PHYS 121H122-Lecture 12:
Electromagnetic Induction

Today: Chap 29:

a) Faraday's Law

Maxwell's Laws [almost complete!]

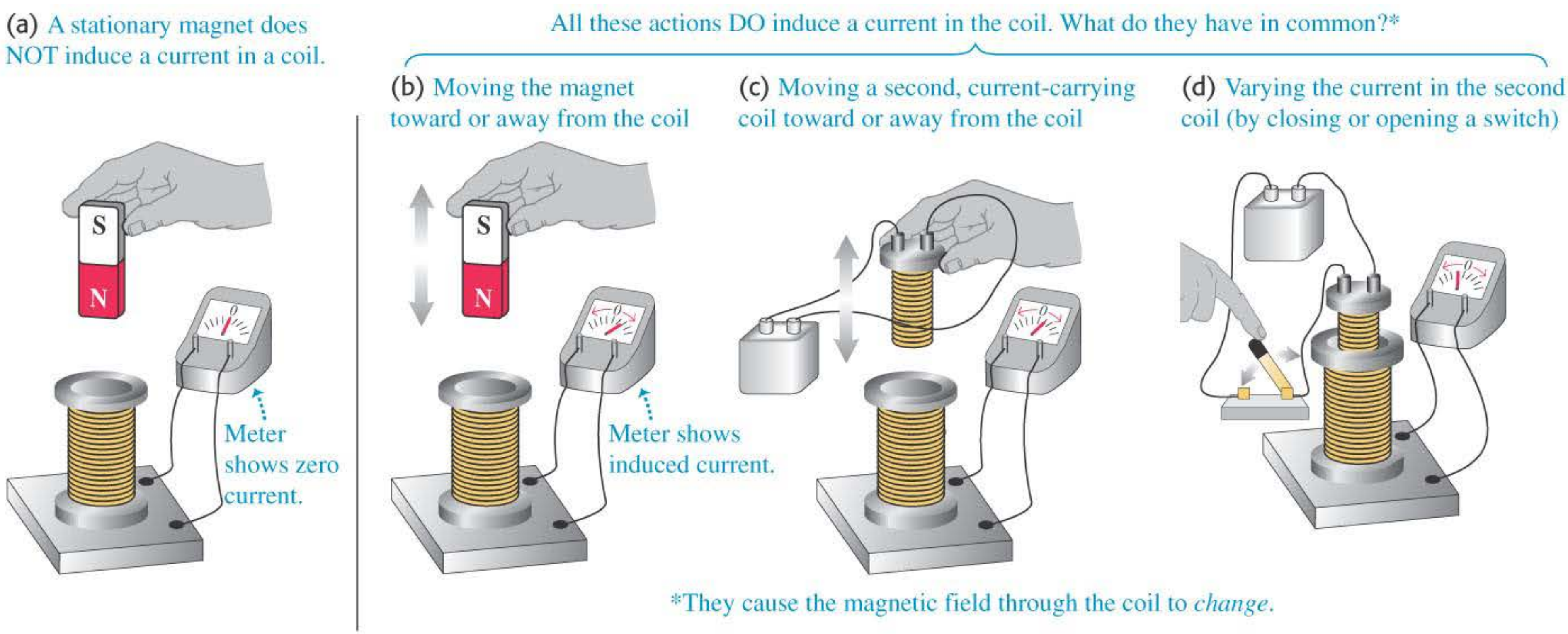
b) Lenz's Law

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.



Faraday's Law

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

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

Faraday's Law

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

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

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

Faraday's Law

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

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

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

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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

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

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

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

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

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

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

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

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

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"

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

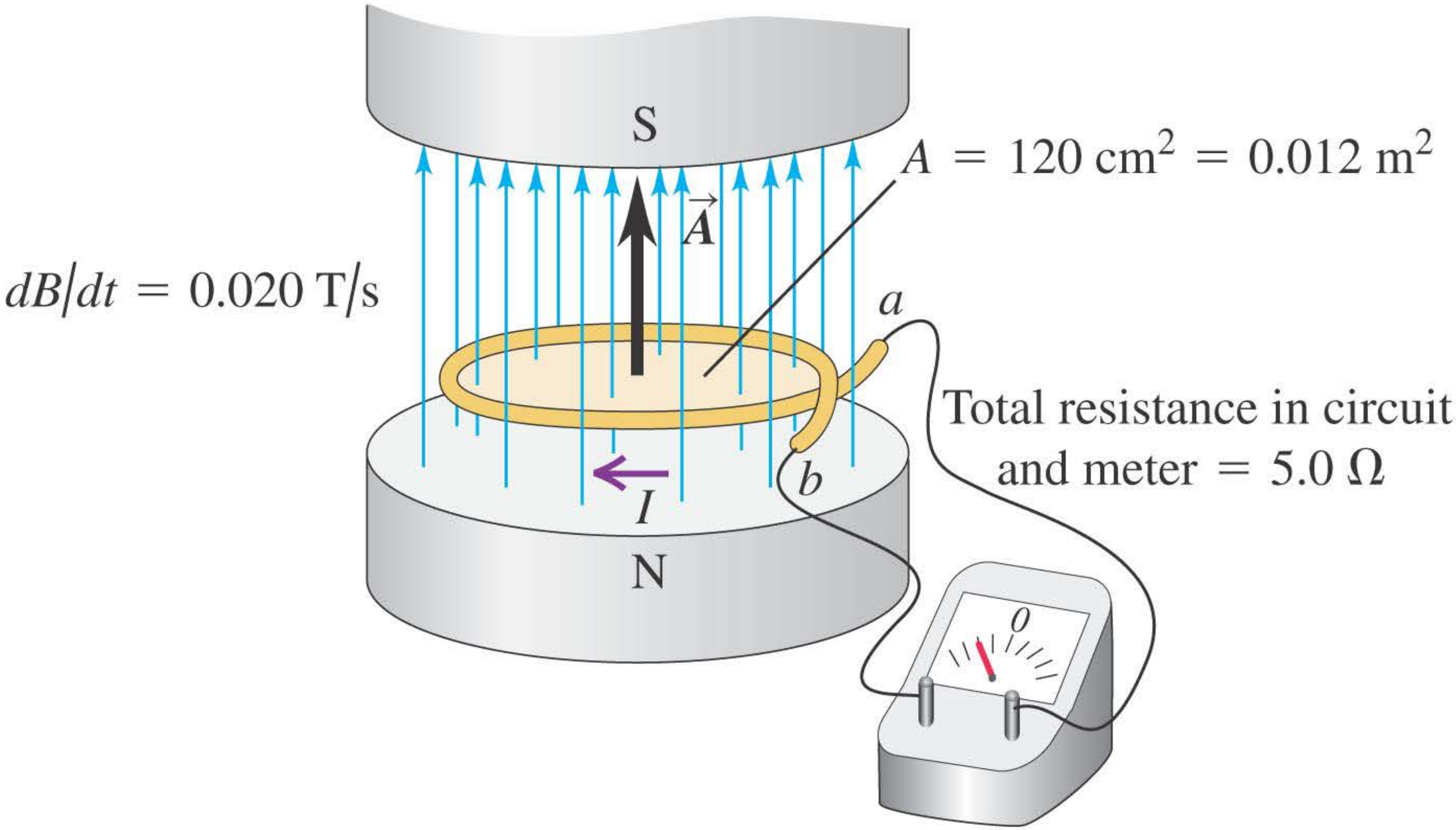
Ampere's Law

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

Faraday's Law

Emf and the current induced in a loop

- Follow Example 29.1 using Figure 29.5 below.

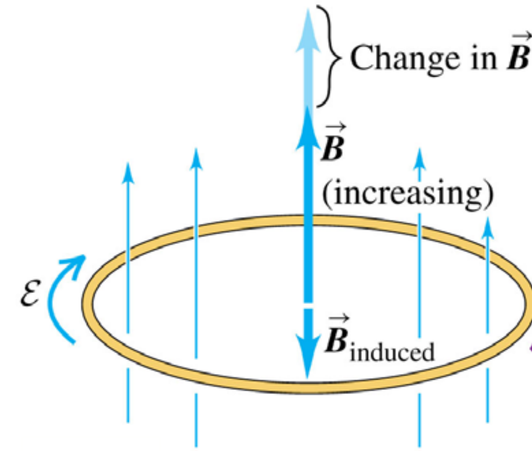


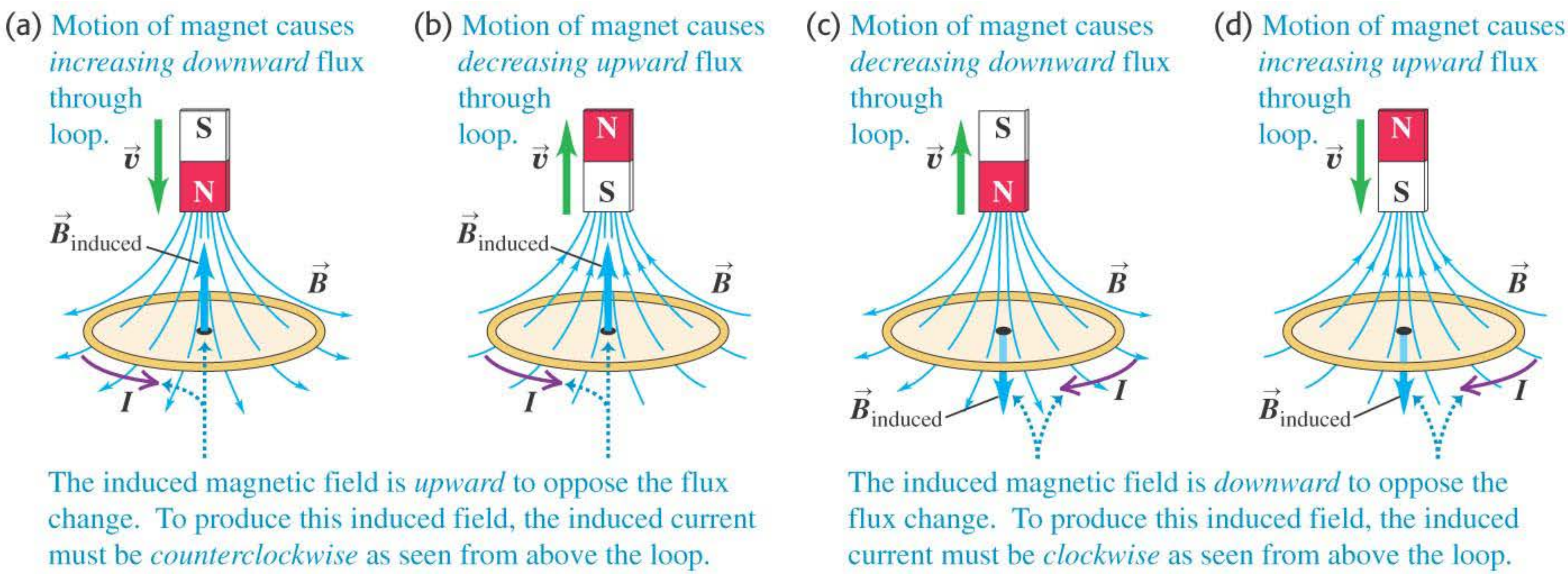
Lenz's law

- *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.

Lenz's law and the direction of induced current

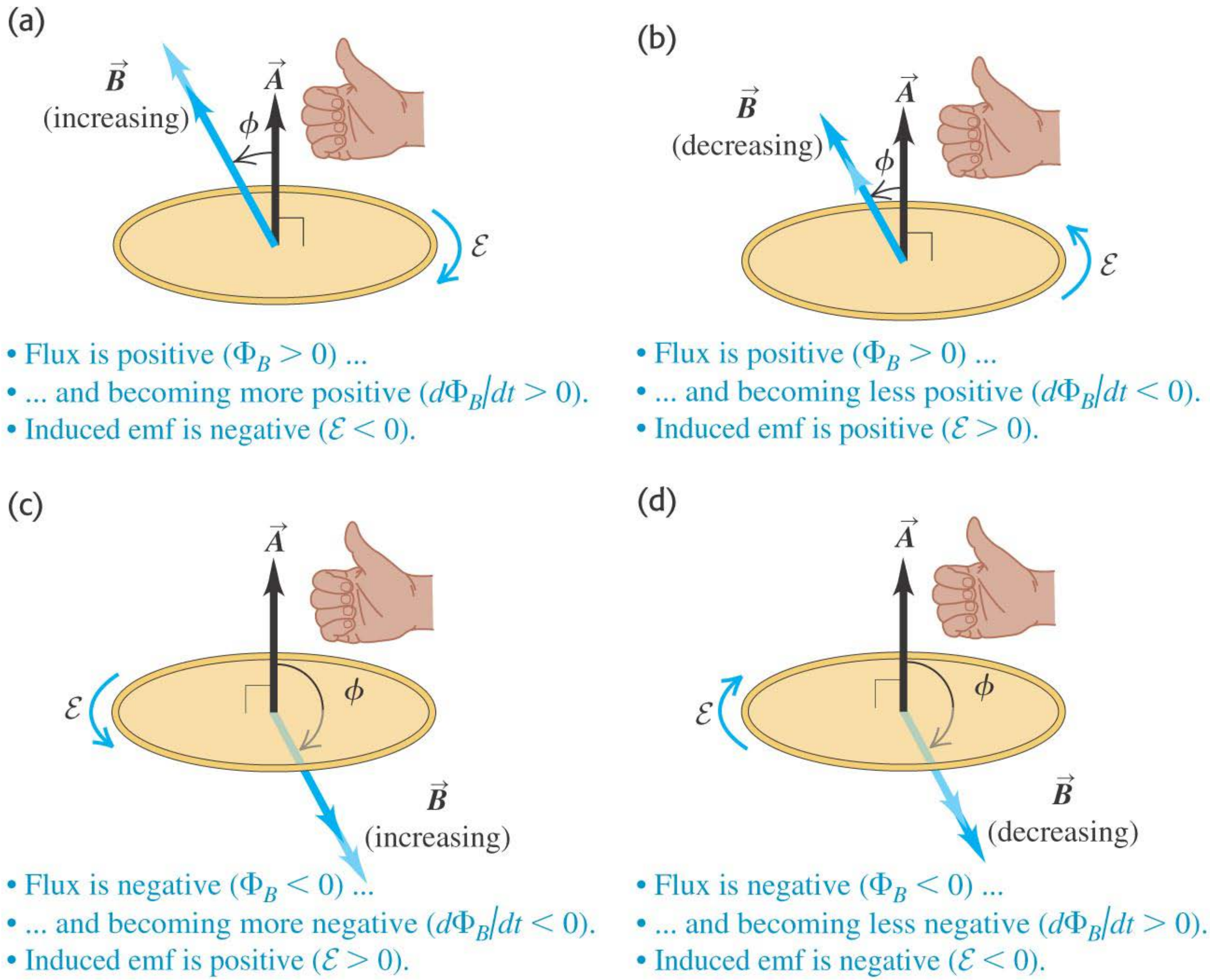
- Follow Example 29.8 using Figures 29.13 (right) and 29.14 (below).





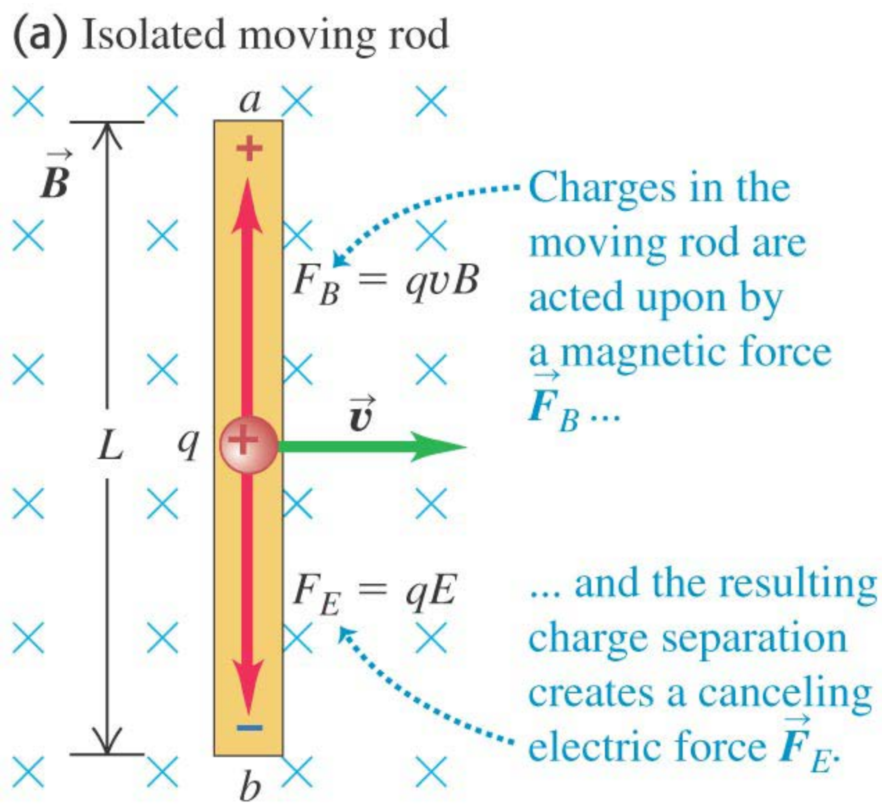
Direction of the induced emf

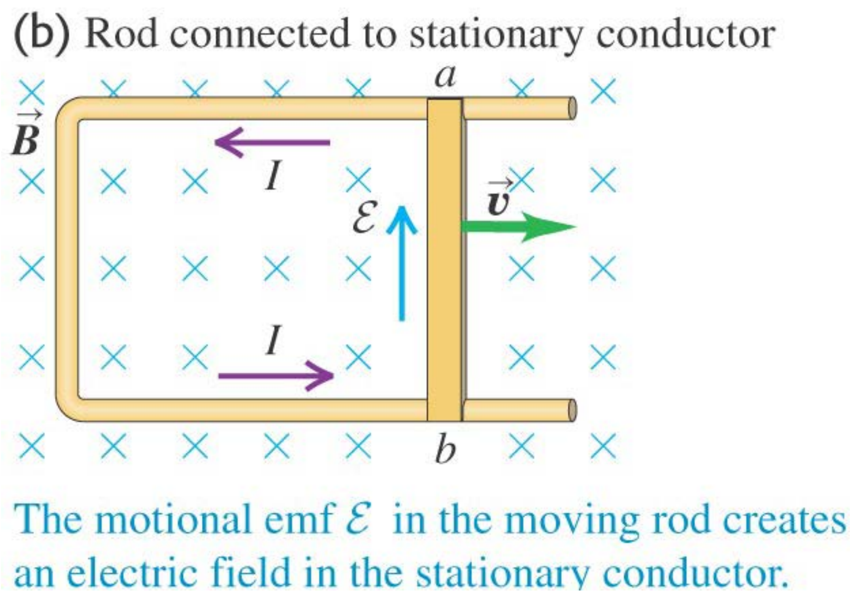
- Follow the text discussion on the direction of the induced emf, using Figure 29.6 below.



Motional electromotive force

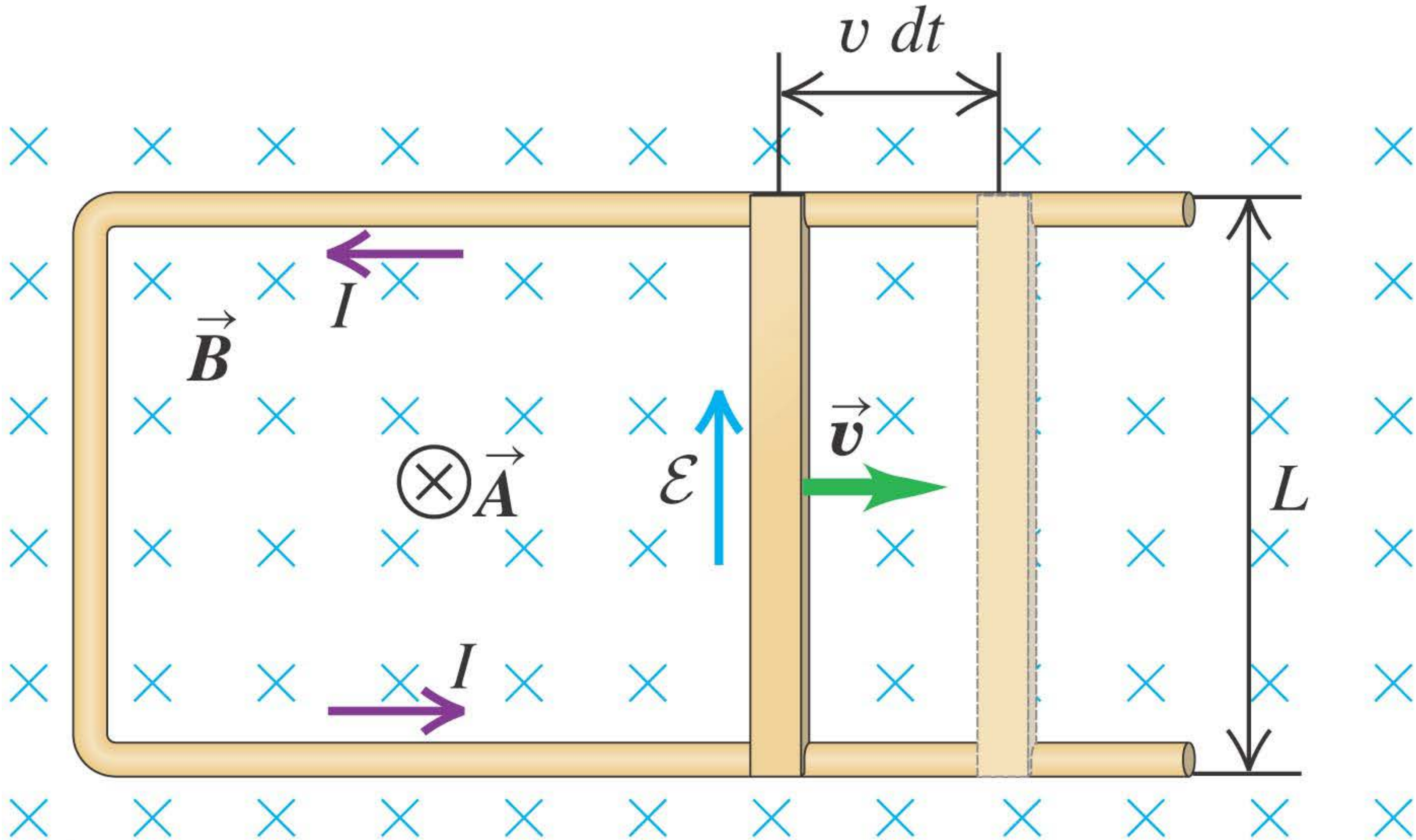
- The *motional electromotive force* across the ends of a rod moving perpendicular to a magnetic field is $\xi = vBL$. Figure 29.15 below shows the direction of the induced current.
- Follow the general form of motional emf in the text.





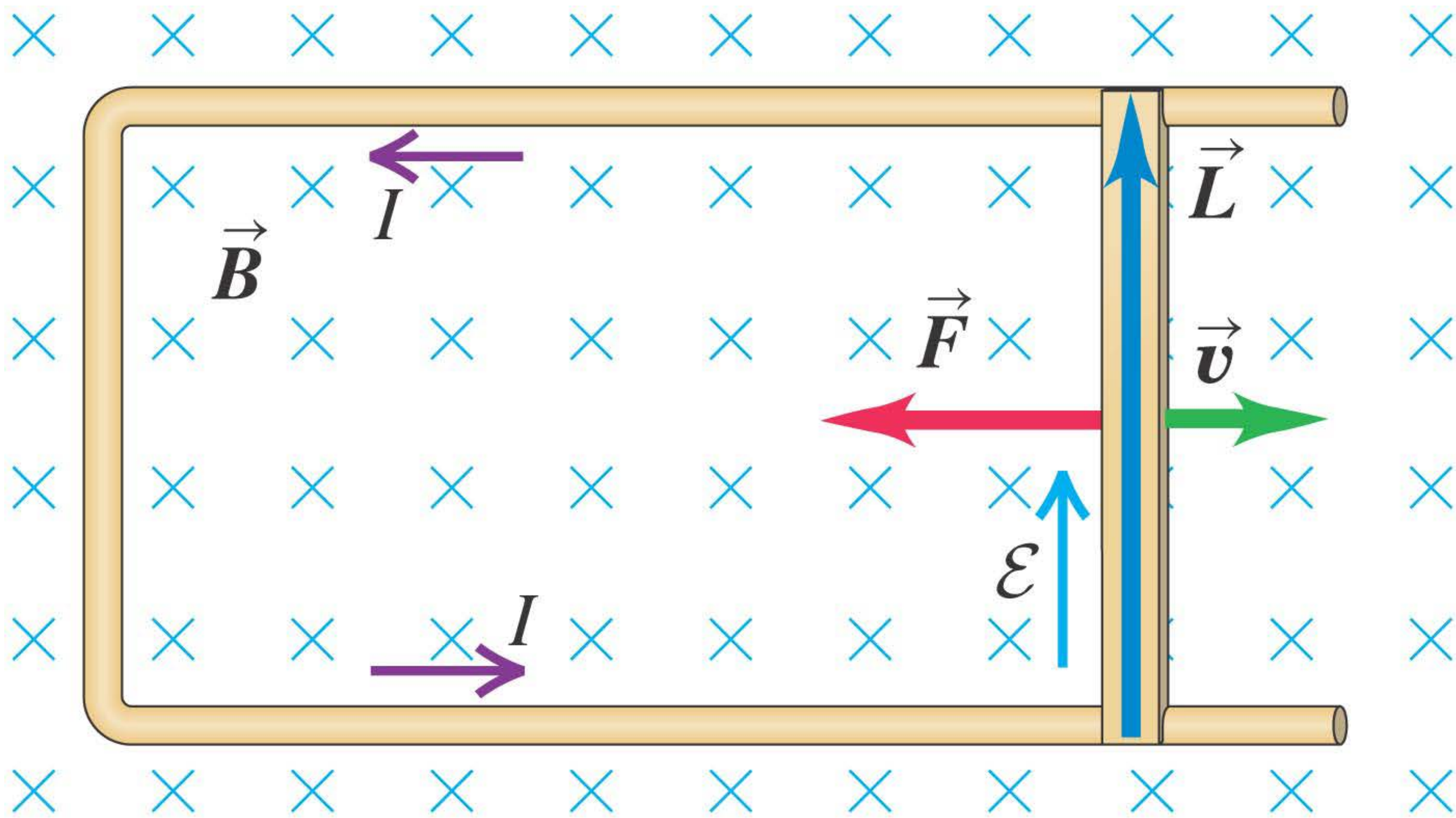
Slidewire generator

- 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

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

Gauss' Law

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

"No Name Law"

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

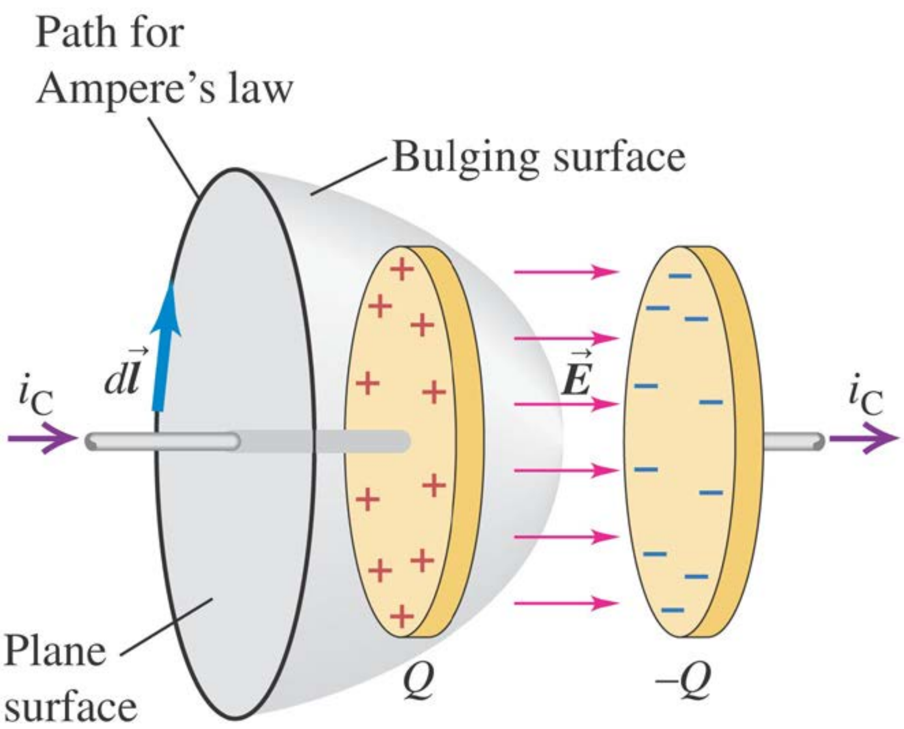
Ampere's Law

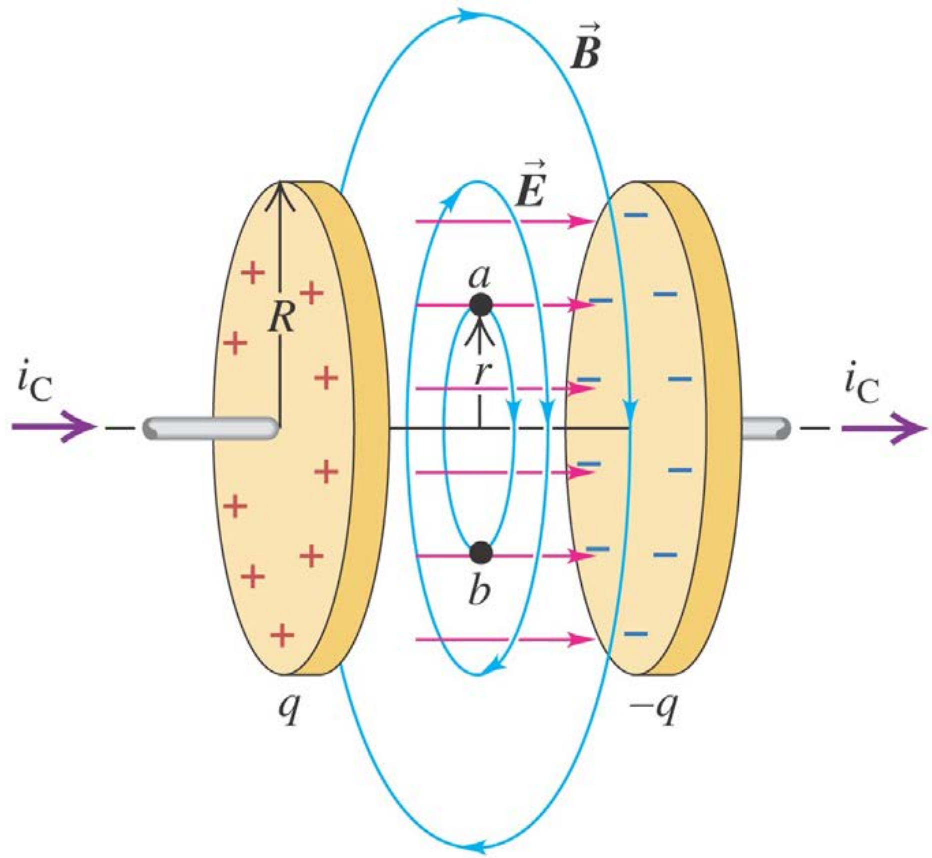
$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{\delta}{\delta t} \int \vec{B} \cdot d\vec{A}$$

Faraday's Law

Displacement current

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





Maxwell's Equations To Date

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

Gauss' 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

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

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

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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

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"

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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

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

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$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{e_{enc}} + \epsilon_o \mu_o \frac{\delta}{\delta t} \int \vec{E} \cdot d\vec{A}$$

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

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$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{e_{enc}} + \epsilon_o \mu_o \frac{\delta}{\delta t} \int \vec{E} \cdot d\vec{A}$$

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!