Chapter 29

Electromagnetic Induction

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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Lectures by Wayne Anderson

Goals for Chapter 29

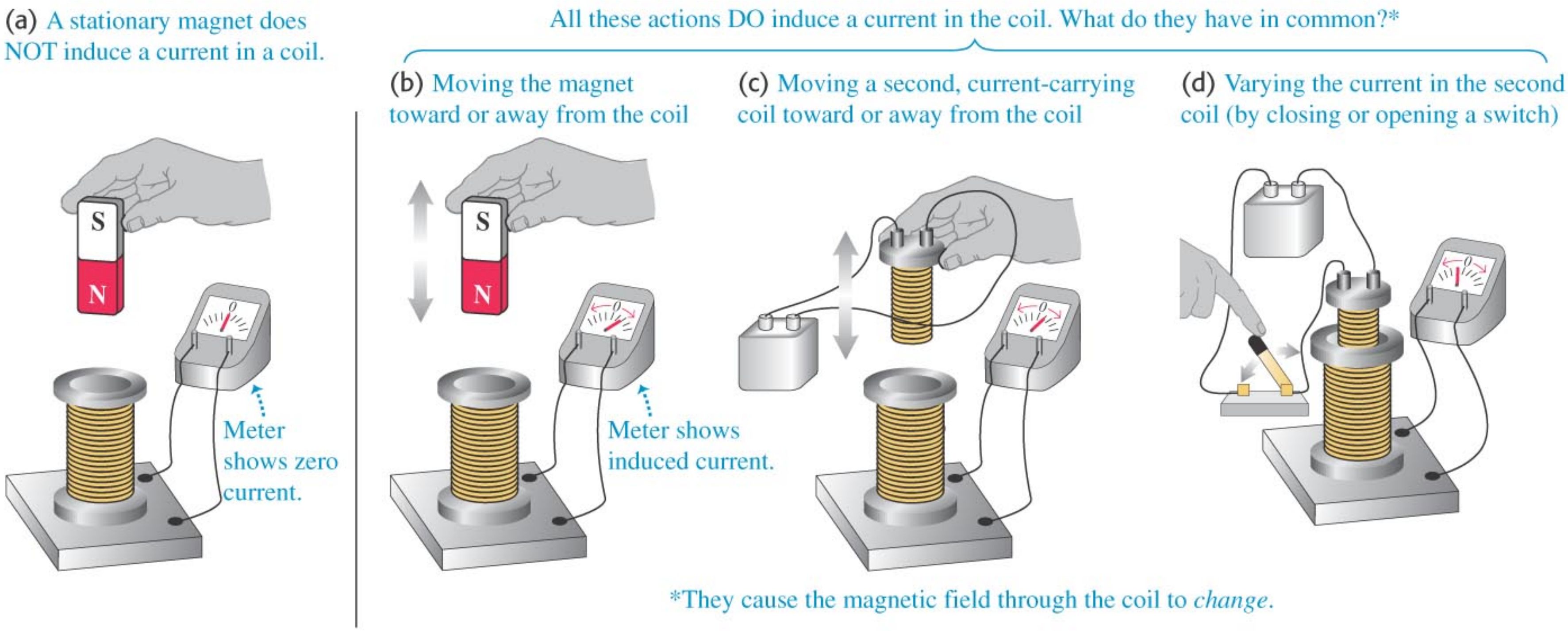
- To examine experimental evidence that a changing magnetic field induces an emf
- To learn how Faraday's law relates the induced emf to the change in flux
- To determine the direction of an induced emf
- To calculate the emf induced by a moving conductor
- To learn how a changing magnetic flux generates 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.

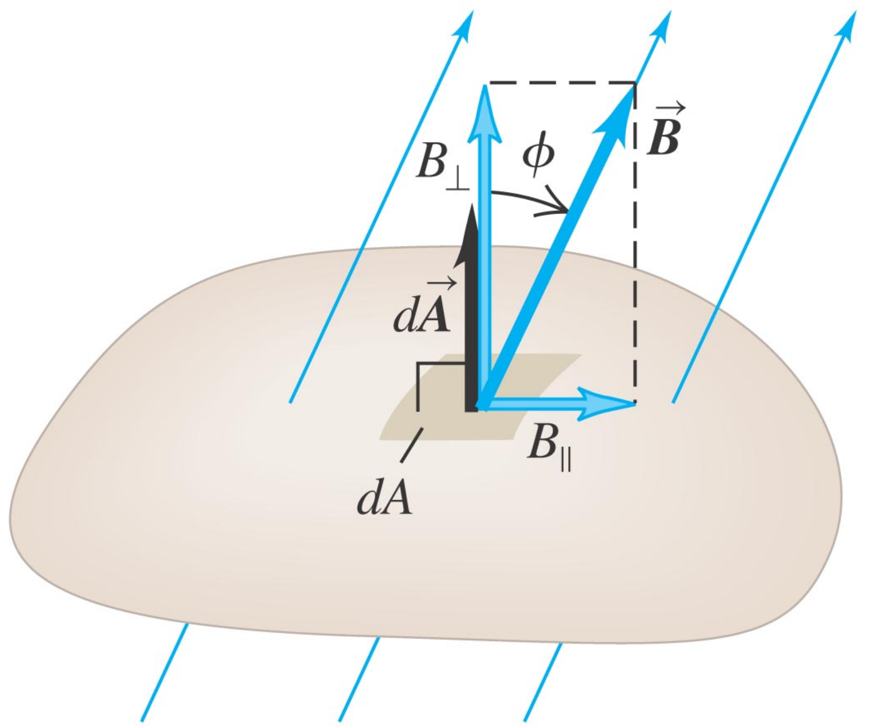
Induced current

- 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

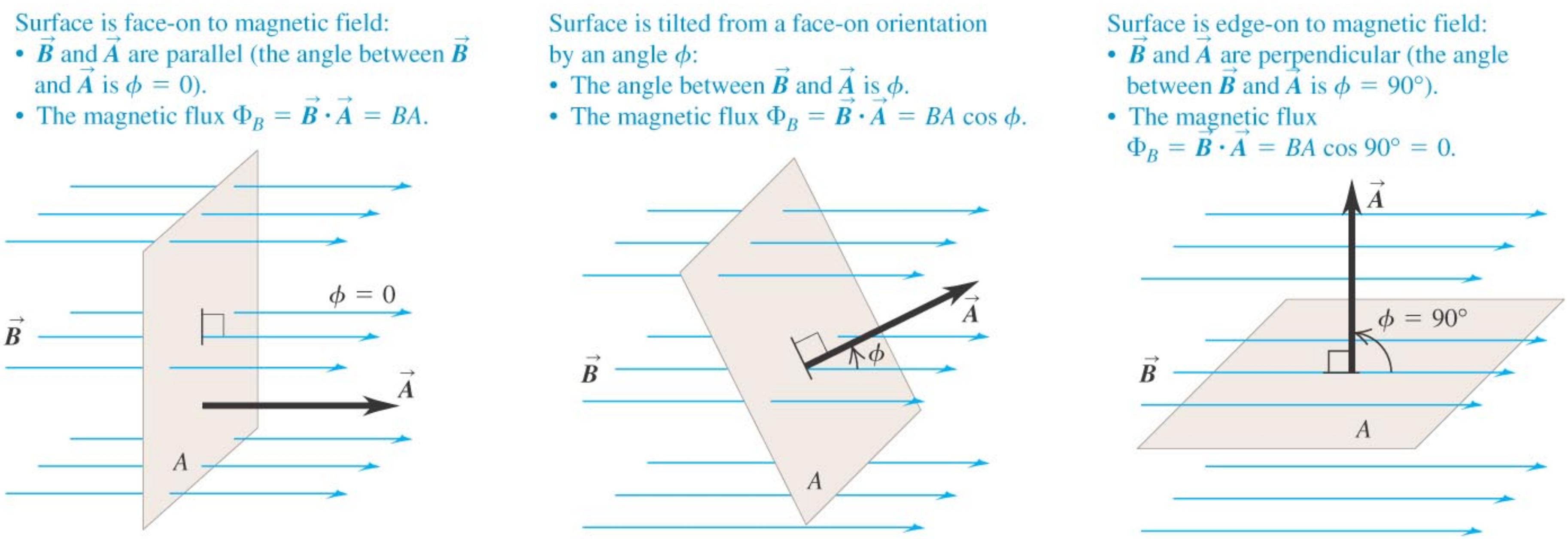
- Figure 29.3 below shows how to calculate the magnetic flux through an element of area.



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

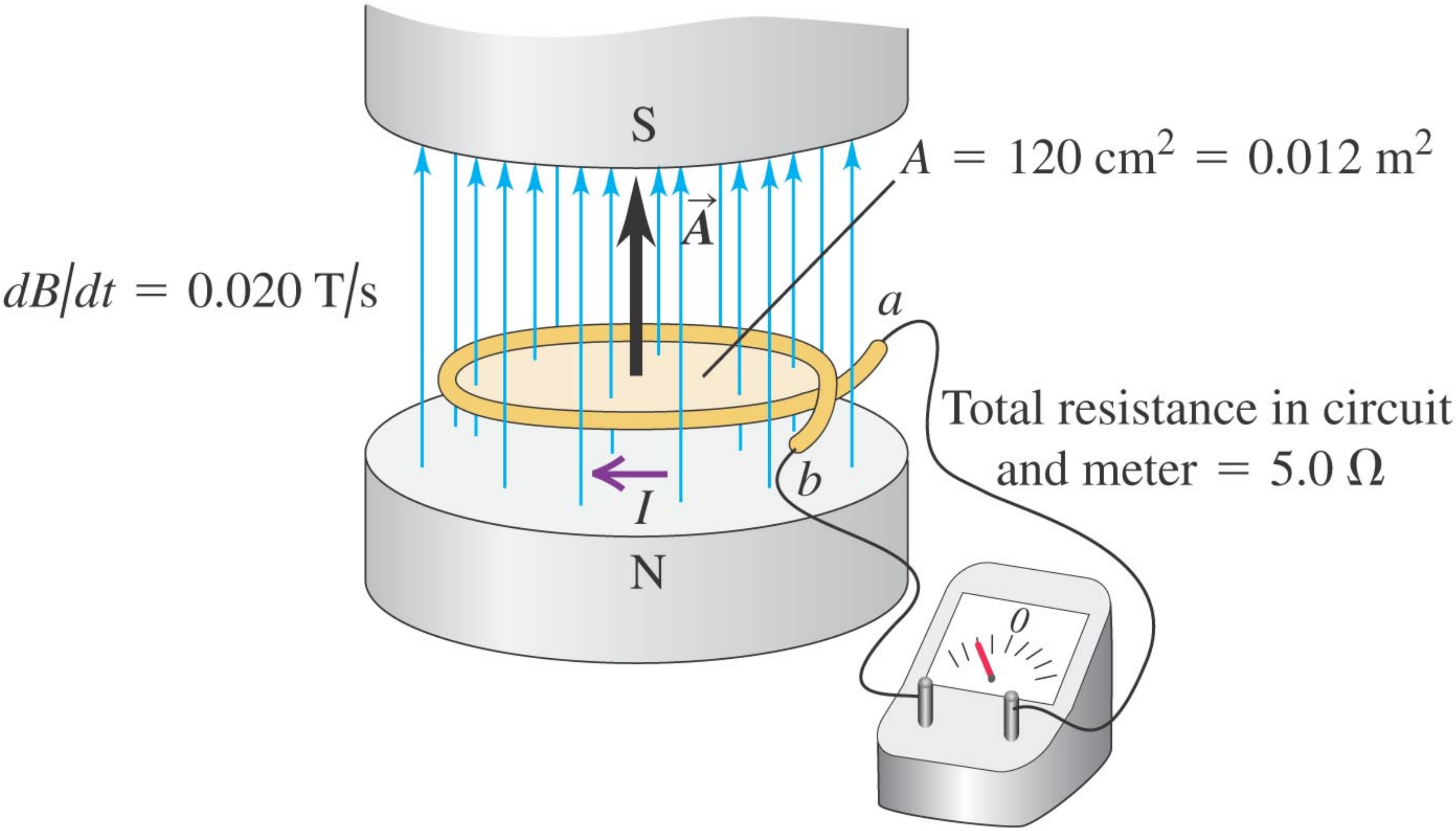
Faraday's law

- 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 $\mathcal{E} = -d\Phi_B/dt$.



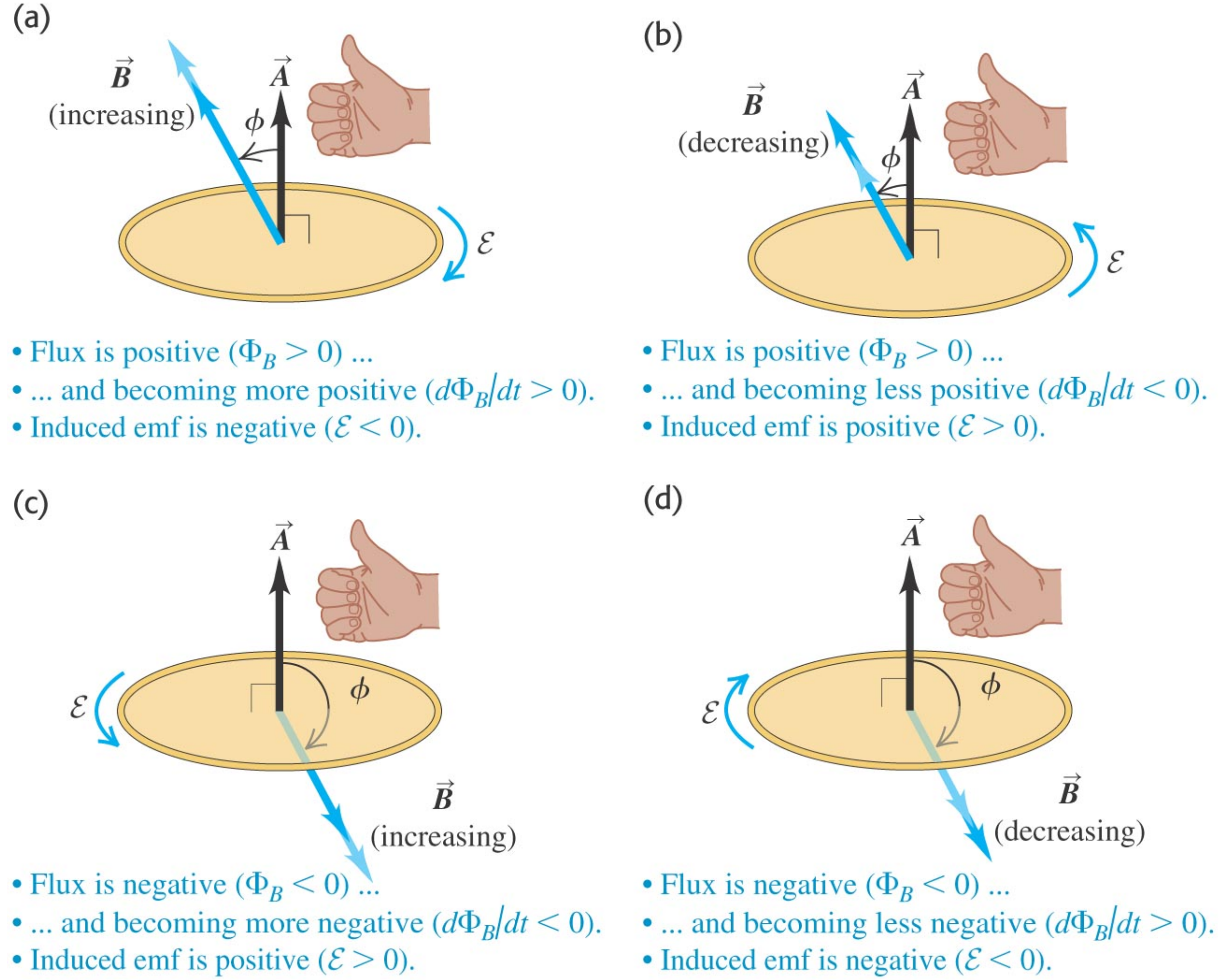
Emf and the current induced in a loop

- Follow Example 29.1 using Figure 29.5 below.



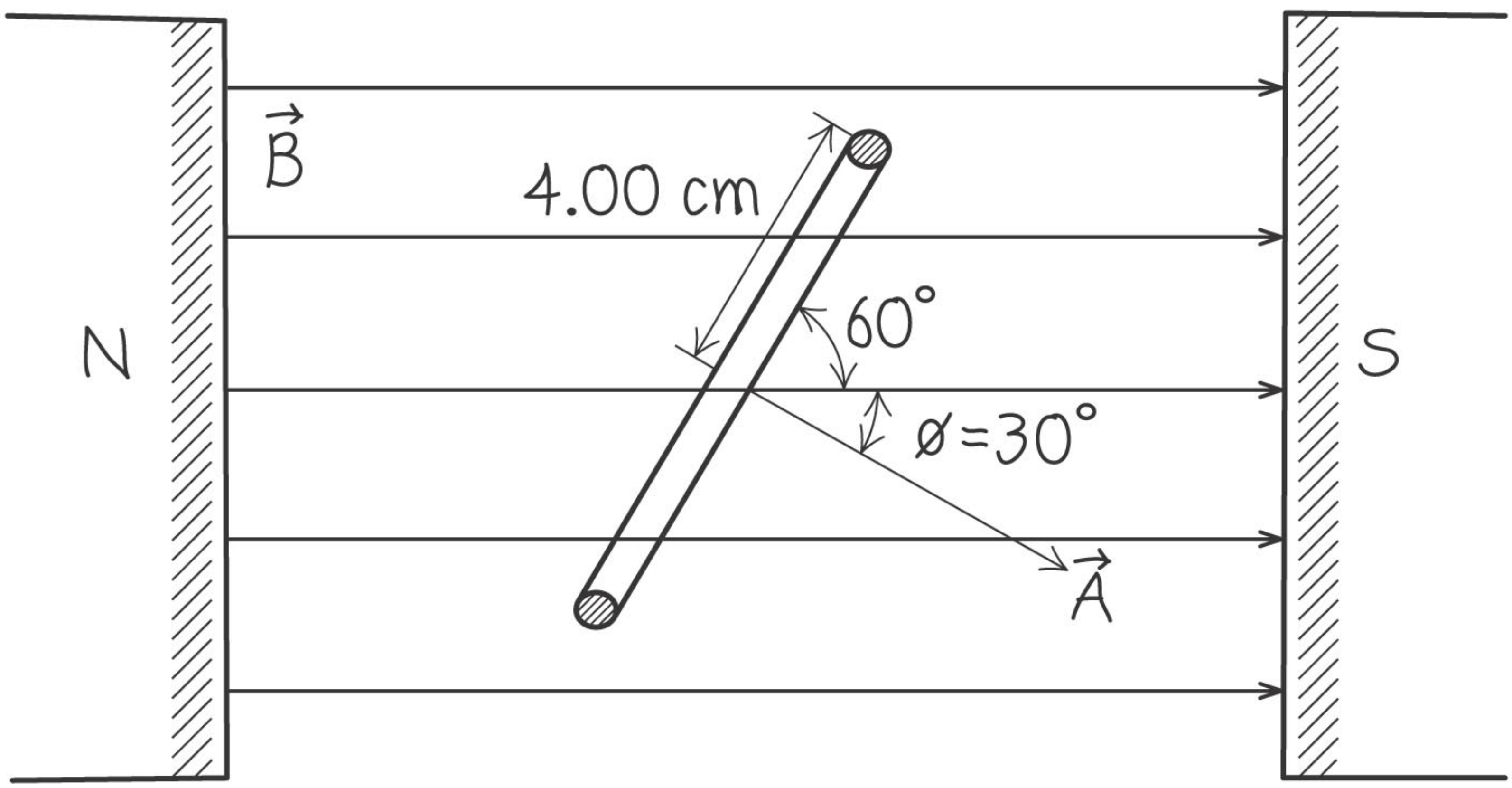
Direction of the induced emf

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



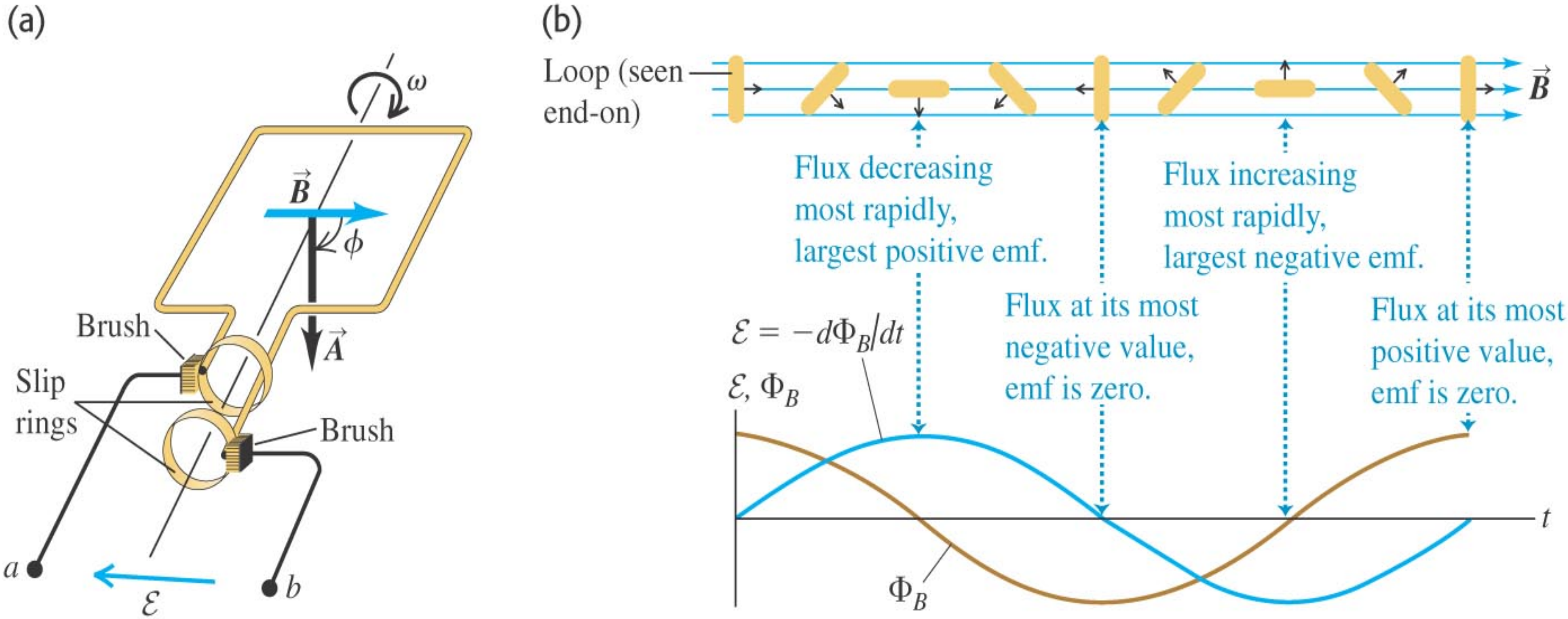
Magnitude and direction of an induced emf

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



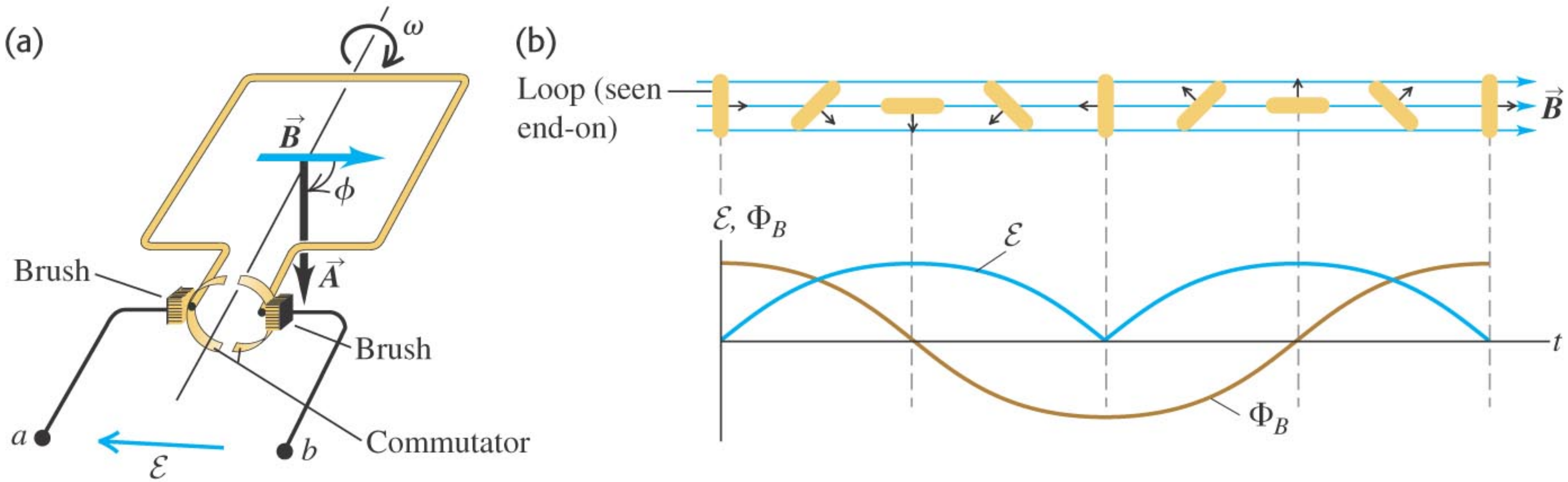
A simple alternator

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



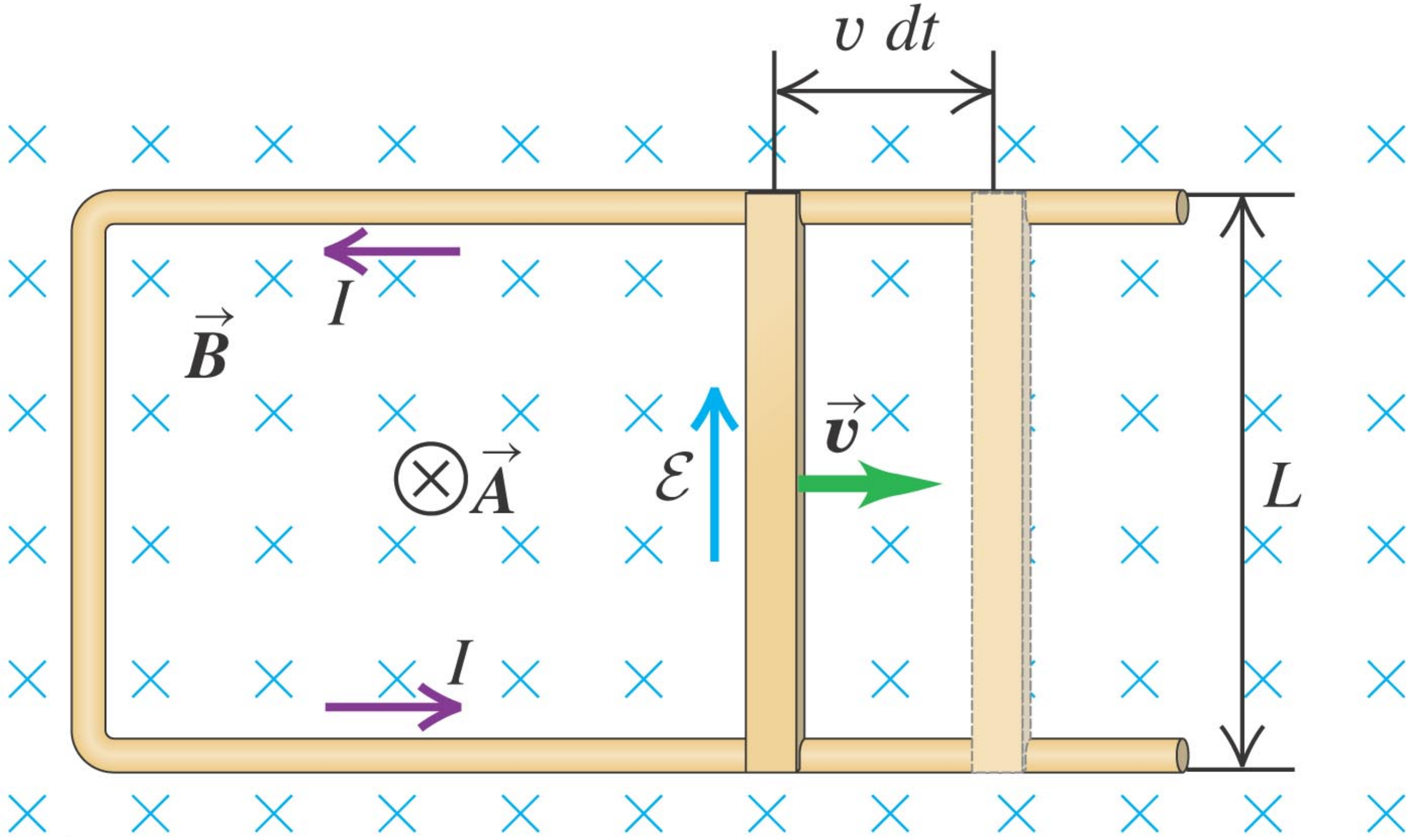
DC generator and back emf in a motor

- Follow Example 29.4 using Figure 29.10 below.



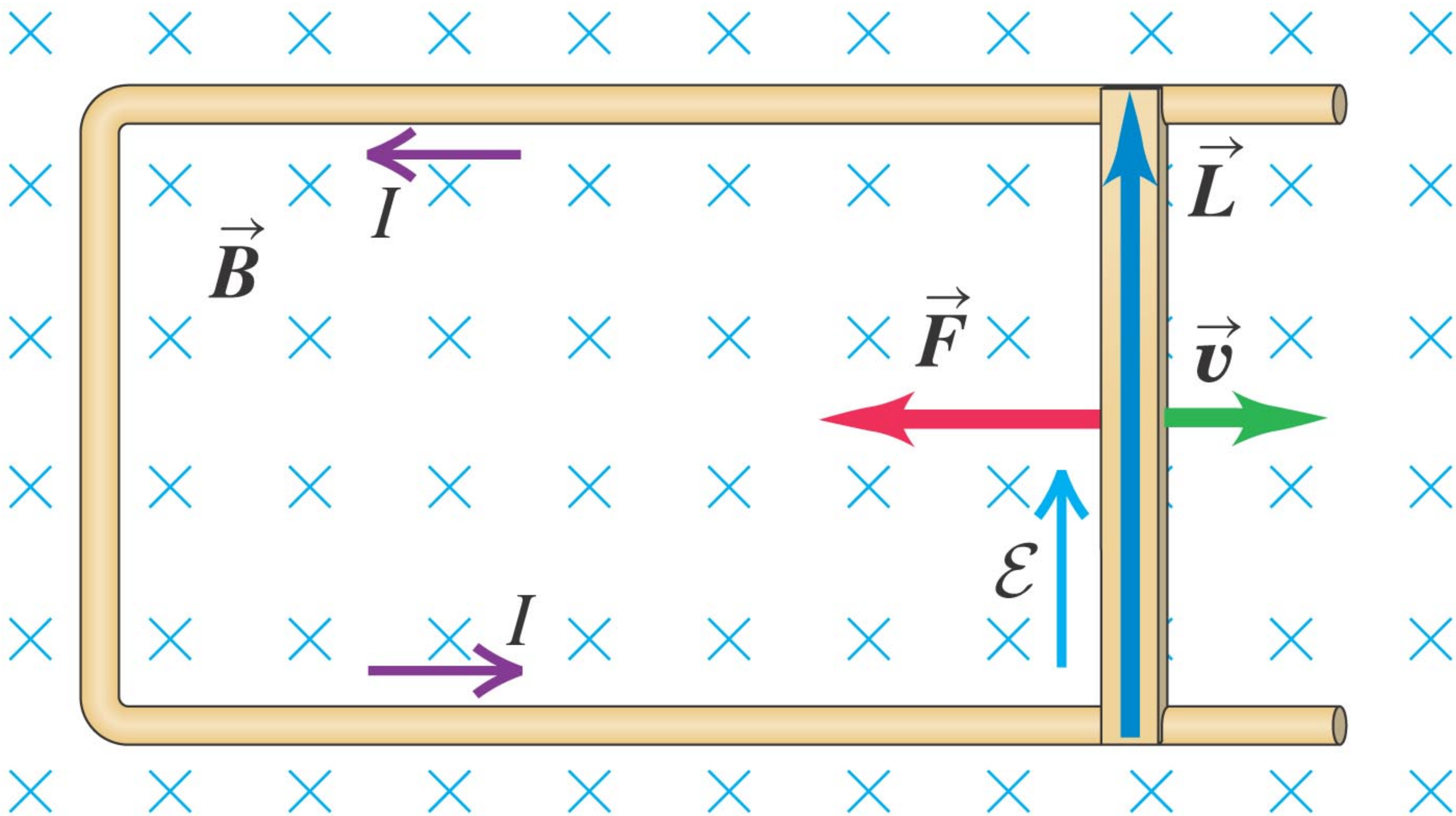
Slidewire generator

- 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.

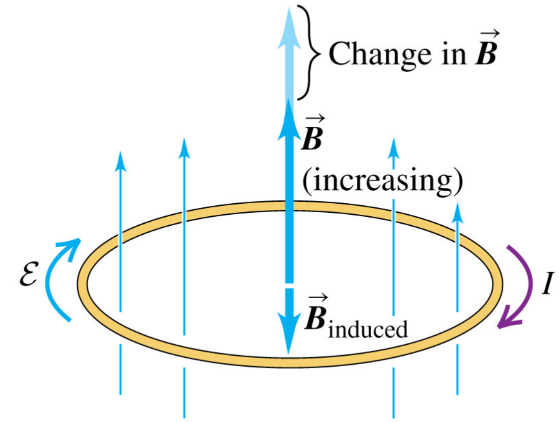


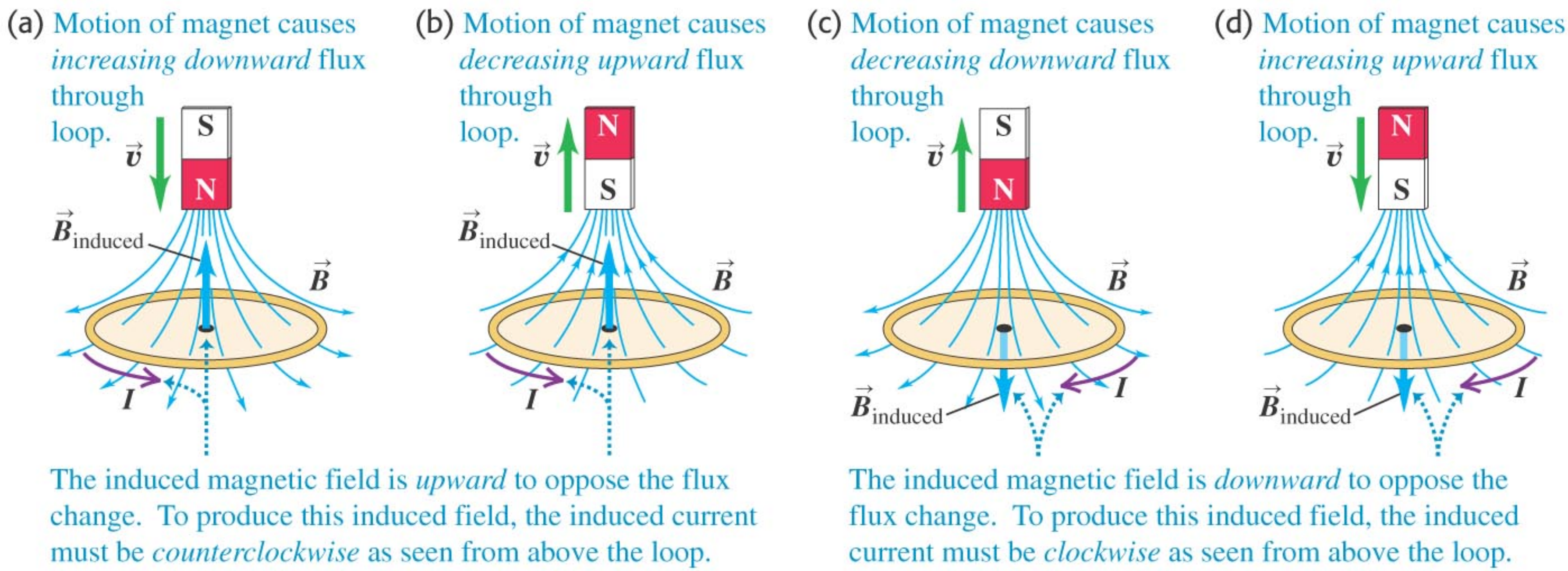
Lenz's law

- *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

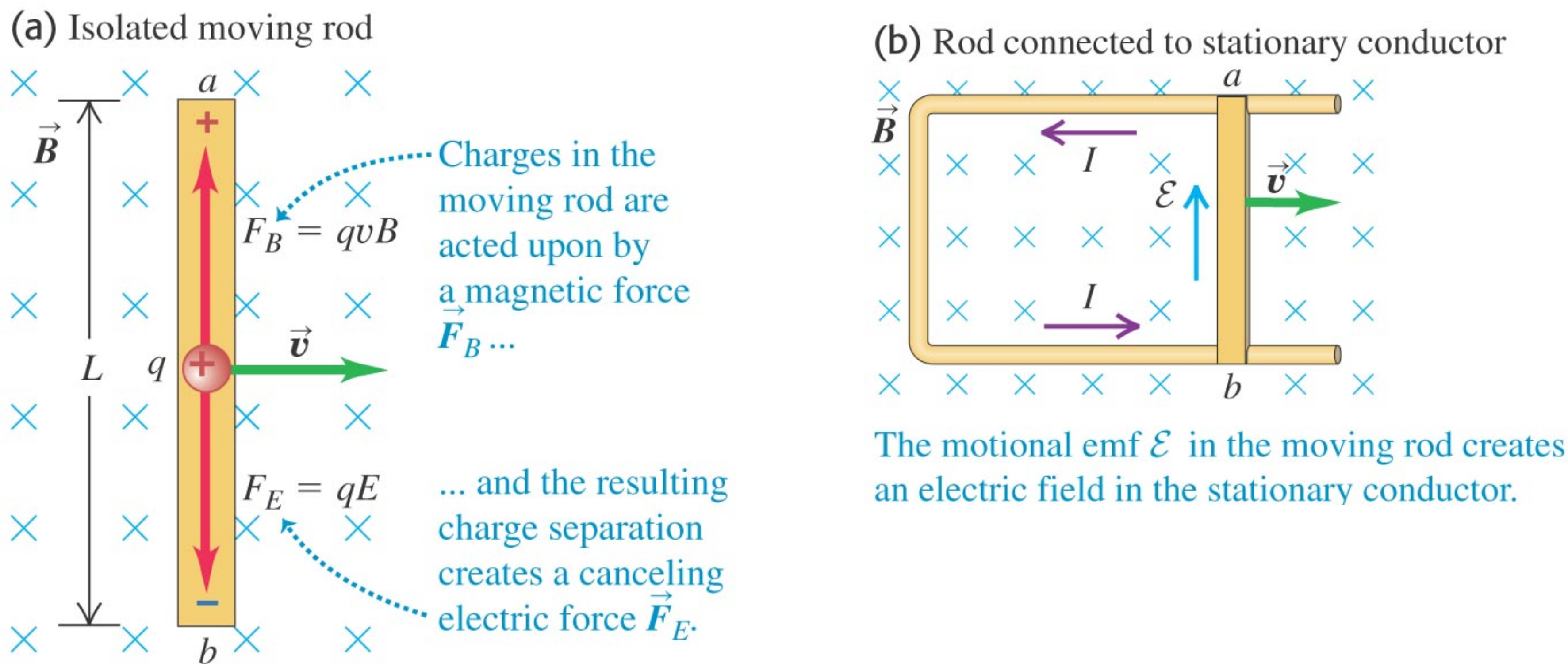
- Follow Example 29.8 using Figures 29.13 (right) and 29.14 (below).





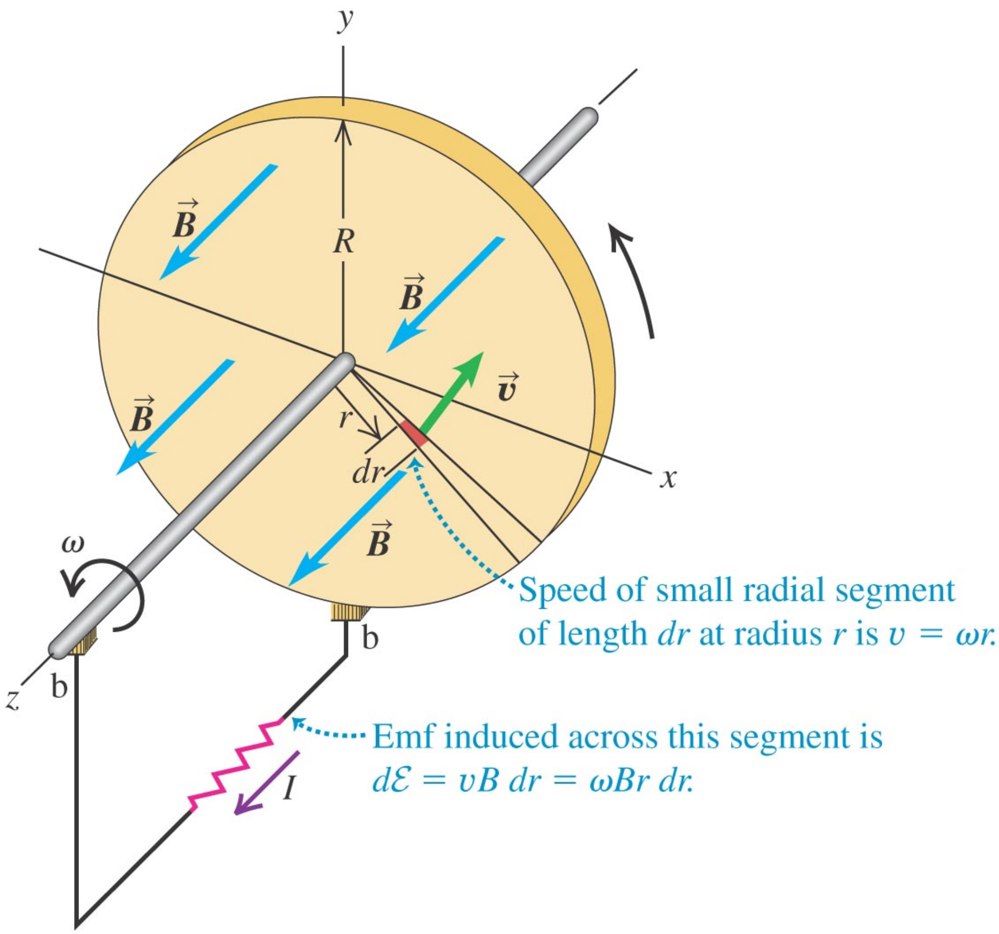
Motional electromotive force

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



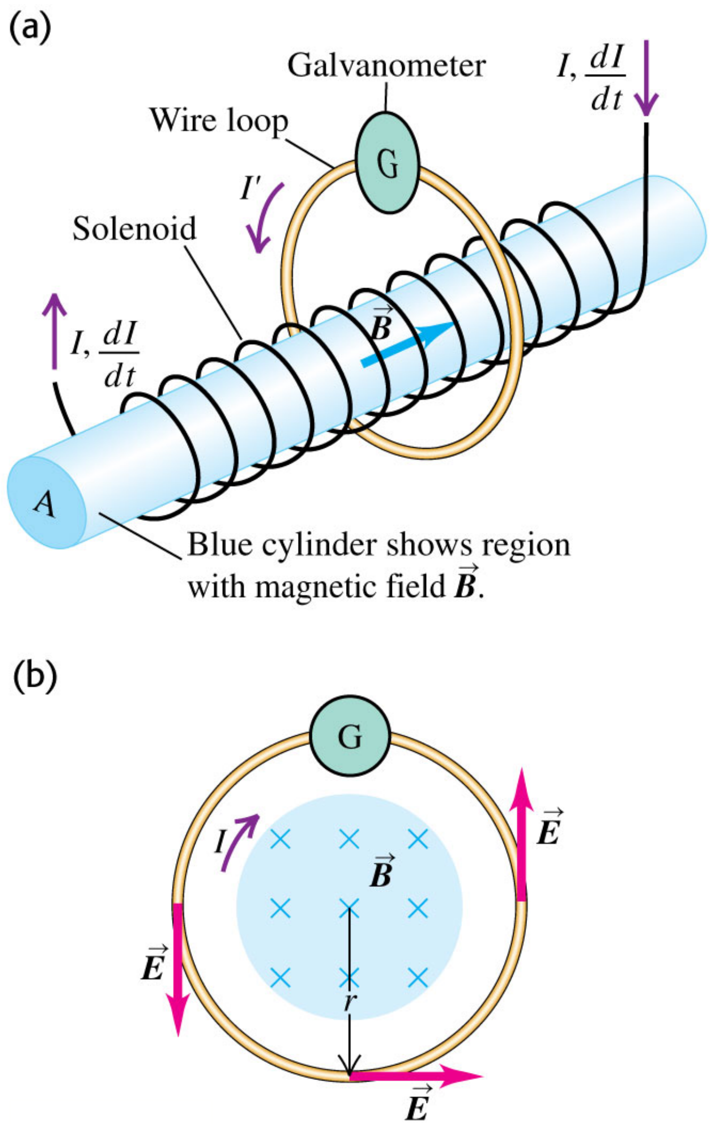
A slidewire generator and a dynamo

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



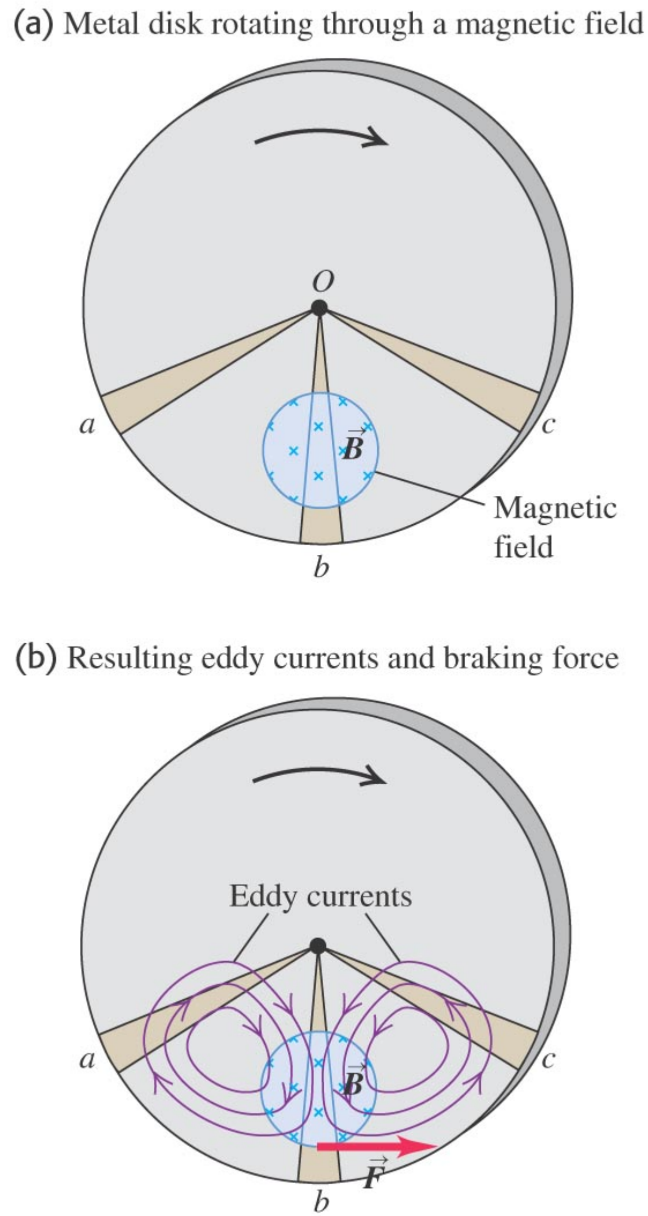
Induced electric fields

- 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.



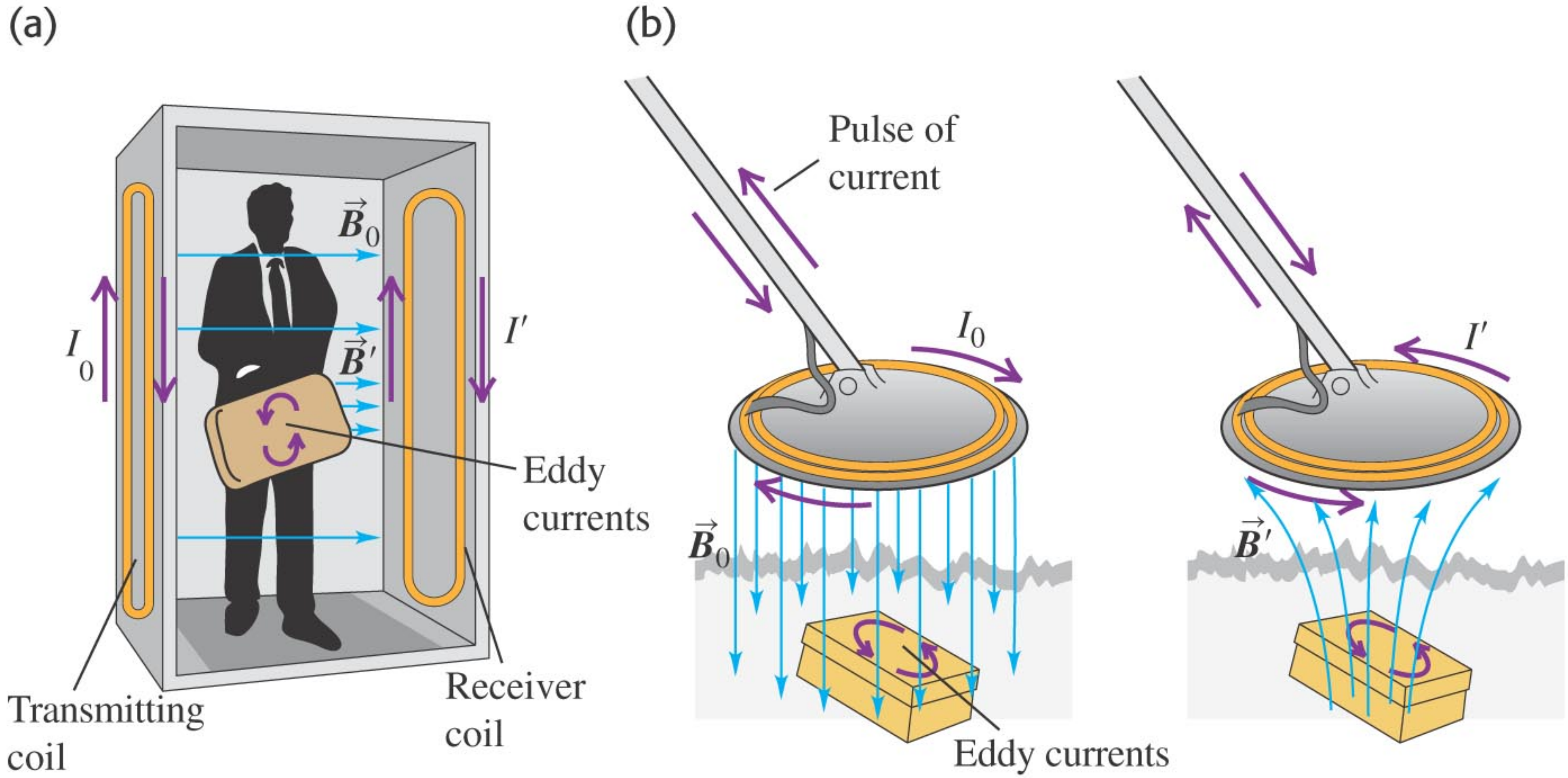
Eddy currents

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



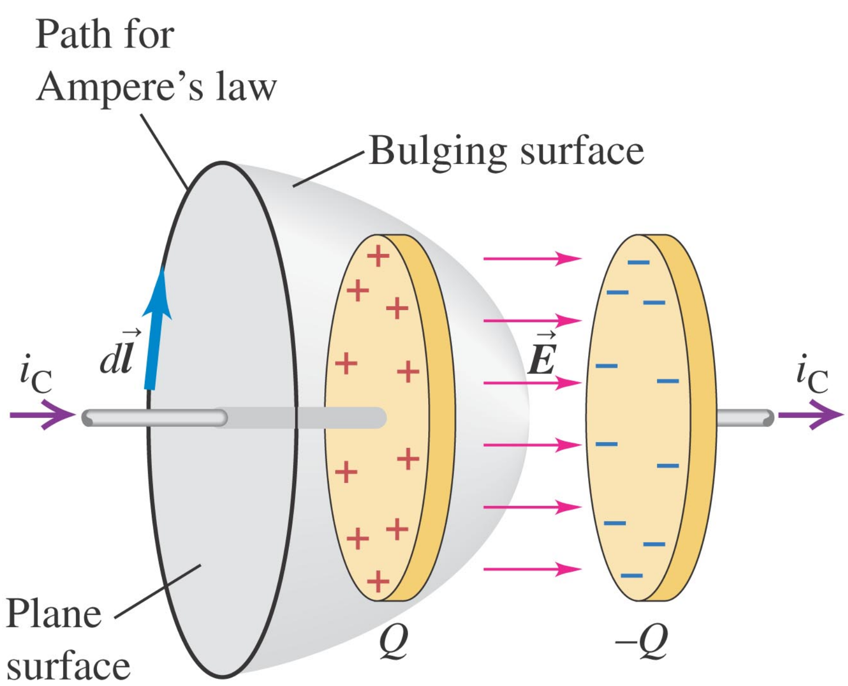
Using eddy currents

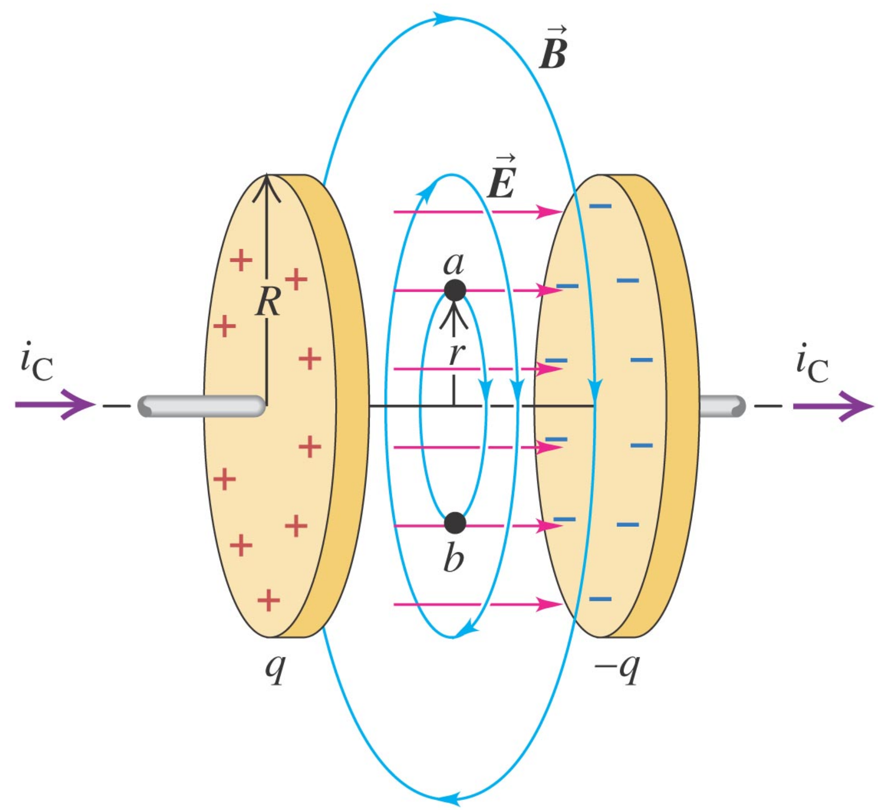
- Figure 29.20 below illustrates an airport metal detector and a portable metal detector, both of which use eddy currents in their design.



Displacement current

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



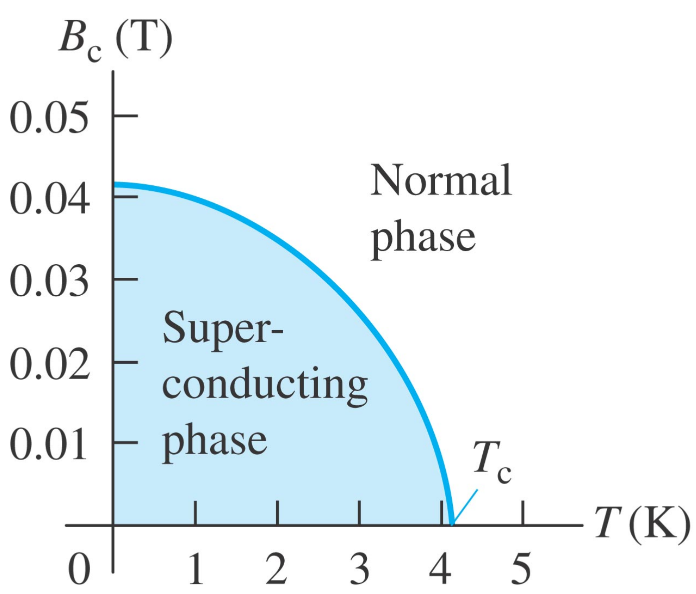


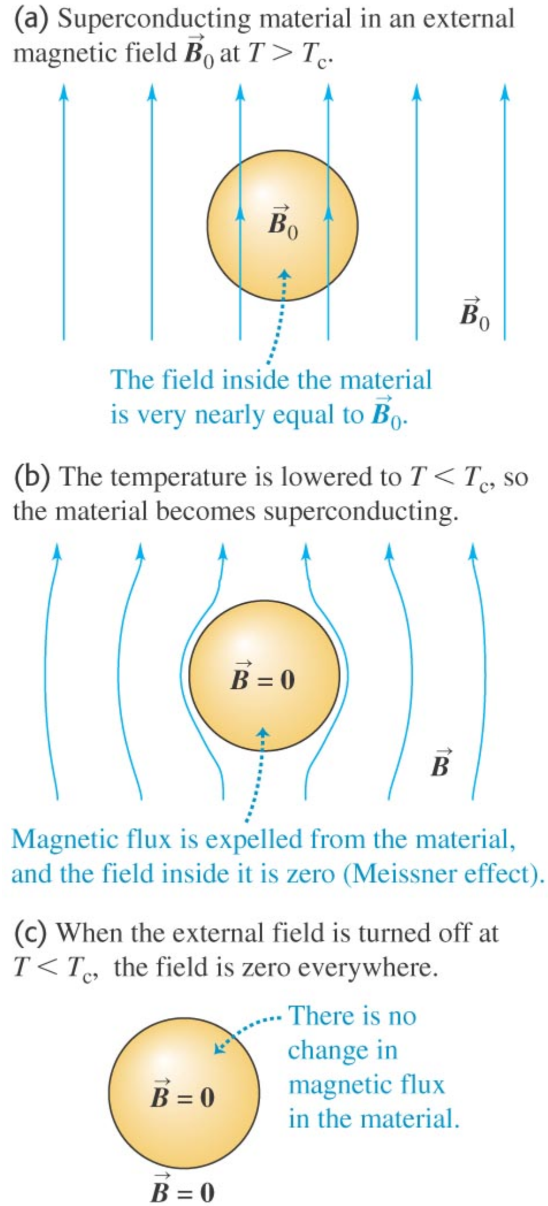
Maxwell's equations

- *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

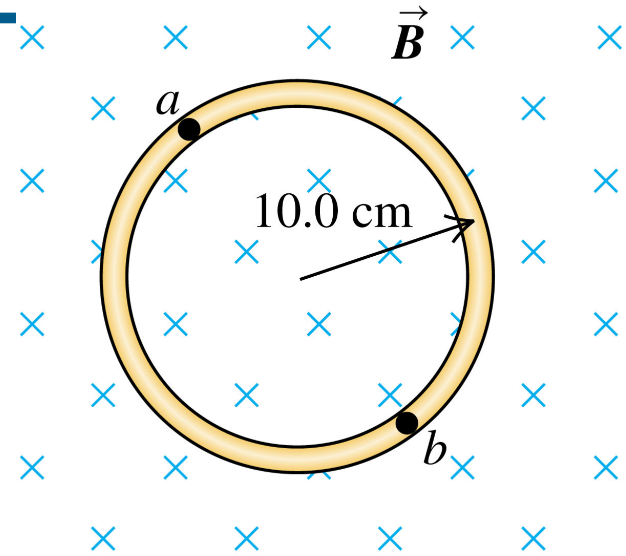
- When a superconductor is cooled below its *critical temperature*, it loses all electrical resistance.
- Follow the text discussion using Figures 29.23 (below) and 29.24 (right).





Q29.1

A circular loop of wire is in a region of spatially uniform magnetic field. The magnetic field is directed into the plane of the figure. If the magnetic field magnitude is constant,



A. the induced emf is clockwise.

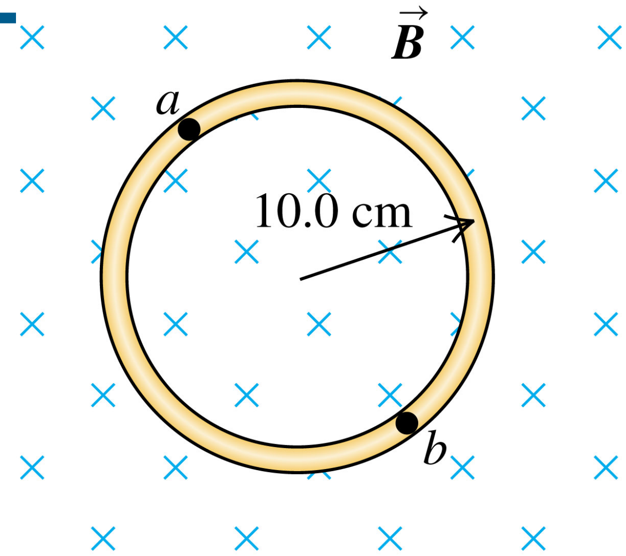
B. the induced emf is counterclockwise.

C. the induced emf is zero.

D. The answer depends on the strength of the field.

Q29.2

A circular loop of wire is in a region of spatially uniform magnetic field. The magnetic field is directed into the plane of the figure. If the magnetic field magnitude is *decreasing*,



A. the induced emf is clockwise.

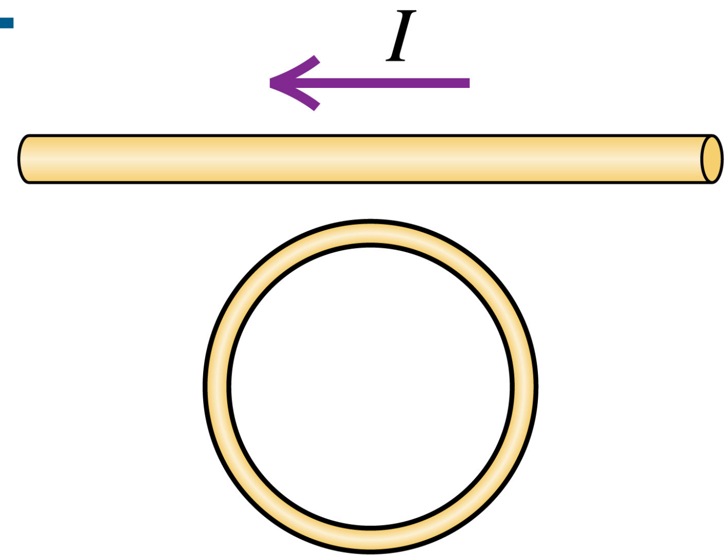
B. the induced emf is counterclockwise.

C. the induced emf is zero.

D. The answer depends on the strength of the field.

Q29.3

A circular loop of wire is placed next to a long straight wire. The current *I* in the long straight wire is increasing. What current does this induce in the circular loop?



A. a clockwise current

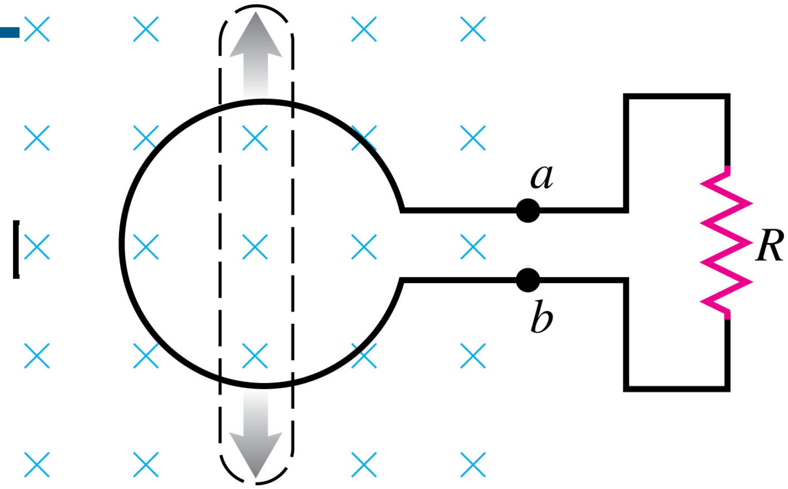
B. a counterclockwise current

C. zero current

D. not enough information given to decide

Q29.4

A flexible loop of wire lies in a uniform magnetic field of magnitude *B* directed into the plane of the picture. The loop is pulled as shown, reducing its area. The induced current



A. flows downward through resistor *R* and is proportional to *B.*

B. flows upward through resistor *R* and is proportional to *B.*

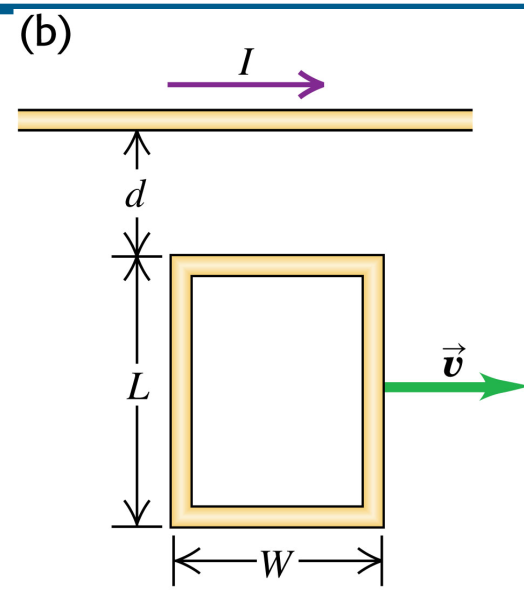
C. flows downward through resistor *R* and is proportional to B^2.

D. flows upward through resistor *R* and is proportional to B^2.

E. none of the above

Q29.5

The rectangular loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long straight wire in the direction shown. The current induced in the loop is



A. clockwise and proportional to *I*.

B. counterclockwise and proportional to *I*.

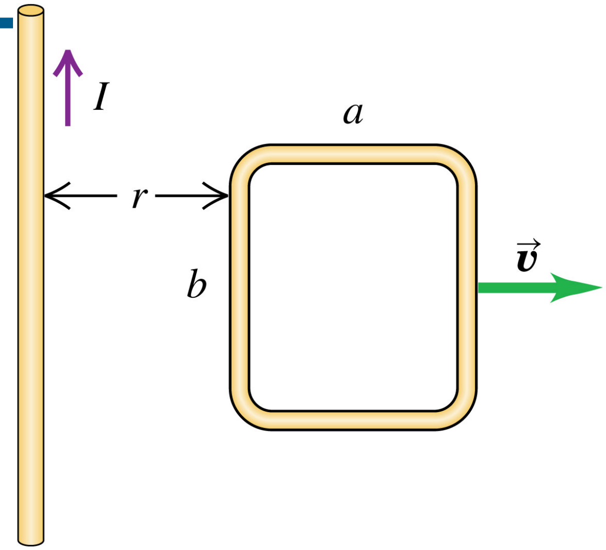
C. clockwise and proportional to I^2.

D. counterclockwise and proportional to I^2.

E. zero.

Q29.6

The loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long straight wire in the direction shown. The current induced in the loop is



A. clockwise and proportional to *I*.

B. counterclockwise and proportional to *I*.

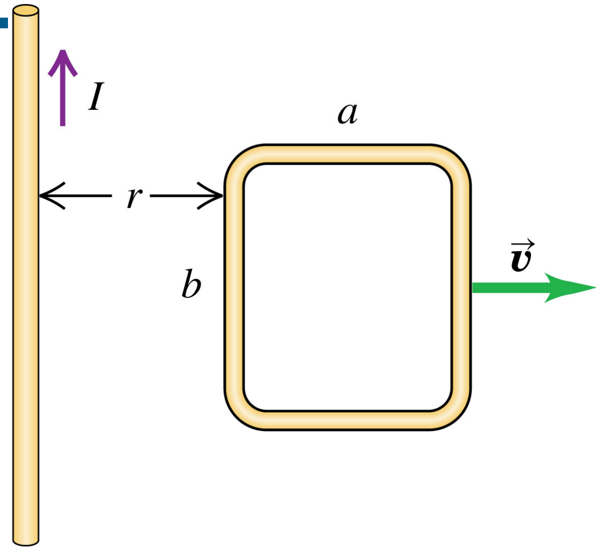
C. clockwise and proportional to I^2.

D. counterclockwise and proportional to I^2.

E. zero.

Q29.7

The rectangular loop of wire is being moved to the right at constant velocity. A constant current *I* flows in the long wire in the direction shown. What are the directions of the magnetic forces on the left-hand (L) and right-hand (R) sides of the loop?



A. L: to the left; R: to the left

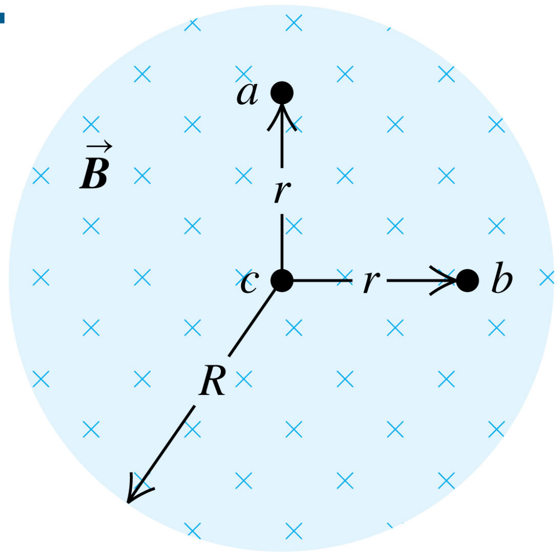
B. L: to the left; R: to the right

C. L: to the right; R: to the left

D. L: to the right; R: to the right

Q29.8

The drawing shows the uniform magnetic field inside a long, straight solenoid. The field is directed into the plane of the drawing and is increasing.



What is the direction of the *electric* force on a positive point charge placed at point *a*?

A. to the left

B. to the right

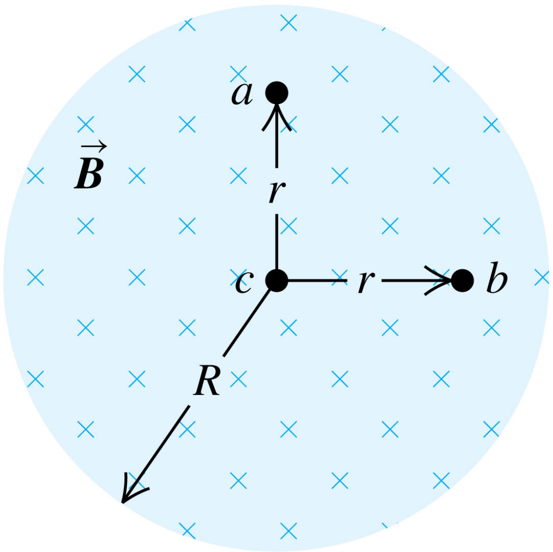
C. straight up

D. straight down

E. misleading question—the electric force at this point is zero

Q29.9

The drawing shows the uniform magnetic field inside a long, straight solenoid. The field is directed into the plane of the drawing and is increasing.



What is the direction of the *electric* force on a positive point charge placed at point *b*?

A. to the left

B. to the right

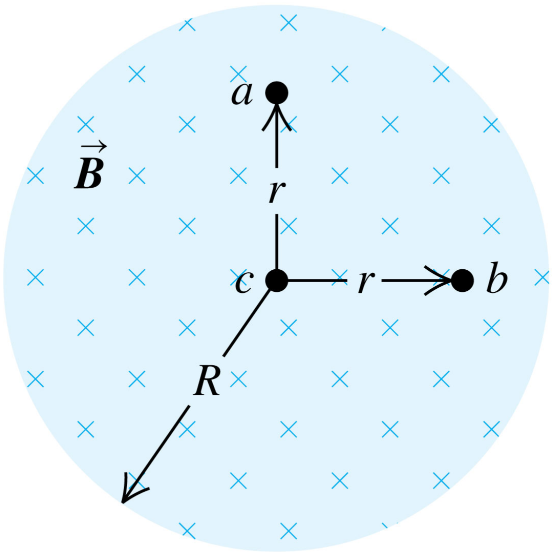
C. straight up

D. straight down

E. misleading question—the electric force at this point is zero

Q29.10

The drawing shows the uniform magnetic field inside a long, straight solenoid. The field is directed into the plane of the drawing and is increasing.



What is the direction of the *electric* forc on a positive point charge placed at point *c* (at the center of the solenoid)?

A. to the left

B. to the right

C. straight up

D. straight down

E. misleading question—the electric force at this point is zero