Chapter 29

Electromagnetic Induction

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University Physics, Thirteenth Edition
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Lectures by Wayne Anderson

Goals for Chapter 29

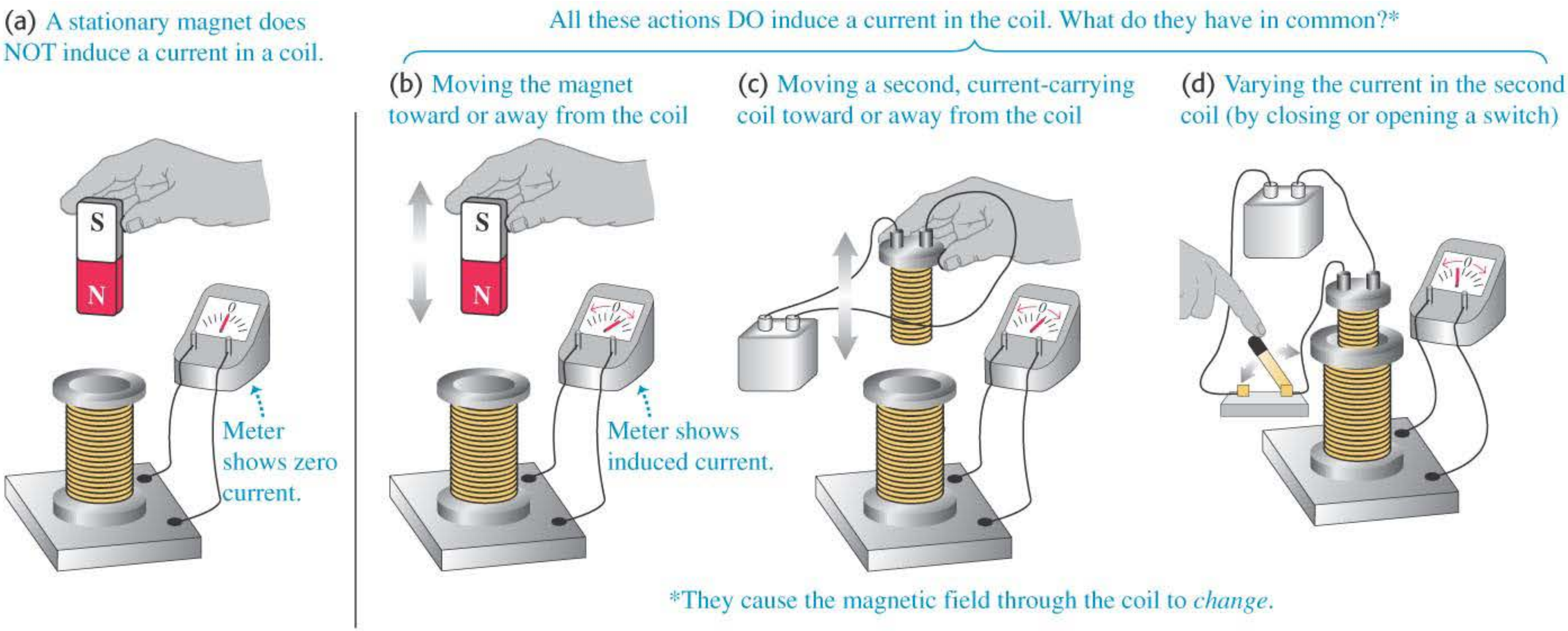
- To examine experimental evidence that a changing magnetic field induces an emf
- To learn how Faraday's law relates the induced emf to the change in flux
- To determine the direction of an induced emf
- To calculate the emf induced by a moving conductor
- To learn how a changing magnetic flux generates an electric field
- To study the four fundamental equations that describe electricity and magnetism

Introduction

- How is a credit card reader related to magnetism?
- Energy conversion makes use of electromagnetic induction.
- Faraday's law and Lenz's law tell us about induced currents.
- Maxwell's equations describe the behavior of electric and magnetic fields in *any* situation.

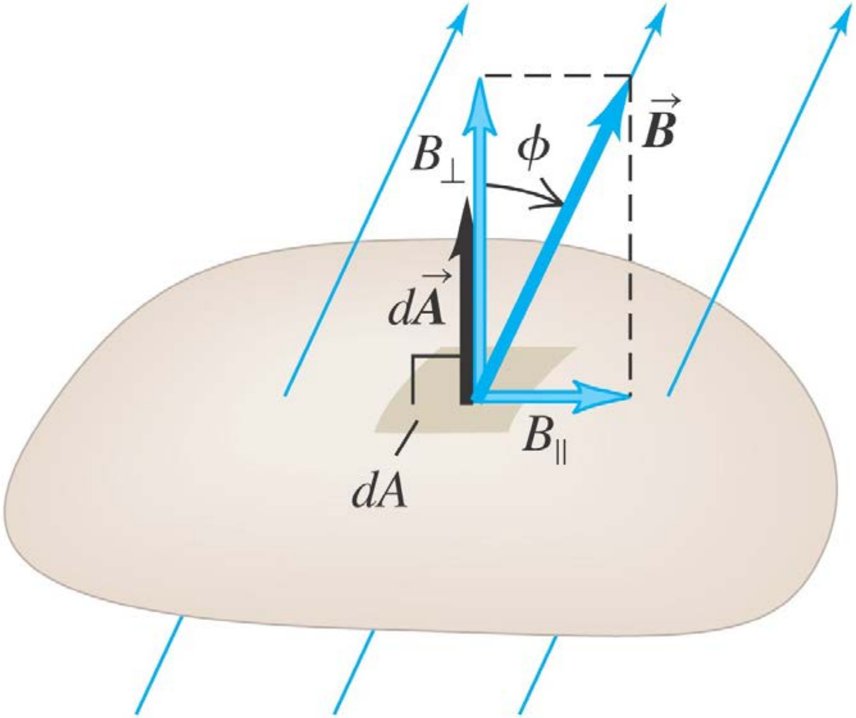
Induced current

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



Magnetic flux through an area element

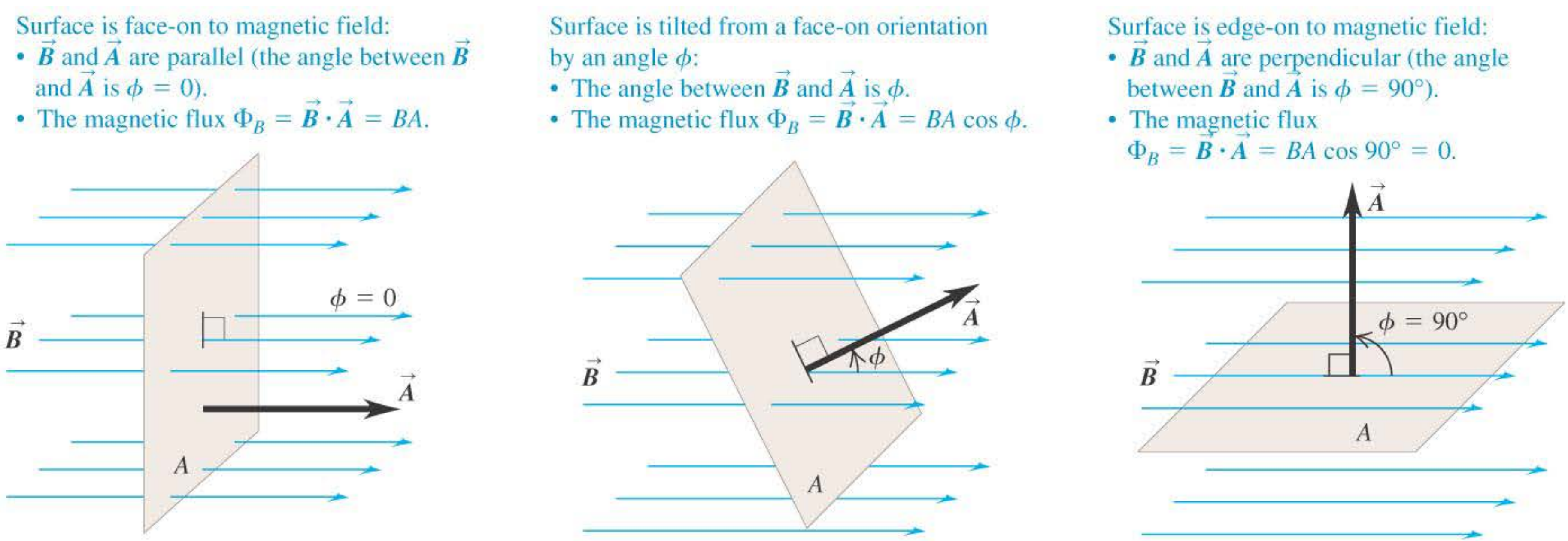
- Figure 29.3 below shows how to calculate the magnetic flux through an element of area.



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

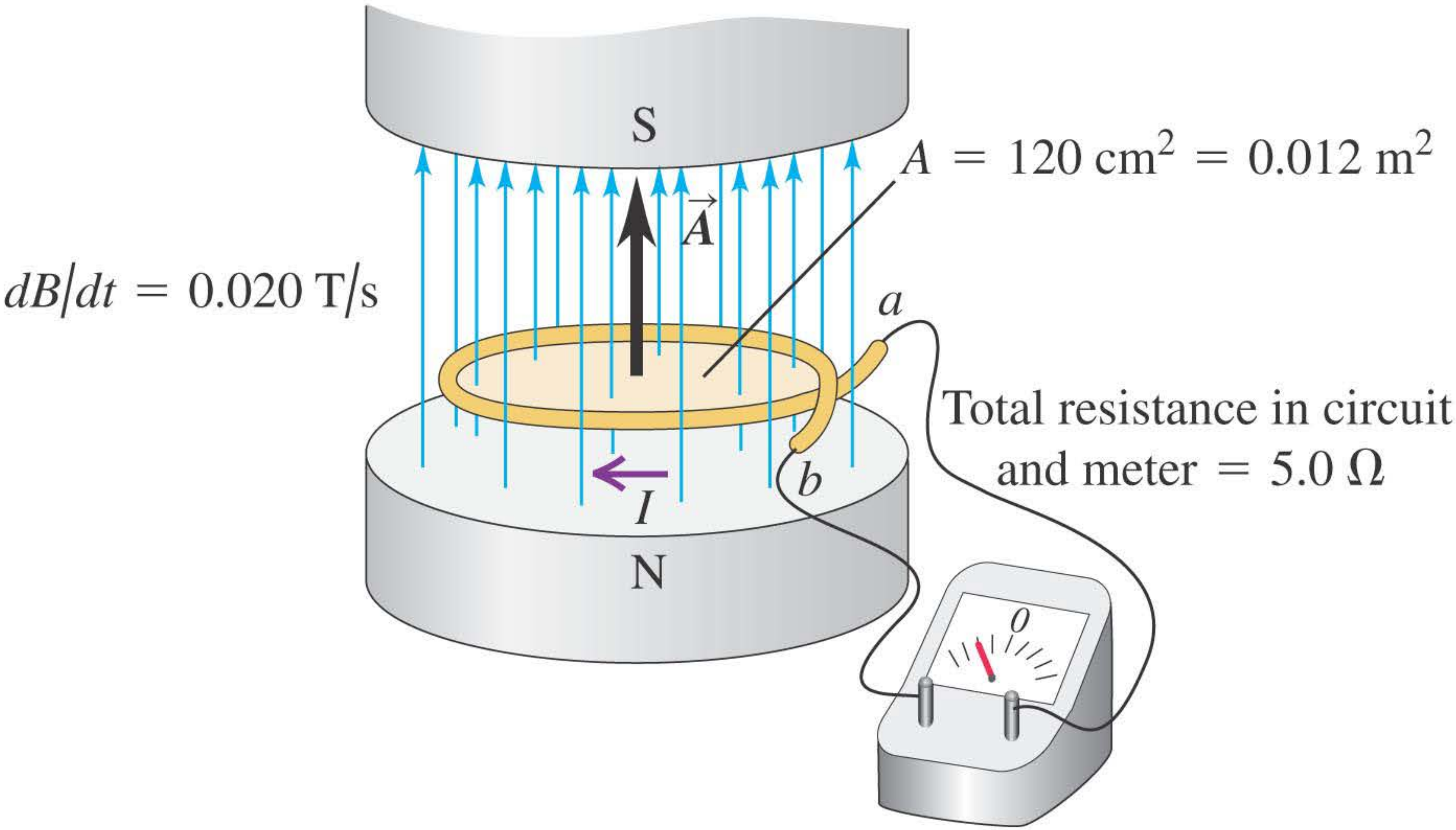
Faraday's law

- 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 $\xi = -d\Phi_B/dt$.



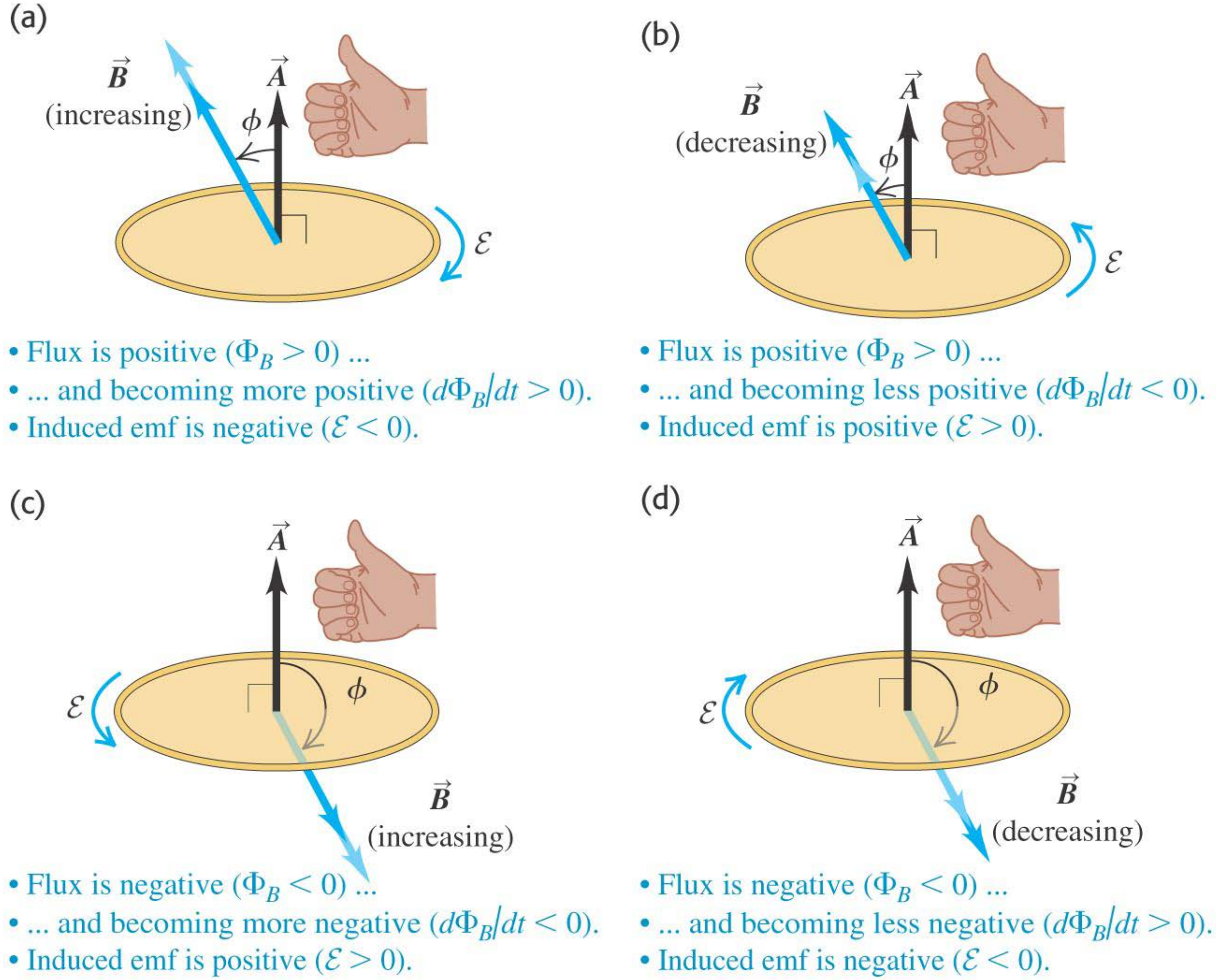
Emf and the current induced in a loop

- Follow Example 29.1 using Figure 29.5 below.



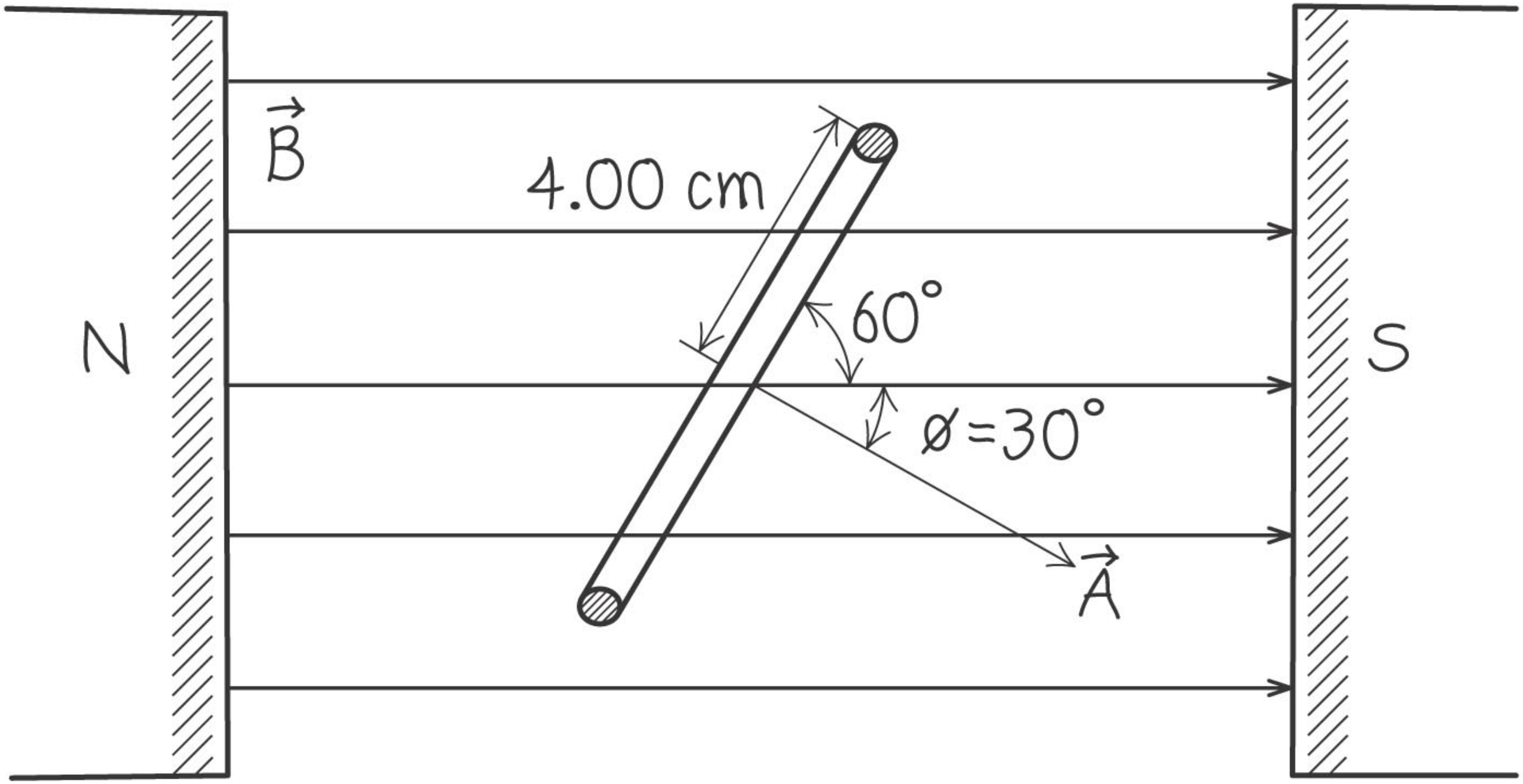
Direction of the induced emf

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



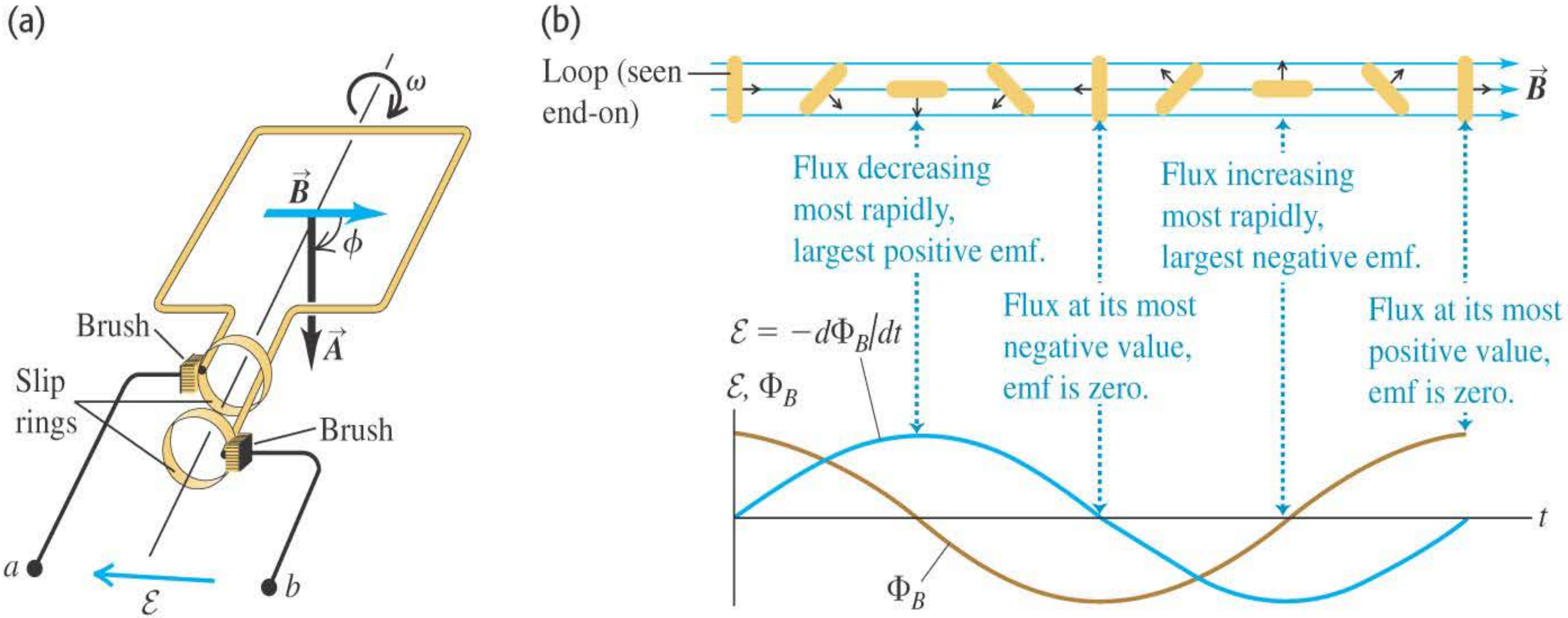
Magnitude and direction of an induced emf

- Read Problem-Solving Strategy 29.1.
- Follow Example 29.2 using Figure 29.7 below.



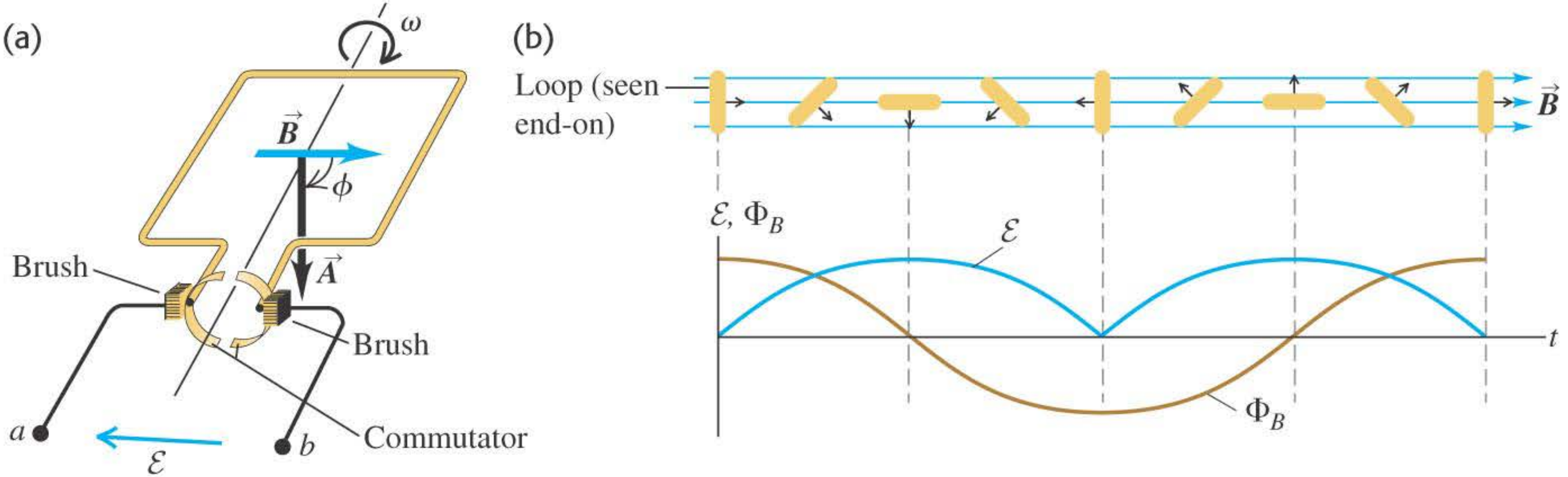
A simple alternator

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



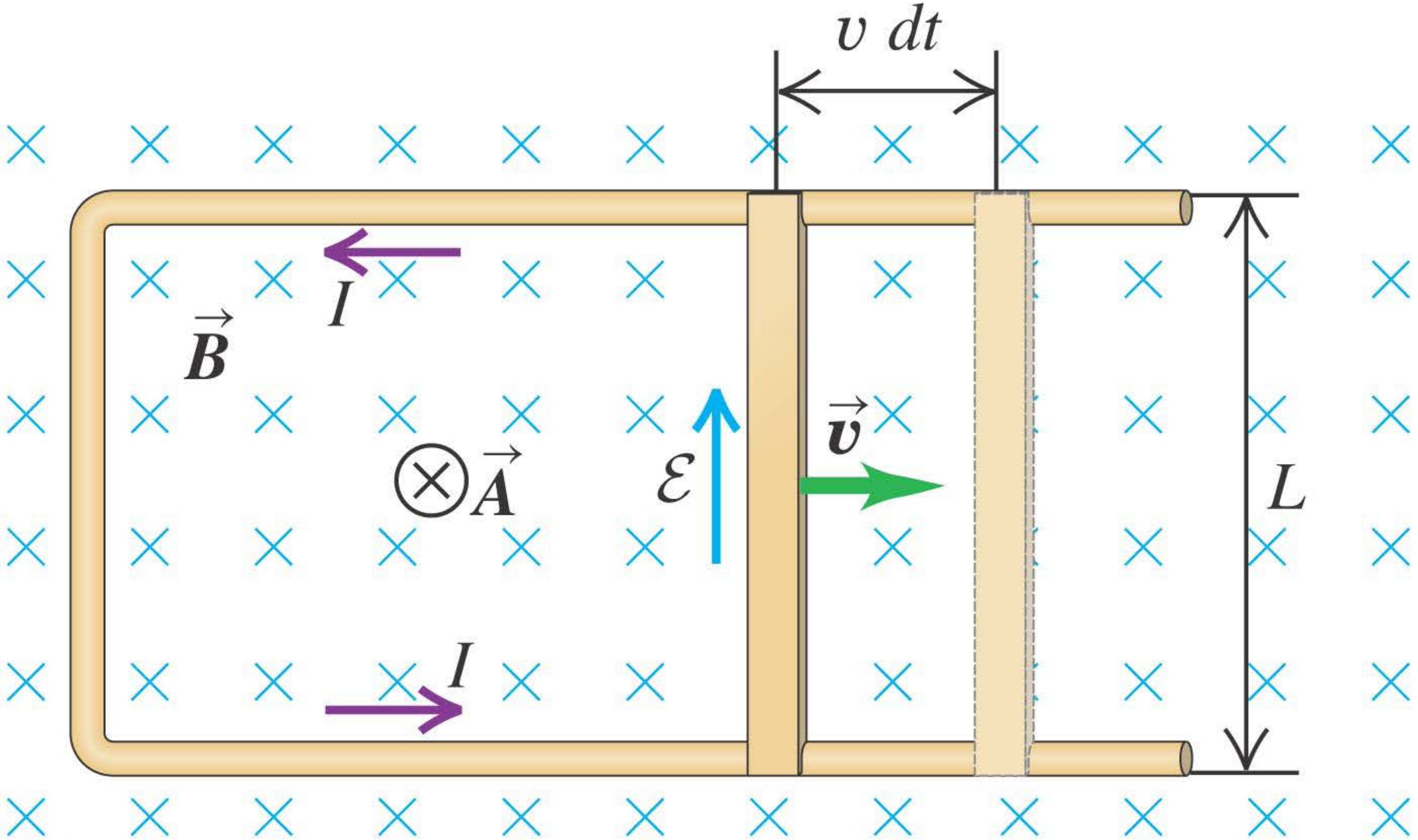
DC generator and back emf in a motor

- Follow Example 29.4 using Figure 29.10 below.



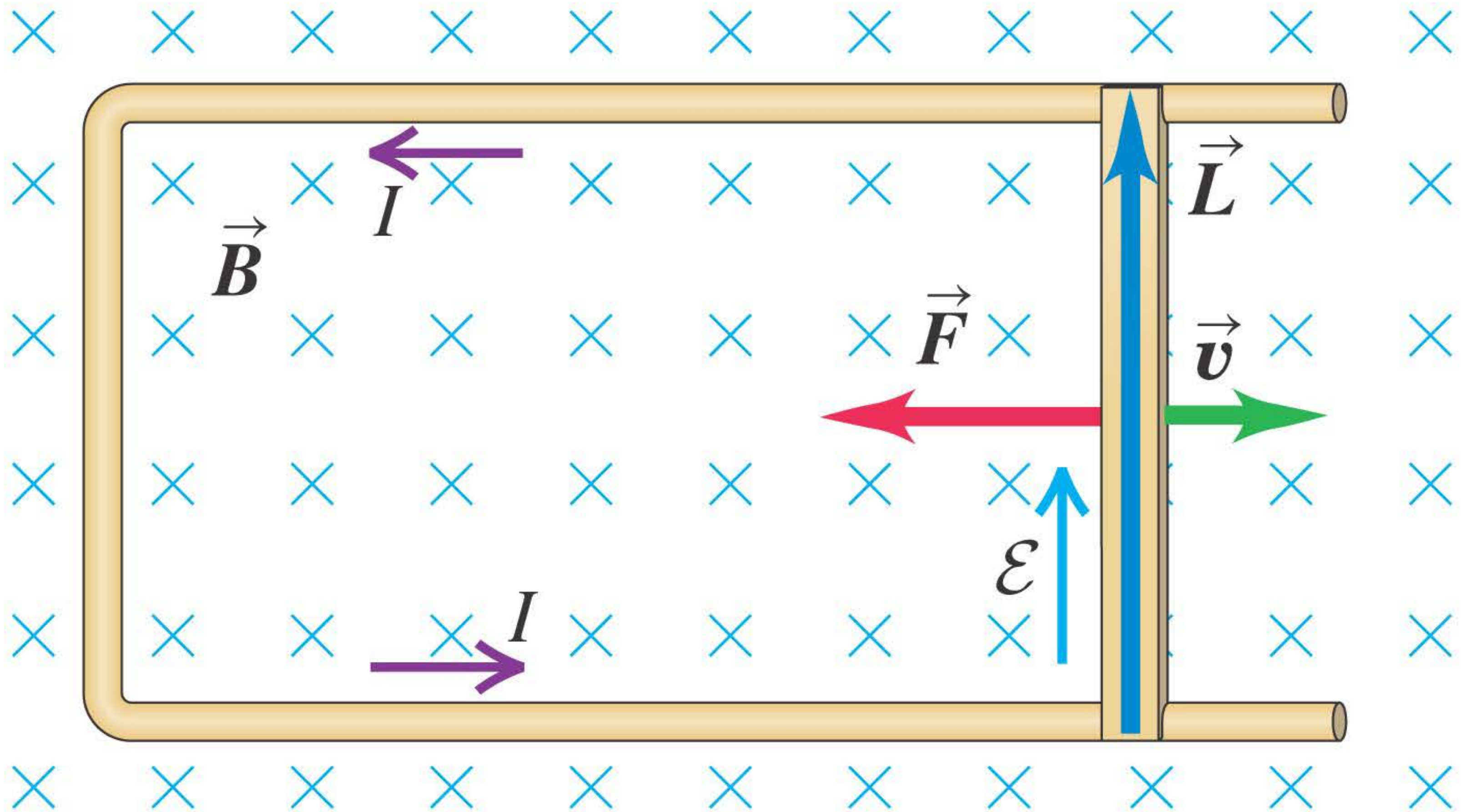
Slidewire generator

- 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.

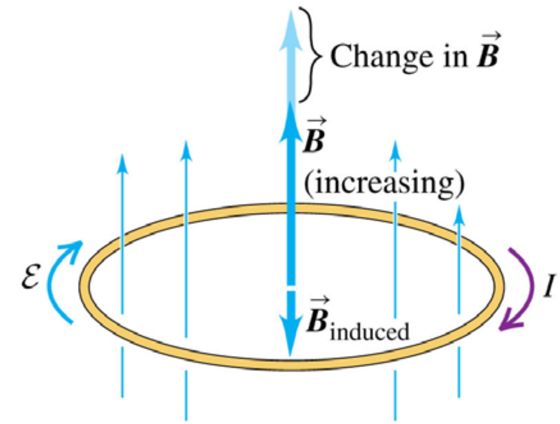


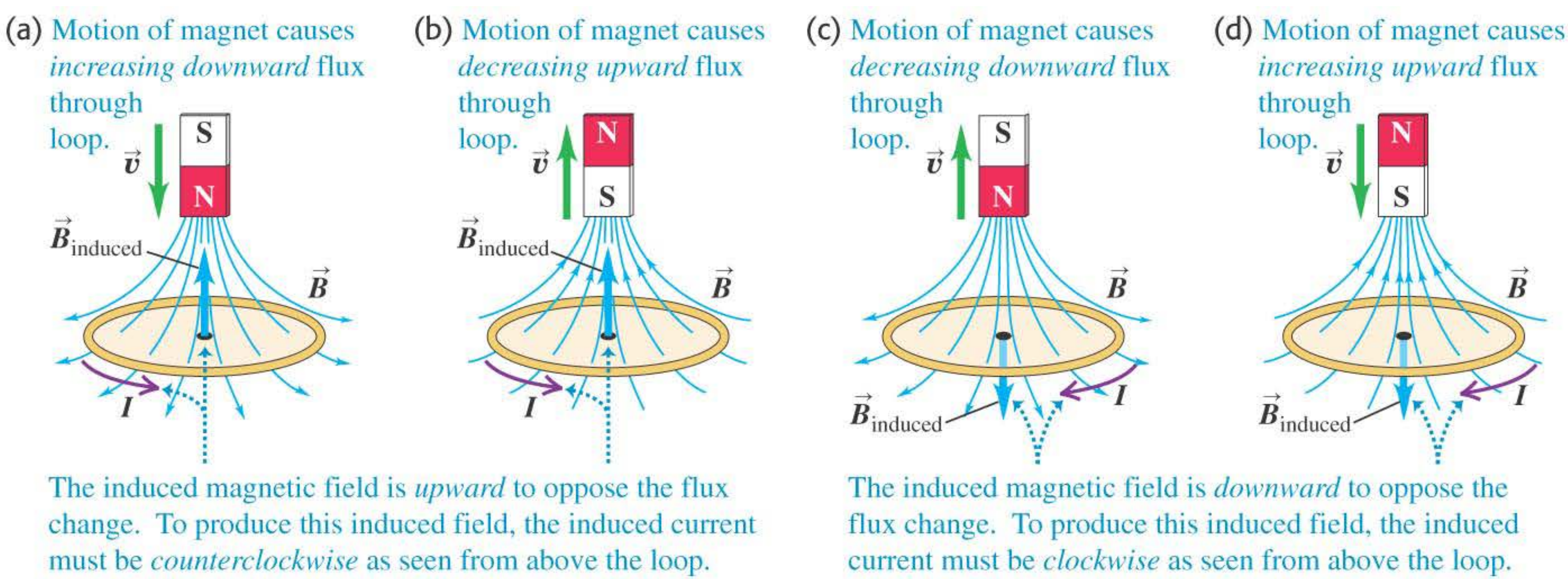
Lenz's law

- *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

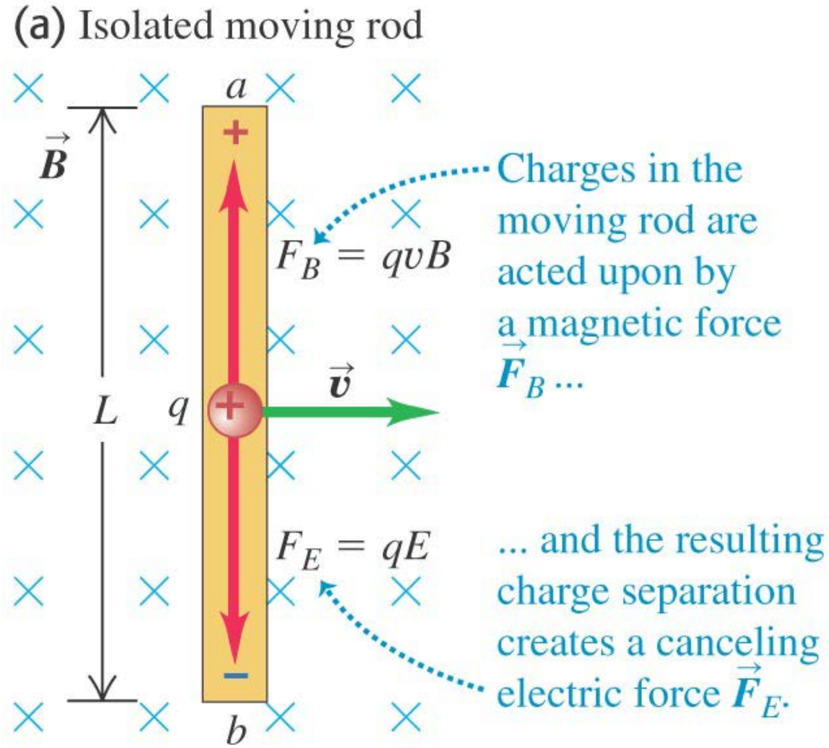
- Follow Example 29.8 using Figures 29.13 (right) and 29.14 (below).

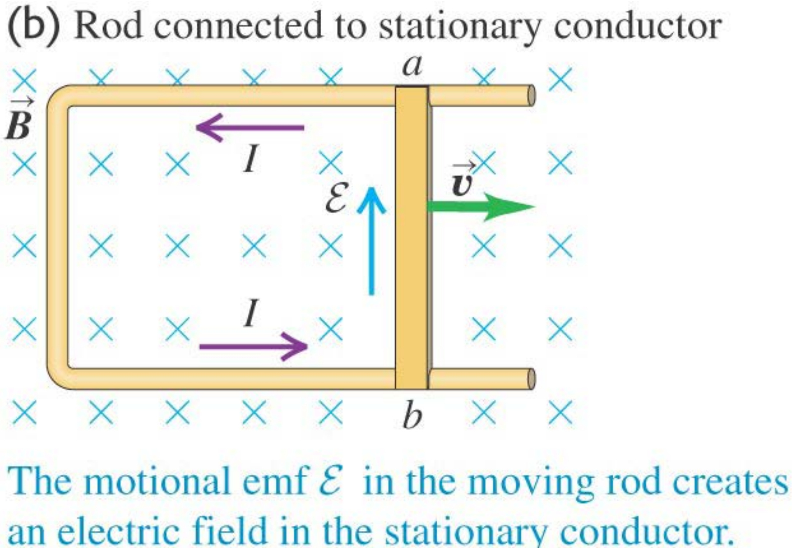




Motional electromotive force

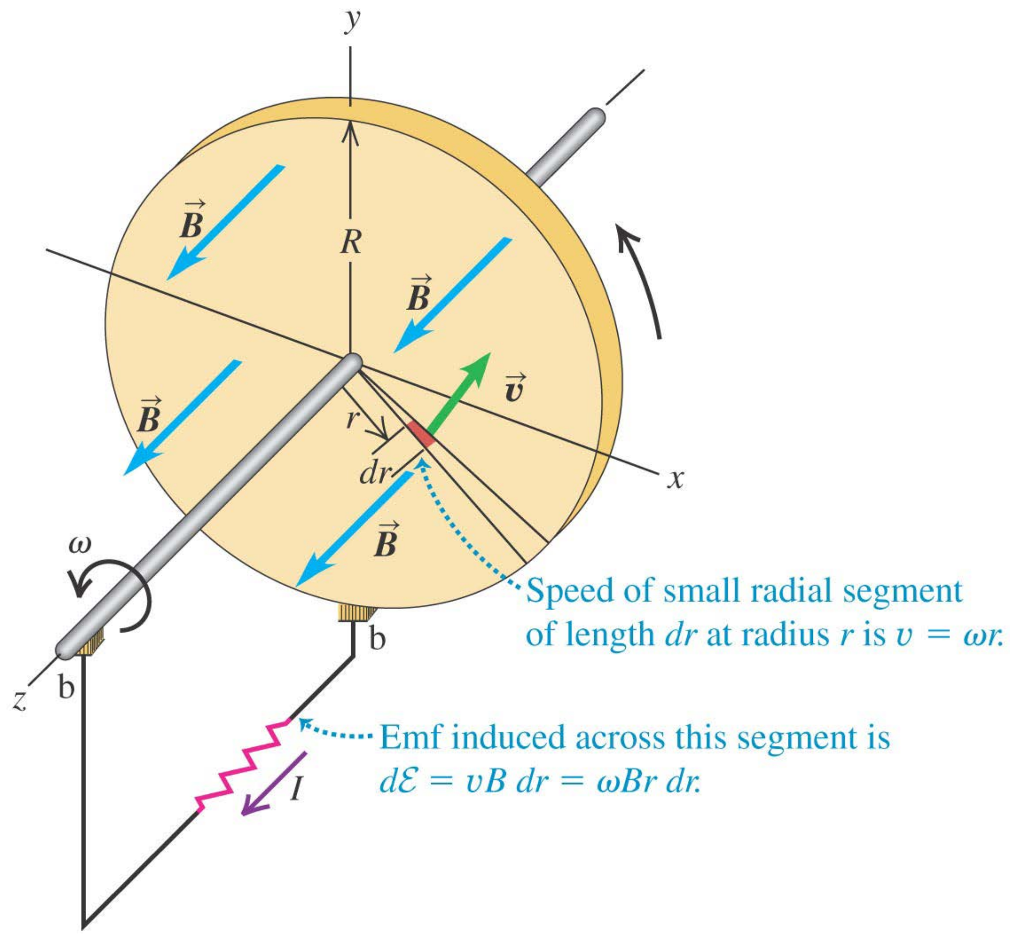
- The *motional electromotive force* across the ends of a rod moving perpendicular to a magnetic field is $\xi = vBL$. Figure 29.15 below shows the direction of the induced current.
- Follow the general form of motional emf in the text.





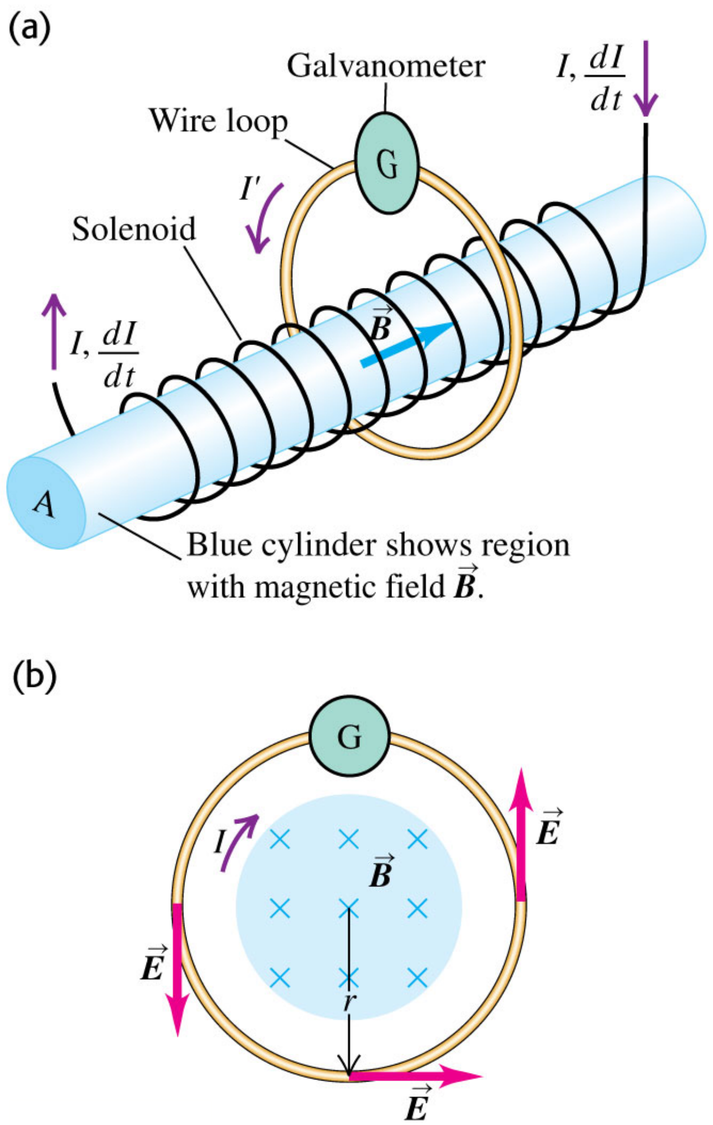
A slidewire generator and a dynamo

- Follow Example 29.9 for the slidewire generator.
- Follow Example 29.10 for the Faraday disk dynamo, using Figure 29.16 below.



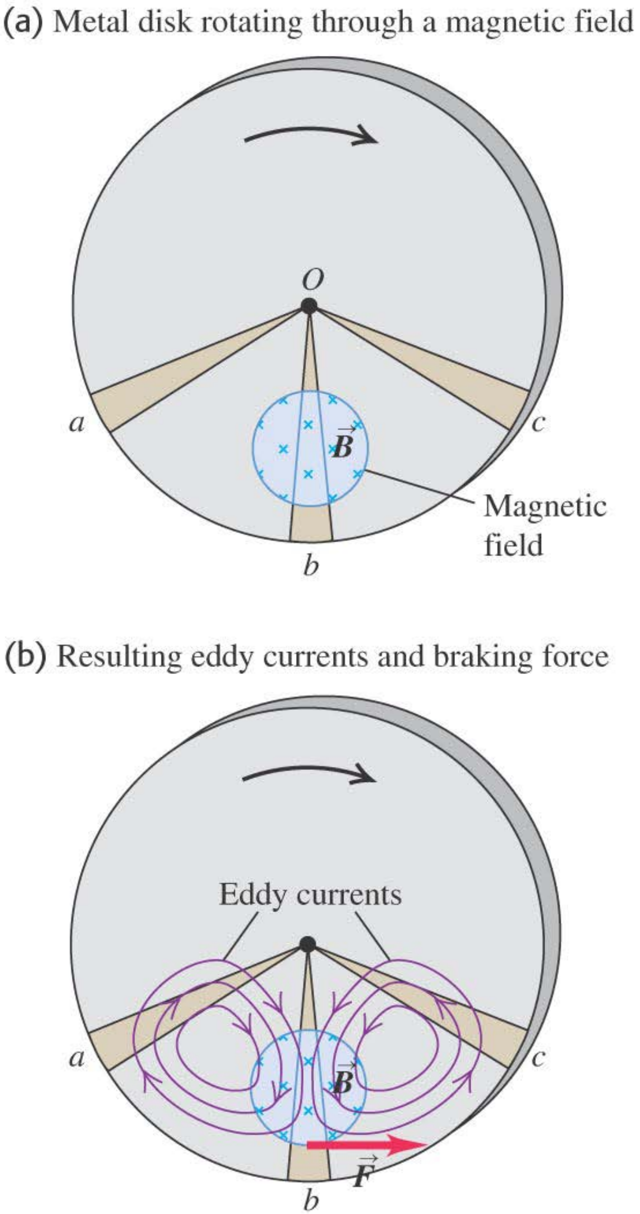
Induced electric fields

- Changing magnetic flux causes an *induced electric field*.
- See Figure 29.17 at the right to see the induced electric field for a solenoid.
- Follow the text discussion for Faraday's law restated in terms of the induced electric field.
- Follow Example 29.11 using Figure 29.17.



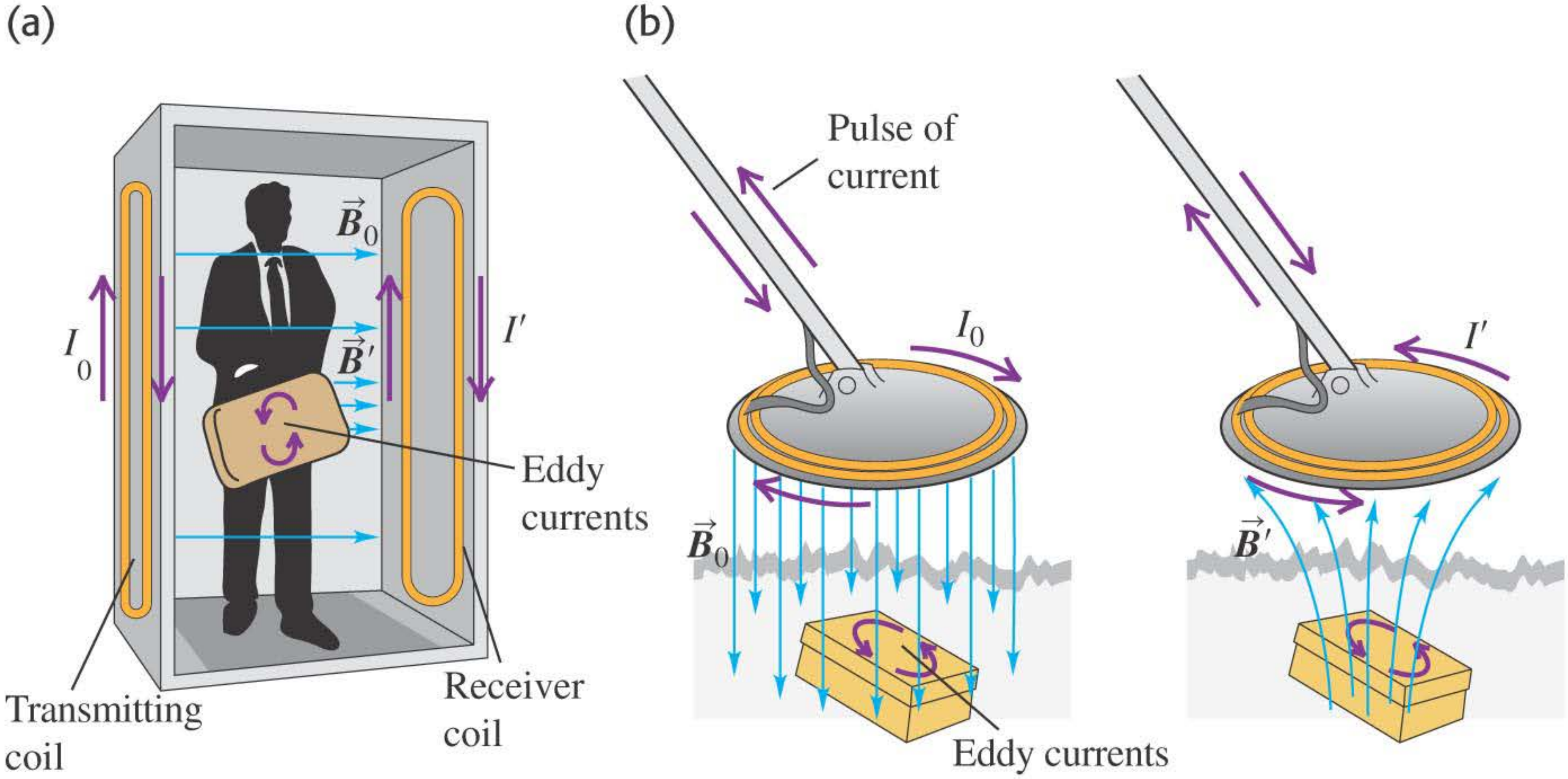
Eddy currents

- Follow the text discussion of *eddy currents*, using Figure 29.19 at the right.



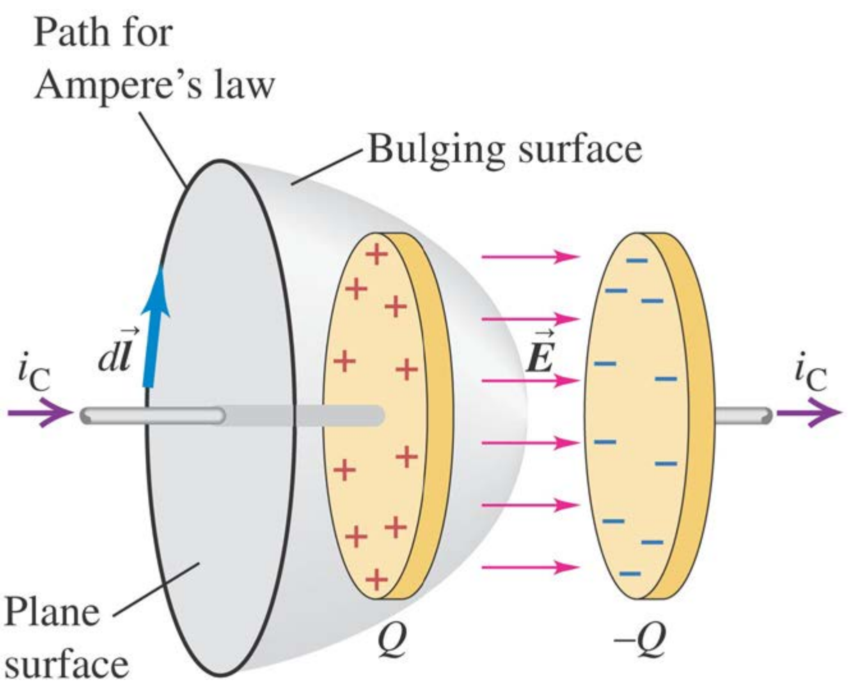
Using eddy currents

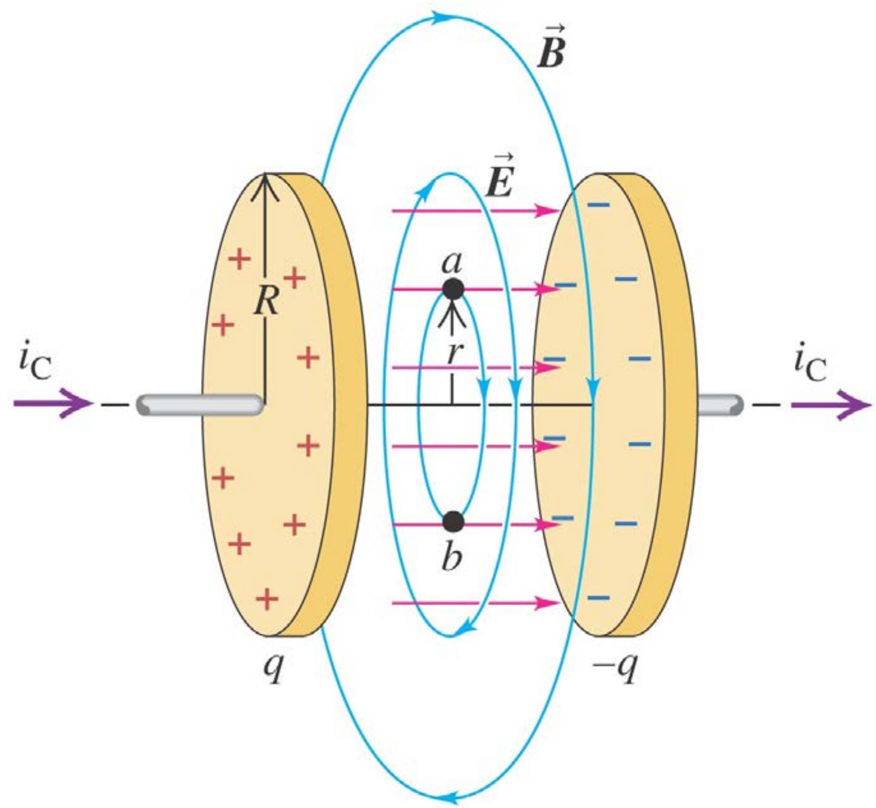
- Figure 29.20 below illustrates an airport metal detector and a portable metal detector, both of which use eddy currents in their design.



Displacement current

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





Maxwell's equations

- *Maxwell's equations* consist of
  - ✓ Gauss's law for the electric field
  - ✓ Gauss's law for the magnetic field
  - ✓ Ampere's law
  - ✓ Faraday's law.
- Follow the text discussion for the mathematical form of these four fundamental laws.

Superconductivity

- When a superconductor is cooled below its *critical temperature*, it loses all electrical resistance.
- Follow the text discussion using Figures 29.23 (below) and 29.24 (right).