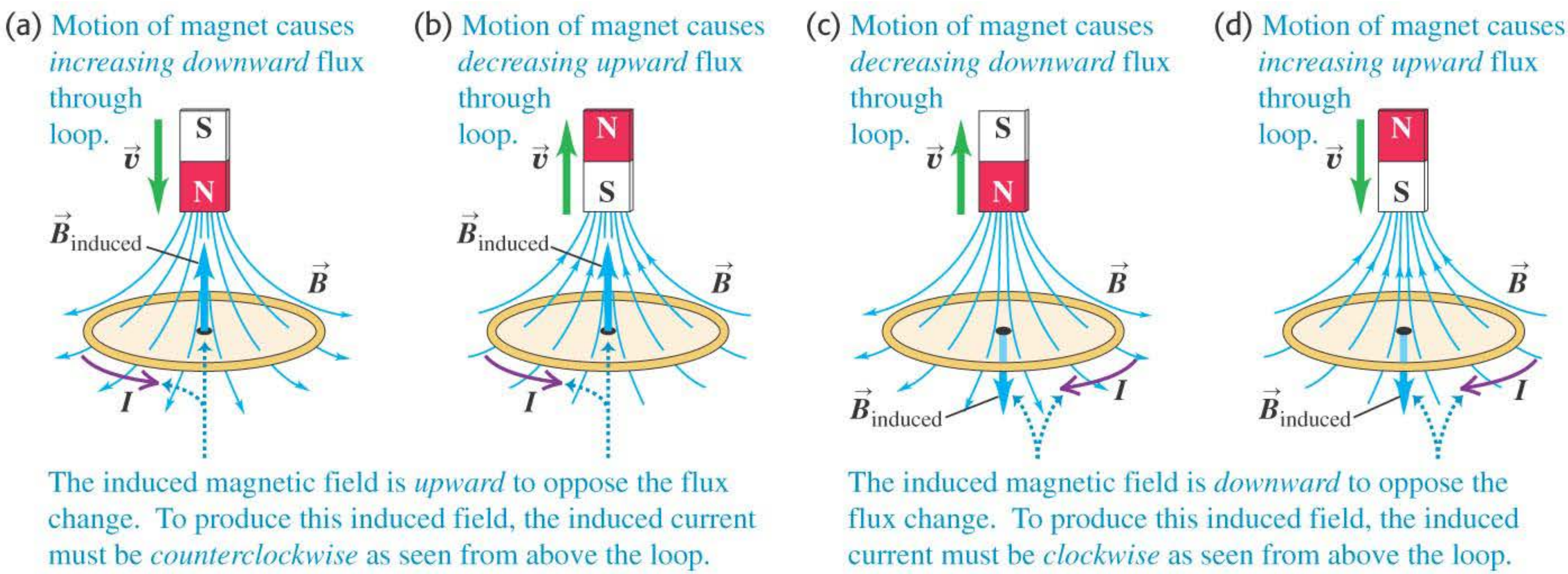
Lenz's law and the direction of induced current

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





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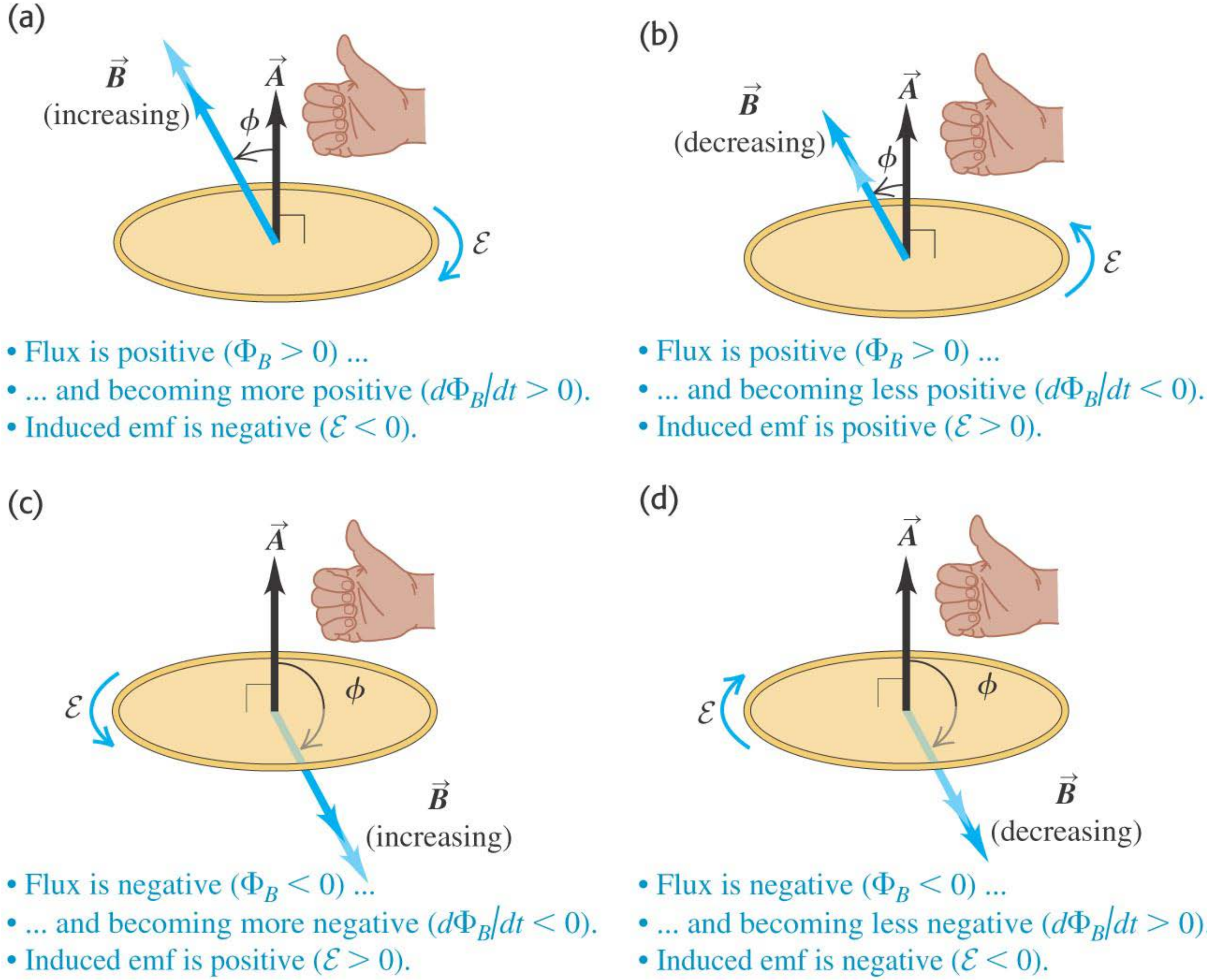
Direction of the induced emf

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



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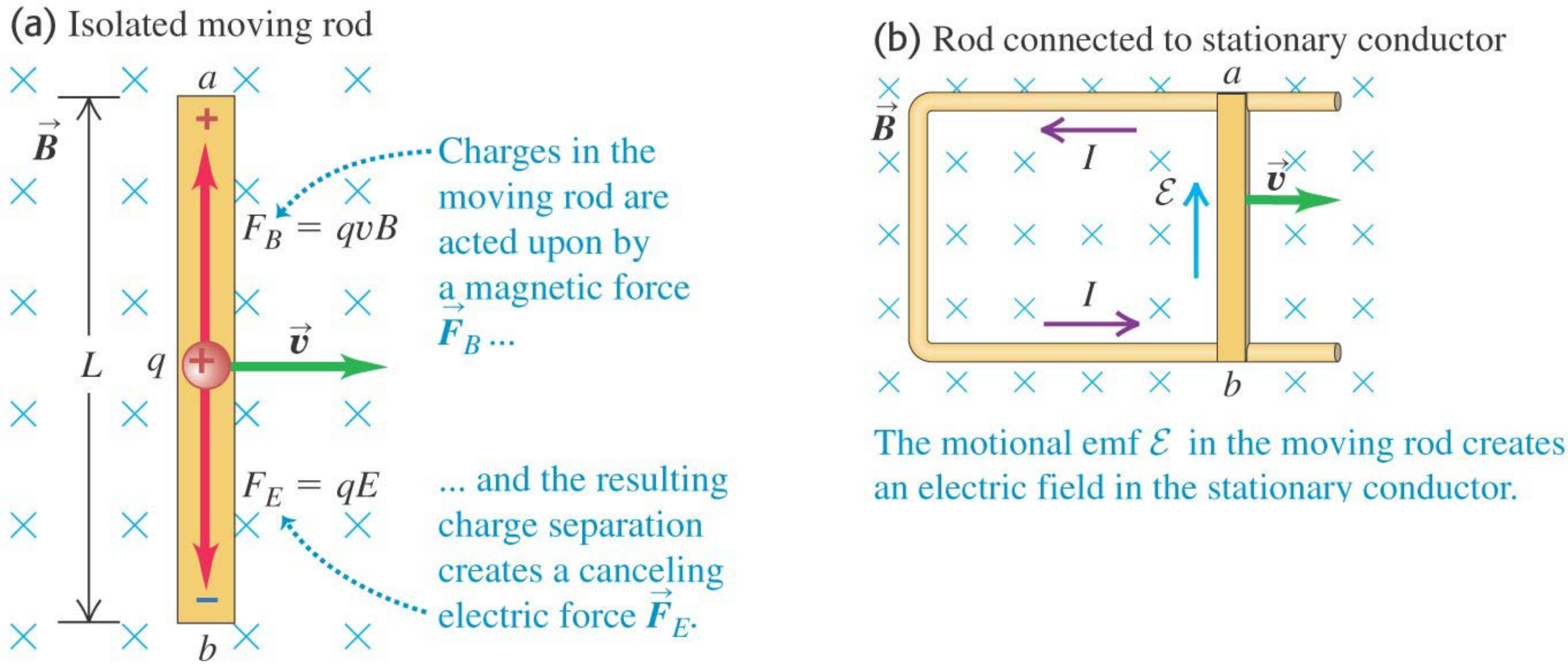
Motional electromotive force

- 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.



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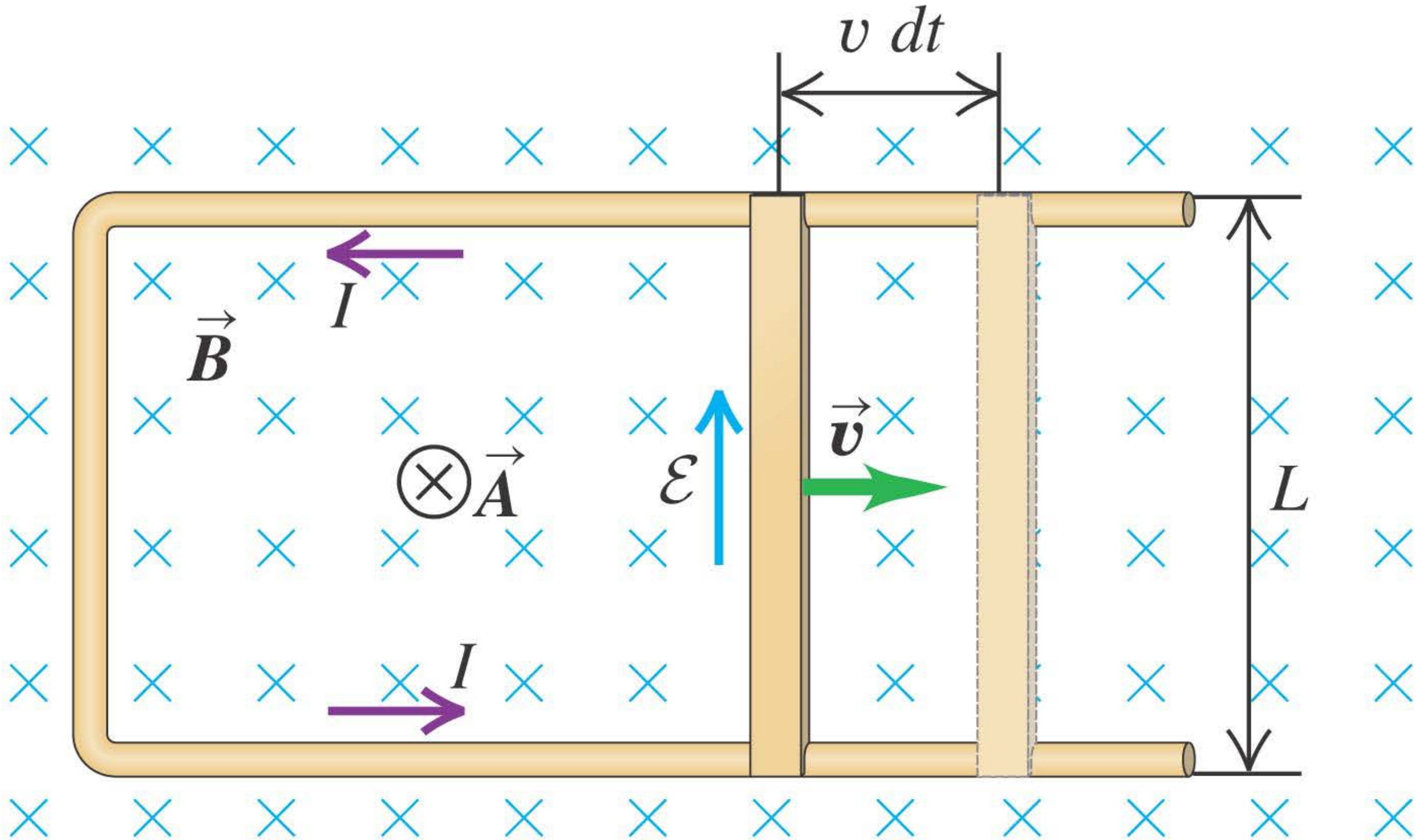
Slidewire generator

- Follow Example 29.5 using Figure 29.11 below.



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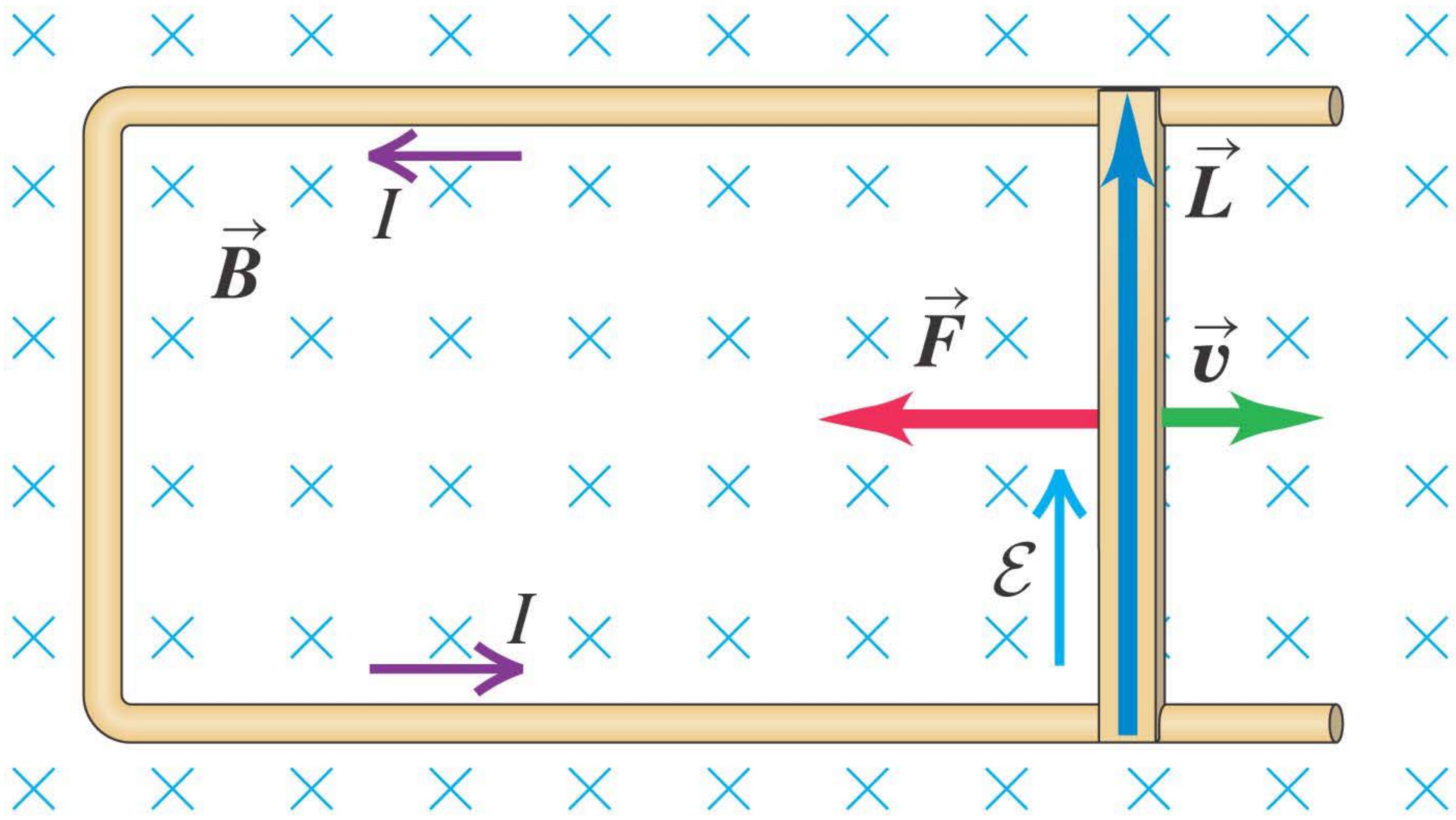
Work and power in the slidewire generator

- Follow Example 29.6 using Figure 29.12 below.



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Maxwell's Equations To Date

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

Gauss' Law

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

"No Name Law"

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

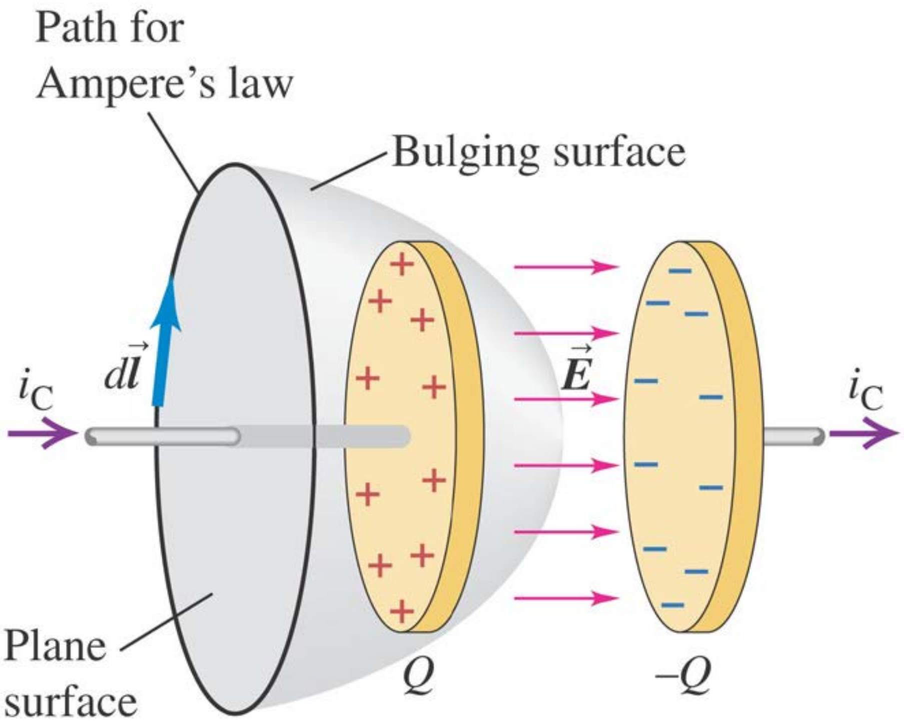
Ampere's Law

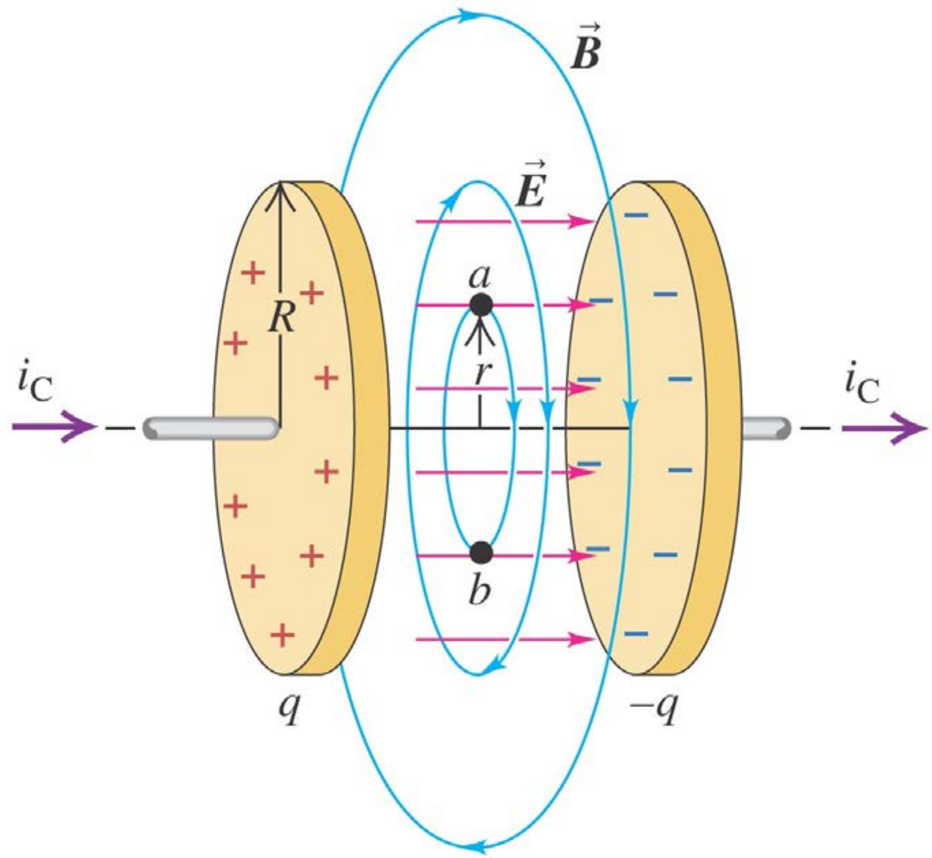
$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{\delta}{\delta t} \int \vec{B} \cdot d\vec{A}$$

Faraday's Law

Displacement current

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





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Maxwell's Equations To Date

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

Gauss' Law

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

"No Name Law"

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

Ampere's Law

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

Faraday's Law

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

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

"No Name Law"

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{e\_enc}$$

Ampere's Law

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

Faraday's Law

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

$$\oint \vec{B} \cdot d\vec{A} = \frac{Q_{m\_enc}}{\mu_o}$$

"No Name Law"

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{e\_enc}$$

Ampere's Law

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

Faraday's Law

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

$$\oint \vec{B} \cdot d\vec{A} = \frac{Q_{m\_enc}}{\mu_o}$$

"No Name Law"

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{e\_enc}$$

Ampere's Law

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

Faraday's Law

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

$$\oint \vec{B} \cdot d\vec{A} = \frac{Q_{m\_enc}}{\mu_o}$$

"No Name Law"

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

Ampere's Law

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

Faraday's Law

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

$$\oint \vec{B} \cdot d\vec{A} = \frac{Q_{m\_enc}}{\mu_o}$$

"No Name Law"

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{e\_enc} - \epsilon_o \, \mu_o \frac{\delta}{\delta t} \int \vec{E} \cdot d\vec{A}$$

Ampere's Law

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

Faraday's Law

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

$$\oint \vec{B} \cdot d\vec{A} = \frac{Q_{m\_enc}}{\mu_o}$$

"No Name Law"

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

Ampere's Law

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

Faraday's Law

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

Maxwell's Equations To Date

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{e\_enc}}{\epsilon_o}$$

Gauss' Law

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

"No Name Law"

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

Ampere's Law
w/ Maxwell's Correction

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

Faraday's Law

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