

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

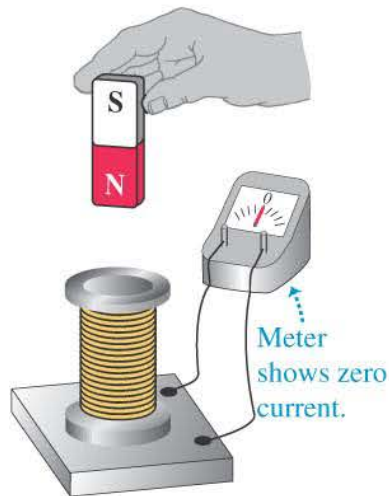
- How is a credit card reader related to magnetism?
- Energy conversion makes use of electromagnetic induction.
- Faraday's law and Lenz's law tell us about induced currents.
- Maxwell's equations describe the behavior of electric and magnetic fields in *any* situation.



Induced current

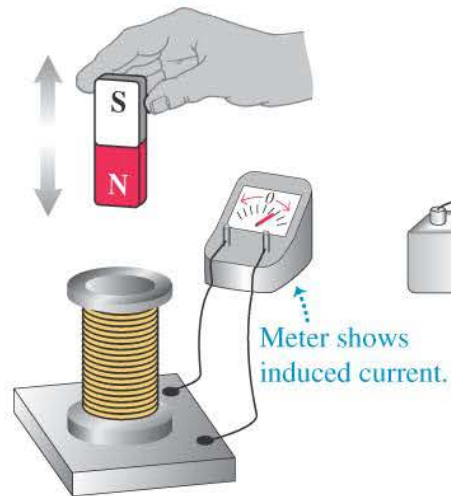
- A changing magnetic flux causes an *induced current*. See Figure 29.1 below.
- The *induced emf* is the corresponding emf causing the current.

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

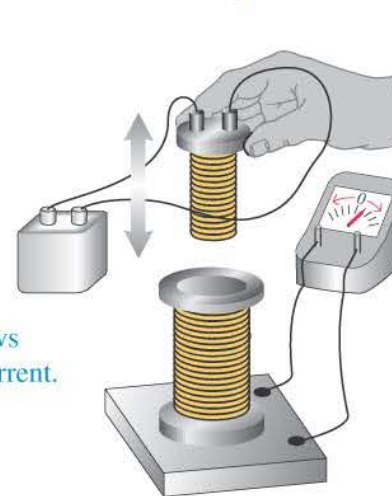


All these actions DO induce a current in the coil. What do they have in common?*

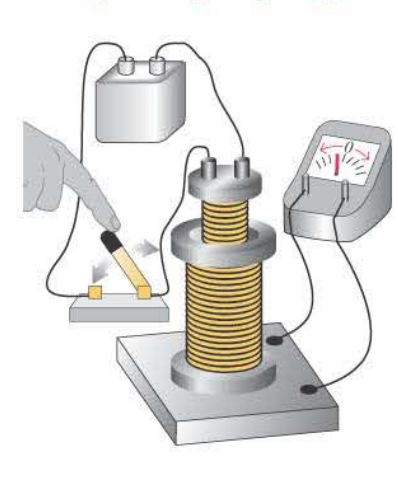
(b) Moving the magnet toward or away from the coil



(c) Moving a second, current-carrying coil toward or away from the coil



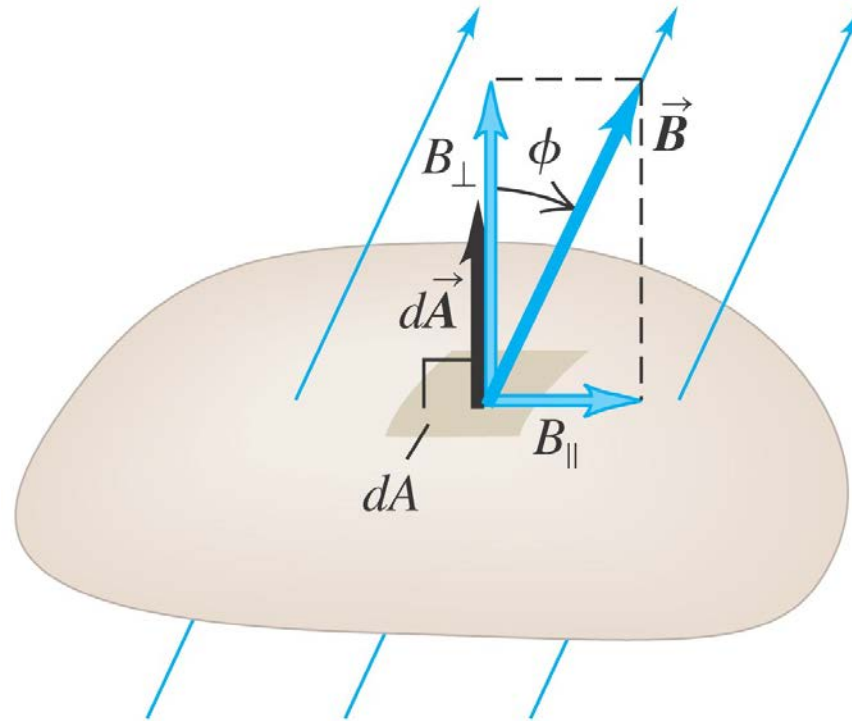
(d) Varying the current in the second coil (by closing or opening a switch)



*They cause the magnetic field through the coil to *change*.

Magnetic flux through an area element

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



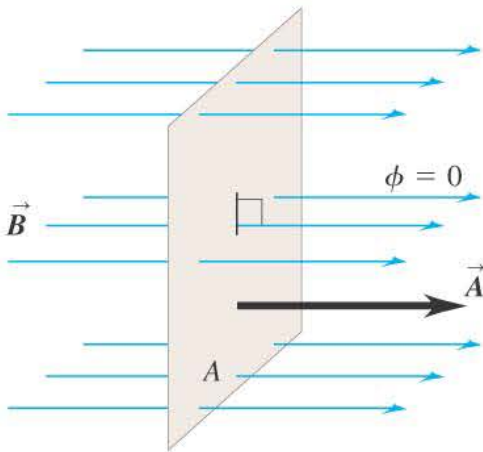
Magnetic flux through element of area $d\vec{A}$:
$$d\Phi_B = \vec{B} \cdot d\vec{A} = B_{\perp} dA = B dA \cos \phi$$

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

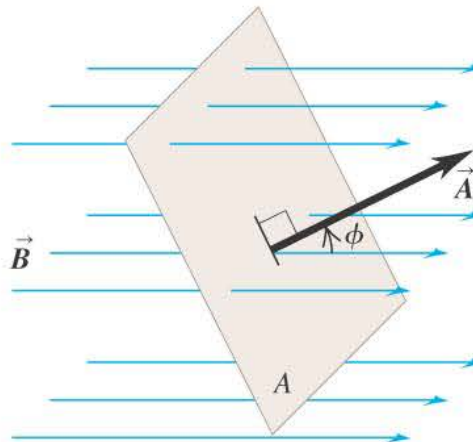
Surface is face-on to magnetic field:

- \vec{B} and \vec{A} are parallel (the angle between \vec{B} and \vec{A} is $\phi = 0$).
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA$.



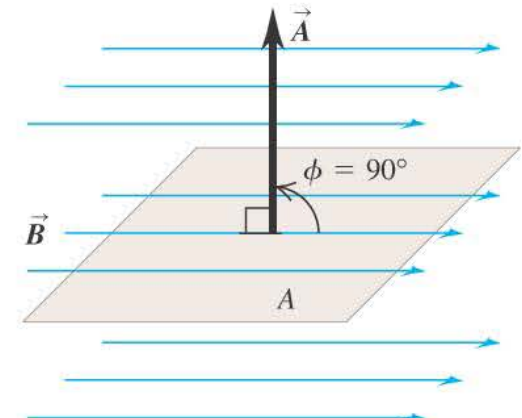
Surface is tilted from a face-on orientation by an angle ϕ :

- The angle between \vec{B} and \vec{A} is ϕ .
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos \phi$.



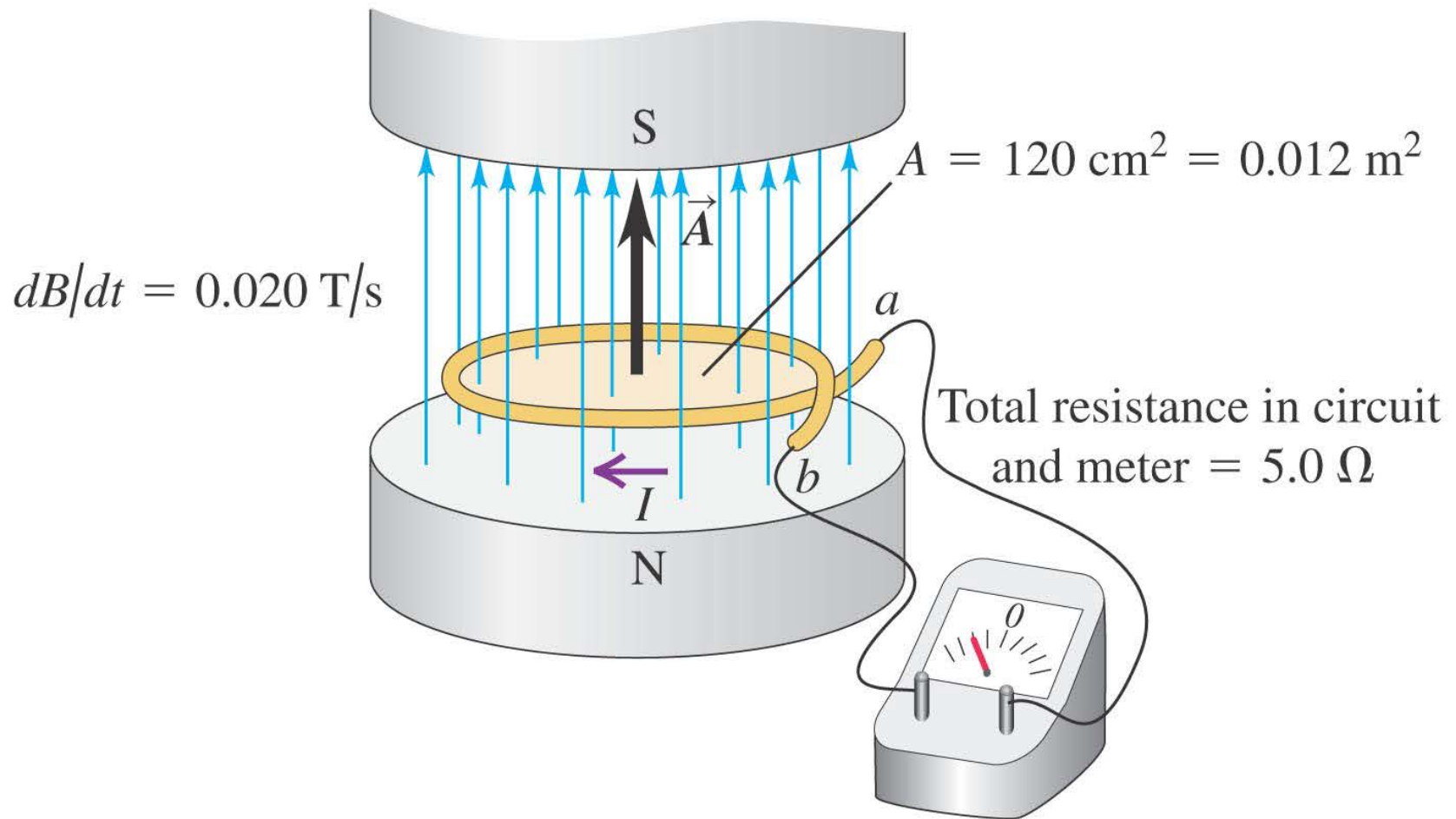
Surface is edge-on to magnetic field:

- \vec{B} and \vec{A} are perpendicular (the angle between \vec{B} and \vec{A} is $\phi = 90^\circ$).
- The magnetic flux $\Phi_B = \vec{B} \cdot \vec{A} = BA \cos 90^\circ = 0$.



Emf and the current induced in a loop

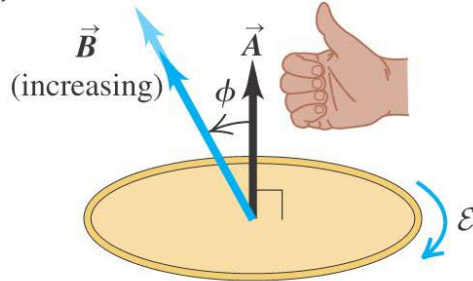
- Follow Example 29.1 using Figure 29.5 below.



Direction of the induced emf

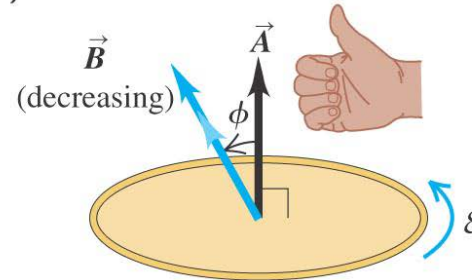
- Follow the text discussion on the direction of the induced emf, using Figure 29.6 below.

(a)



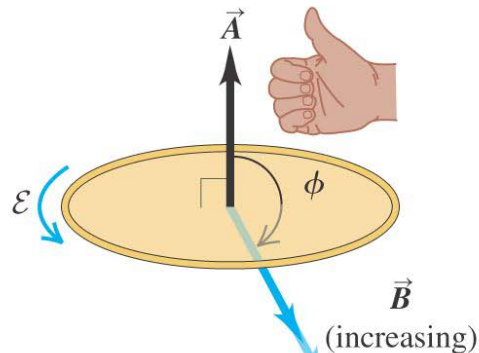
- Flux is positive ($\Phi_B > 0$) ...
- ... and becoming more positive ($d\Phi_B/dt > 0$).
- Induced emf is negative ($\mathcal{E} < 0$).

(b)



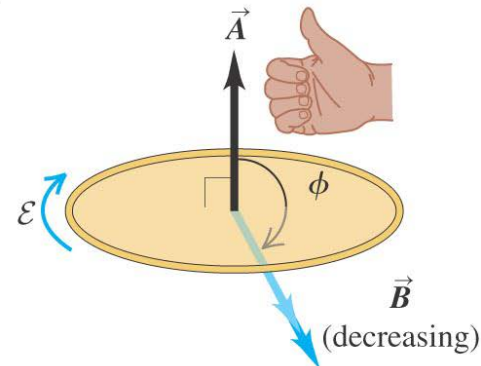
- Flux is positive ($\Phi_B > 0$) ...
- ... and becoming less positive ($d\Phi_B/dt < 0$).
- Induced emf is positive ($\mathcal{E} > 0$).

(c)



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

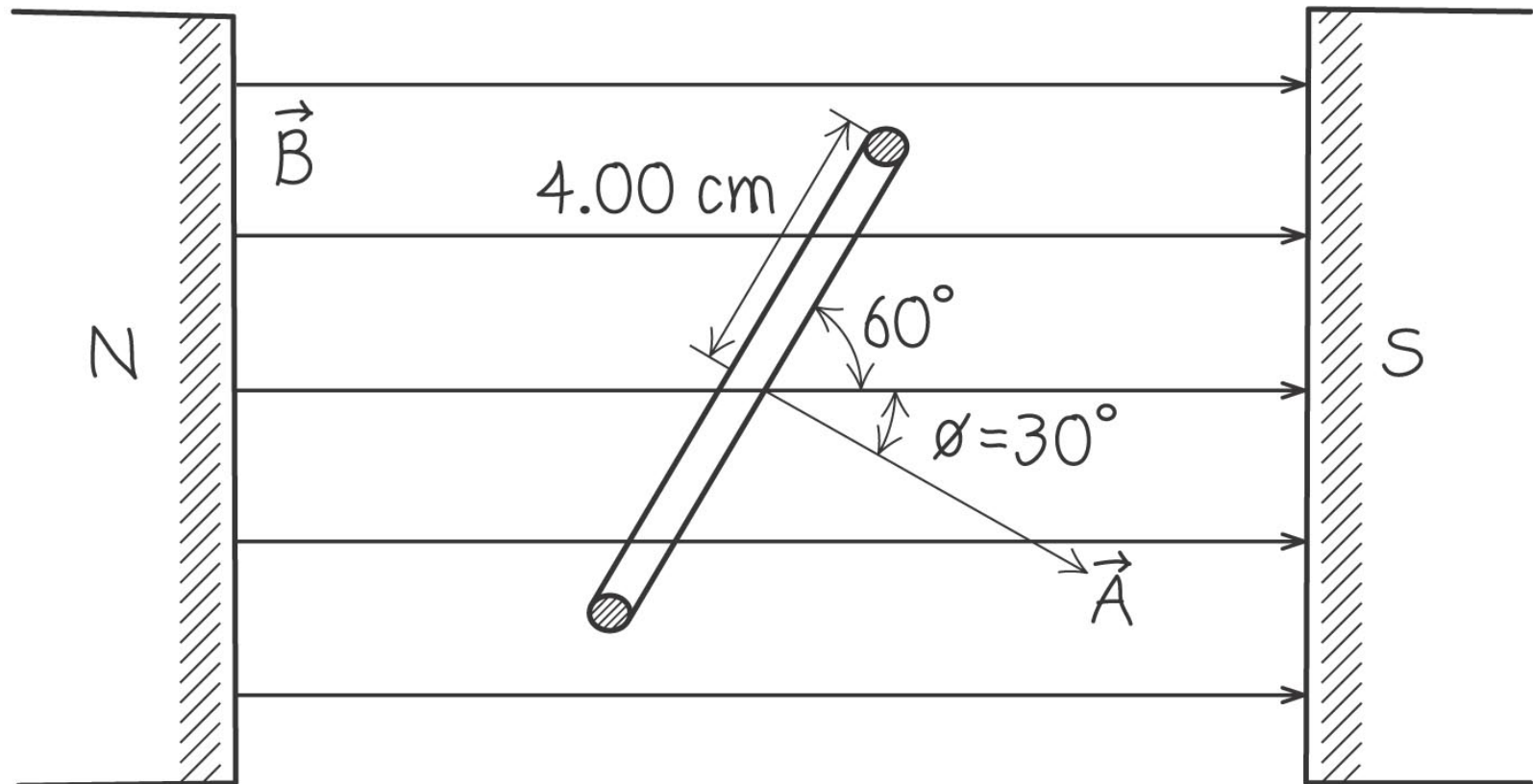
(d)



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

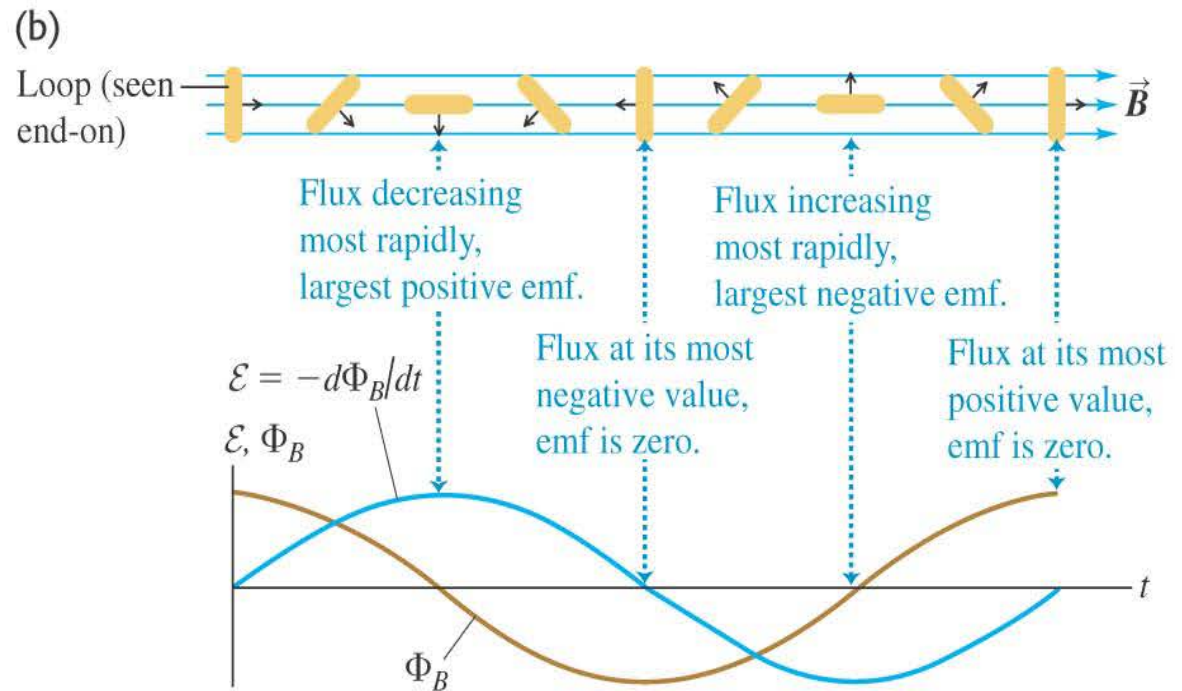
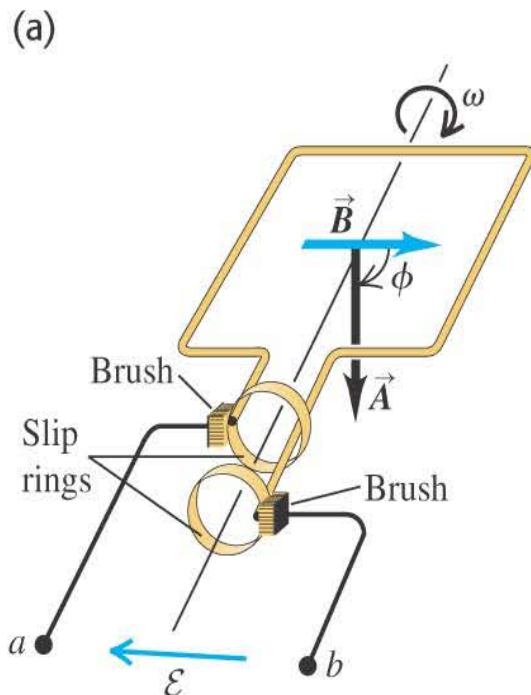
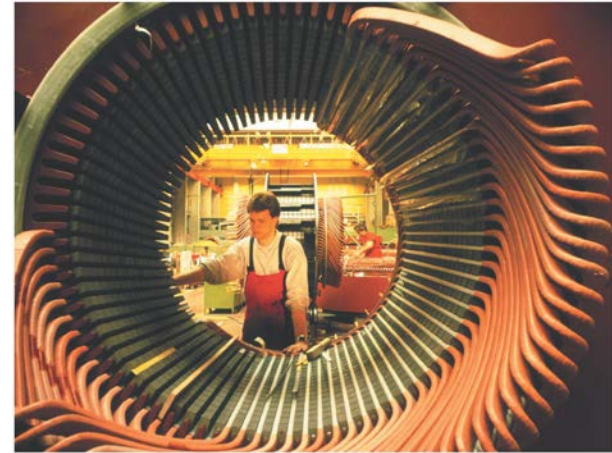
Magnitude and direction of an induced emf

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



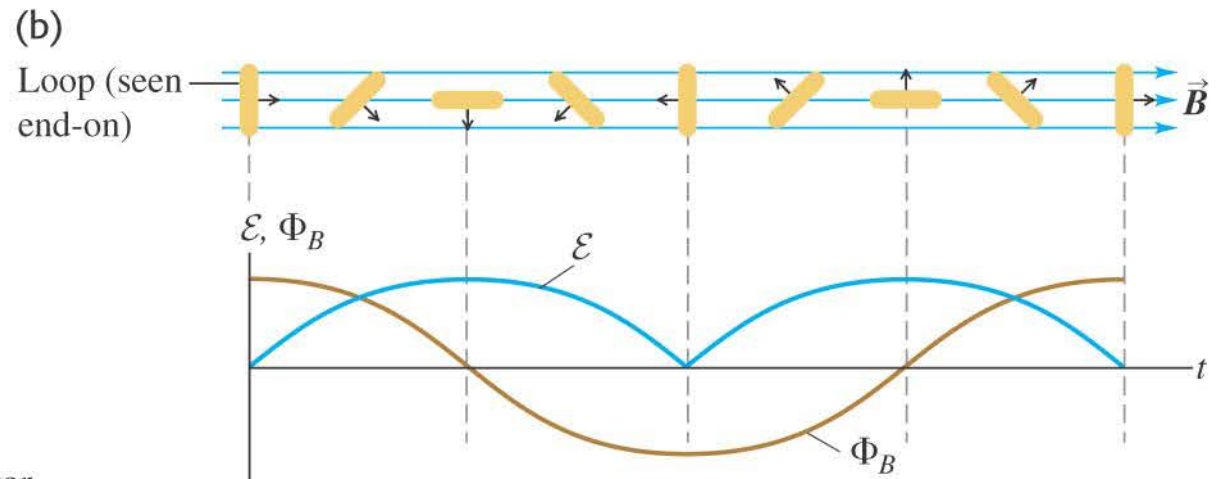
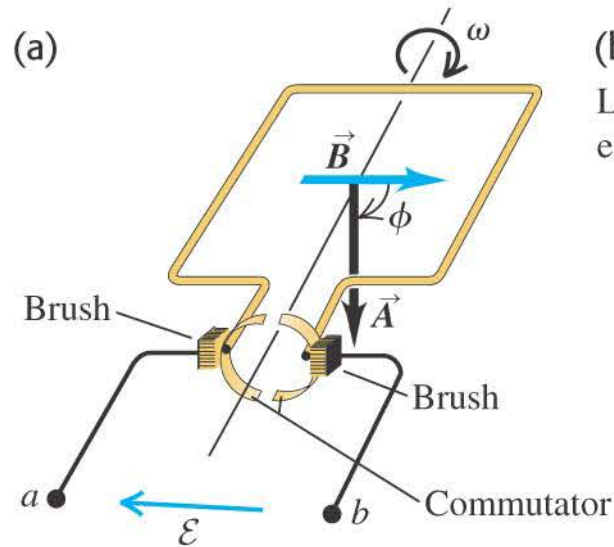
A simple alternator

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



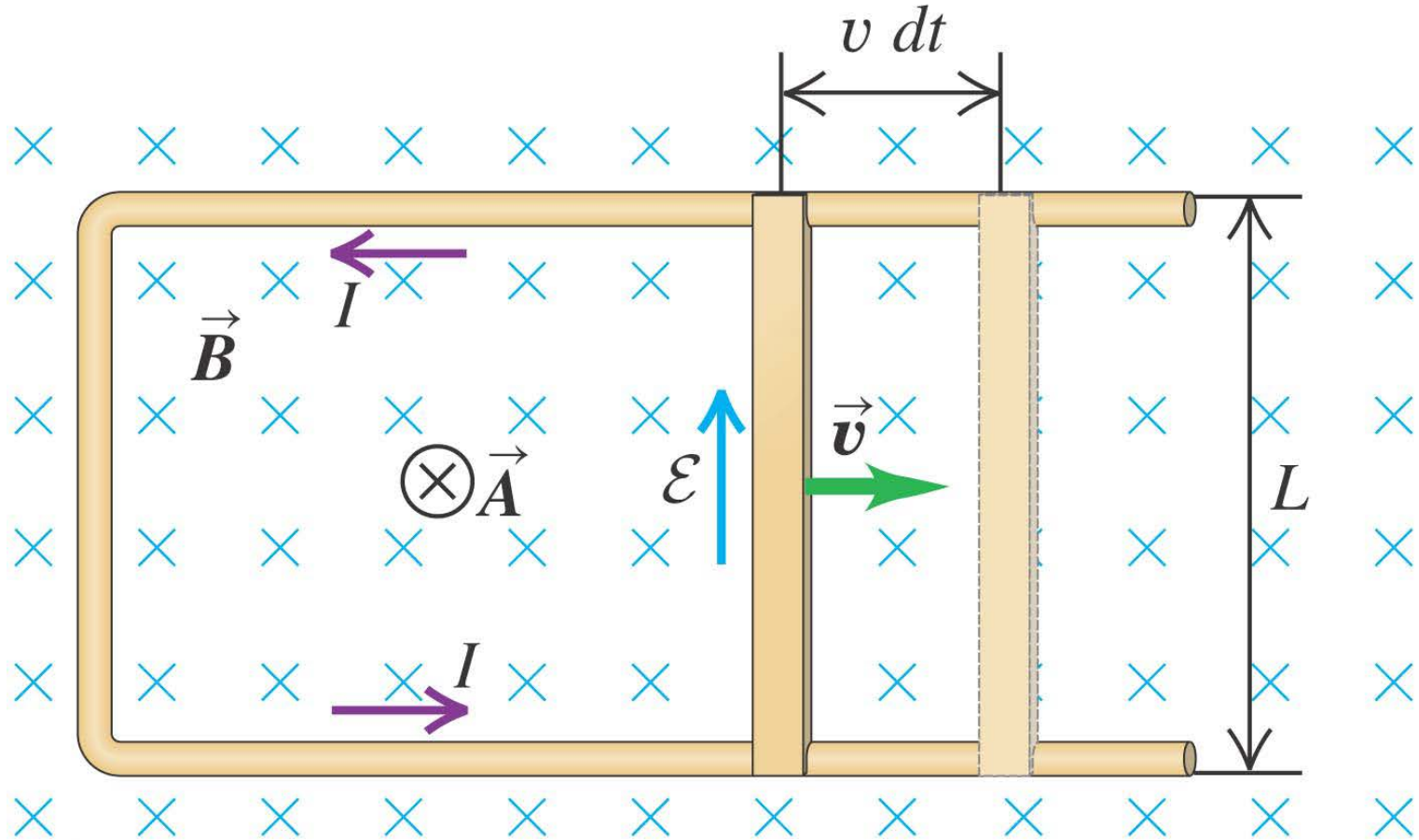
DC generator and back emf in a motor

- Follow Example 29.4 using Figure 29.10 below.



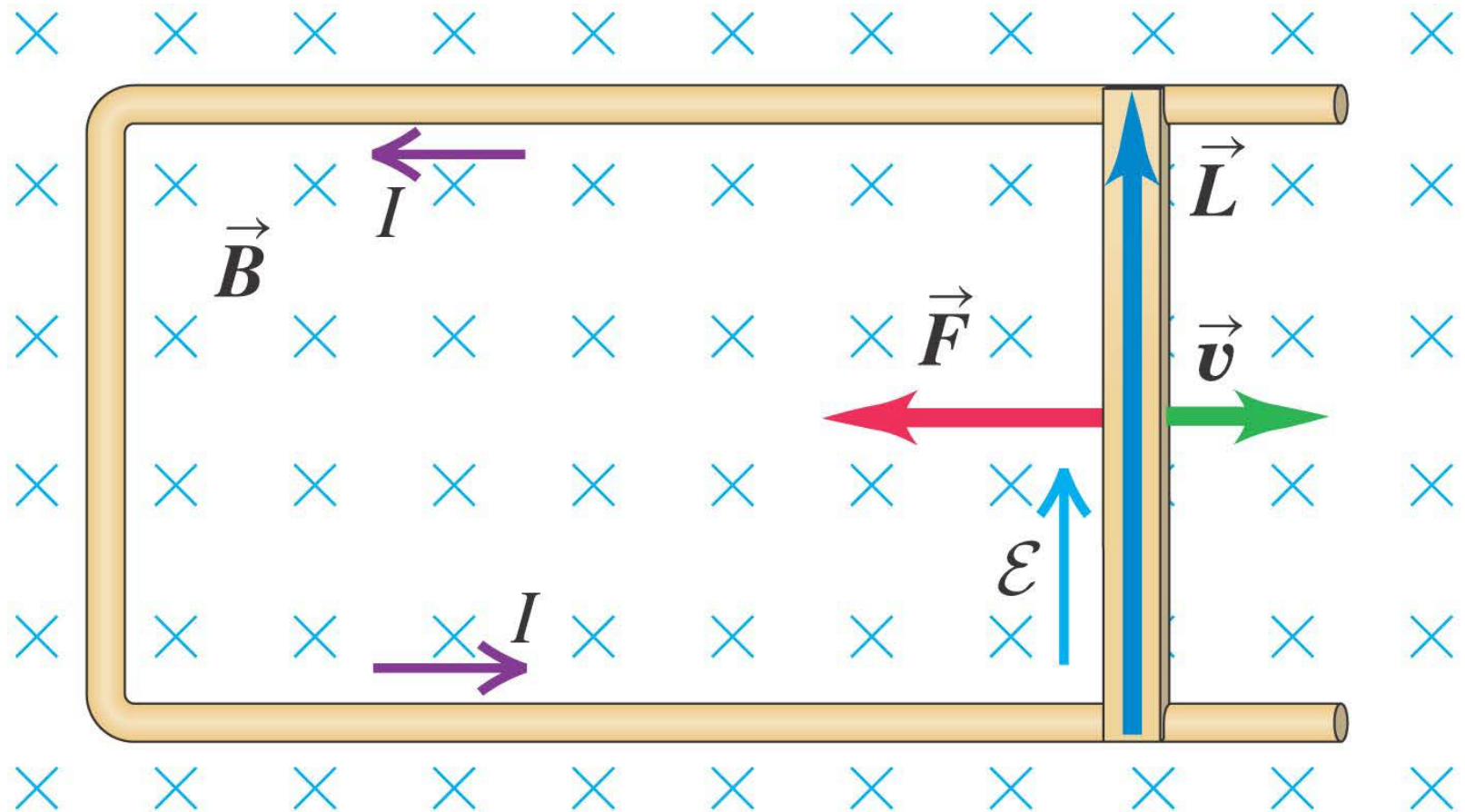
Slidewire generator

- 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.

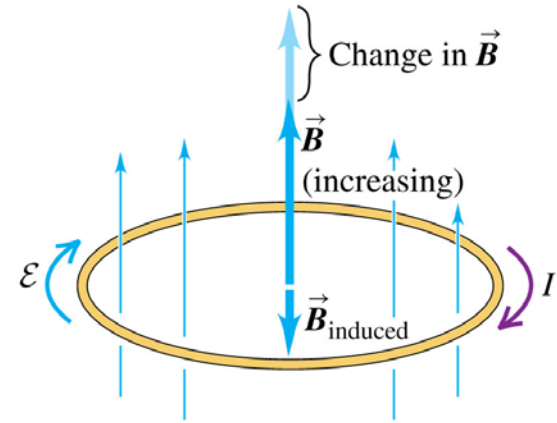


Lenz's law

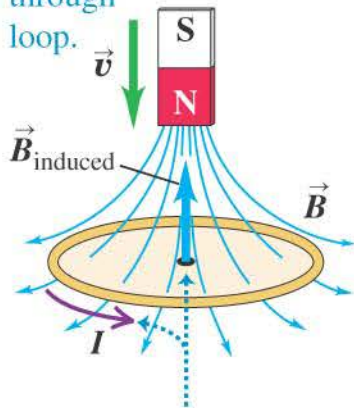
- *Lenz's law*: The direction of any magnetic induction effect is such as to oppose the cause of the effect.
- Follow Conceptual Example 29.7.

Lenz's law and the direction of induced current

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

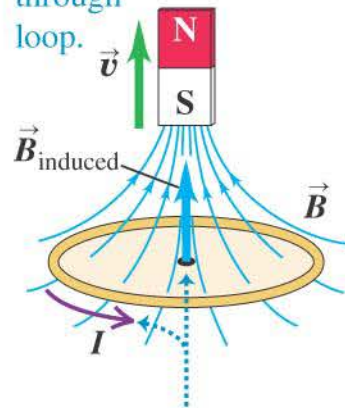


- (a) Motion of magnet causes increasing downward flux through loop.

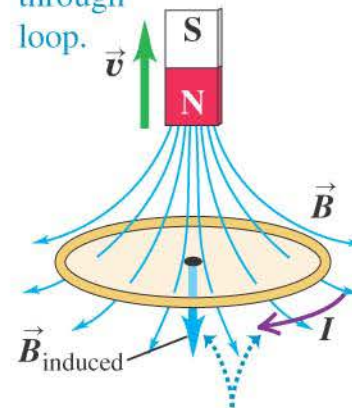


The induced magnetic field is *upward* to oppose the flux change. To produce this induced field, the induced current must be *counterclockwise* as seen from above the loop.

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

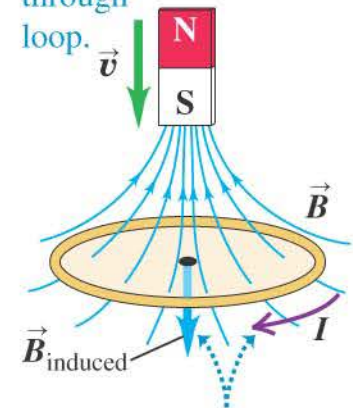


- (c) Motion of magnet causes decreasing downward flux through loop.



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.

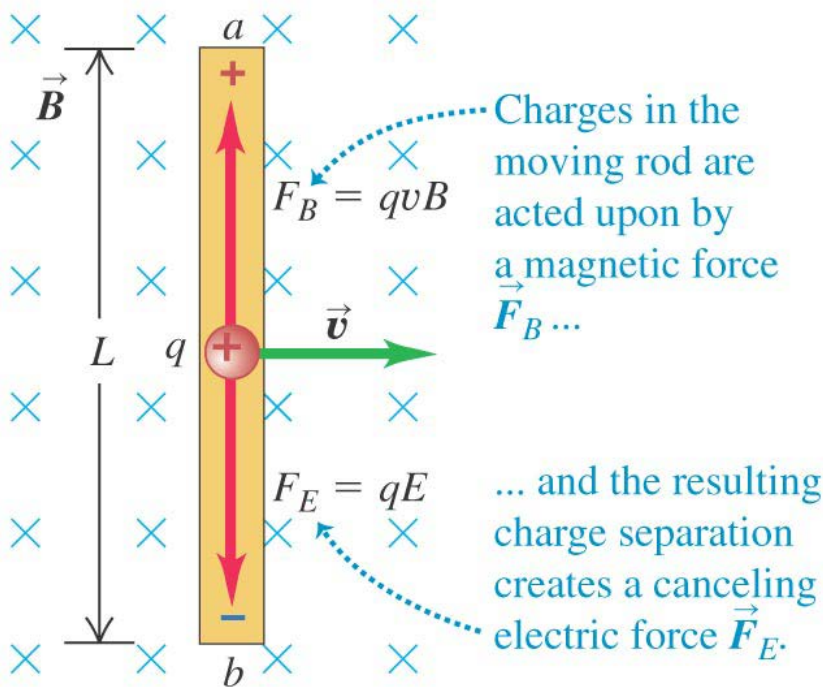
- (d) Motion of magnet causes increasing upward flux through loop.



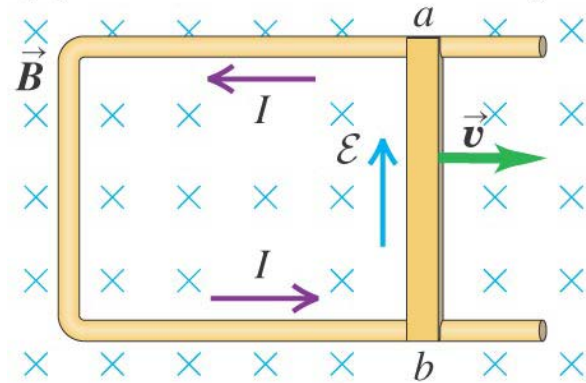
Motional electromotive force

- 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



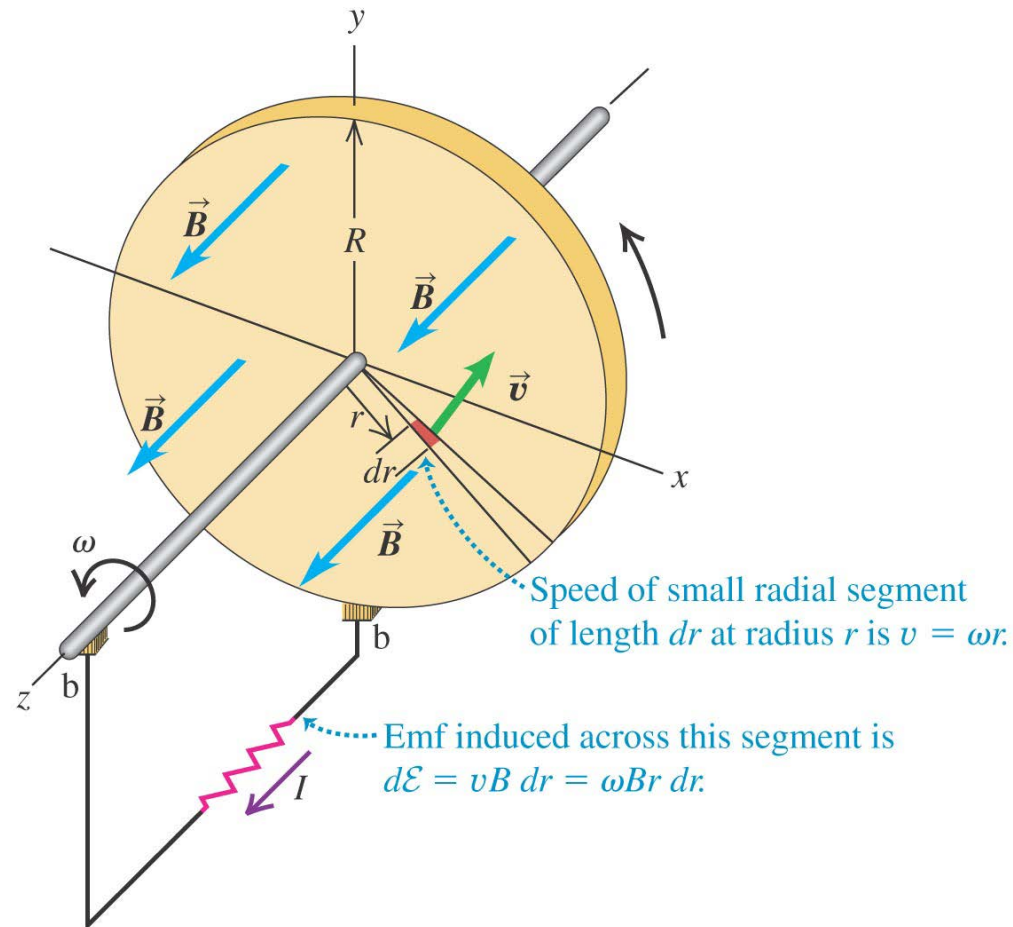
(b) Rod connected to stationary conductor



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

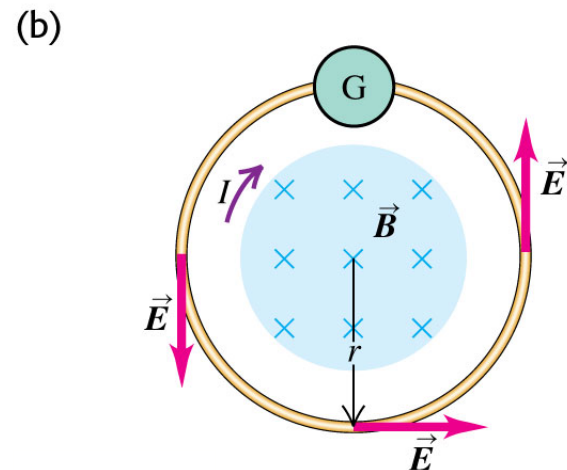
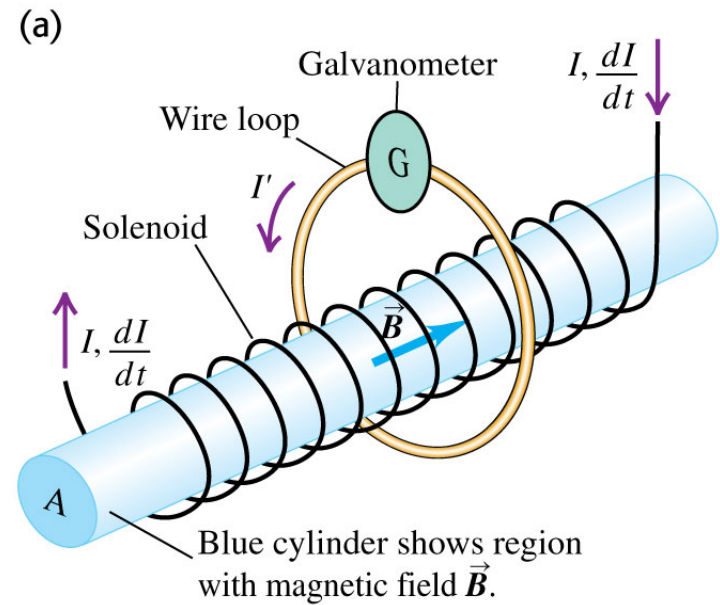
A slidewire generator and a dynamo

- 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

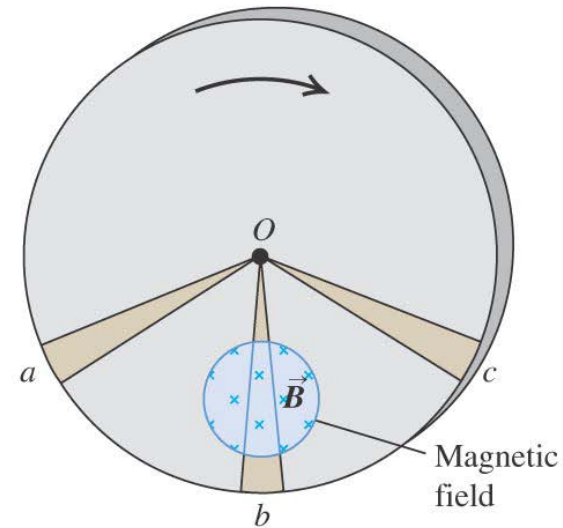
- Changing magnetic flux causes an *induced electric field*.
- See Figure 29.17 at the right to see the induced electric field for a solenoid.
- Follow the text discussion for Faraday's law restated in terms of the induced electric field.
- Follow Example 29.11 using Figure 29.17.



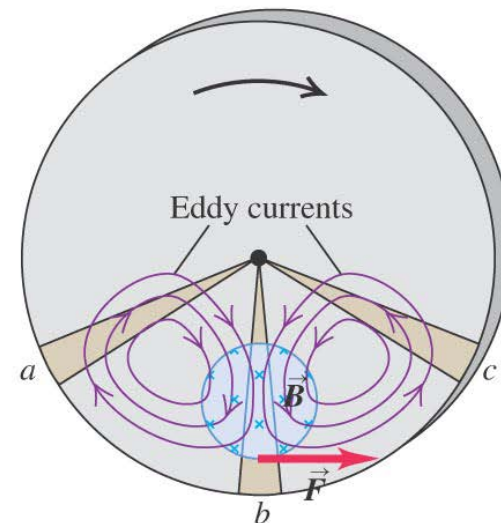
Eddy currents

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

(a) Metal disk rotating through a magnetic field

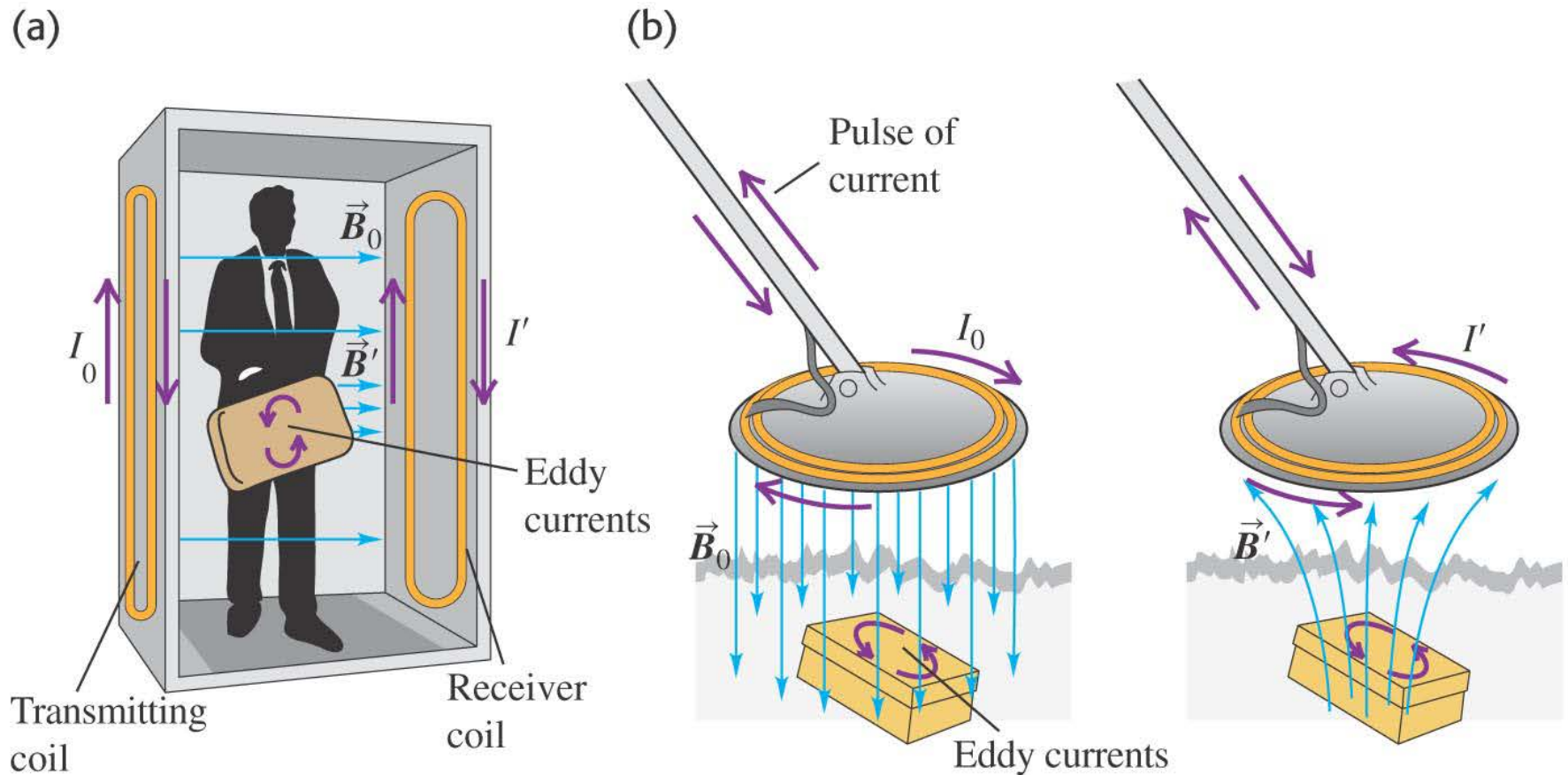


(b) Resulting eddy currents and braking force



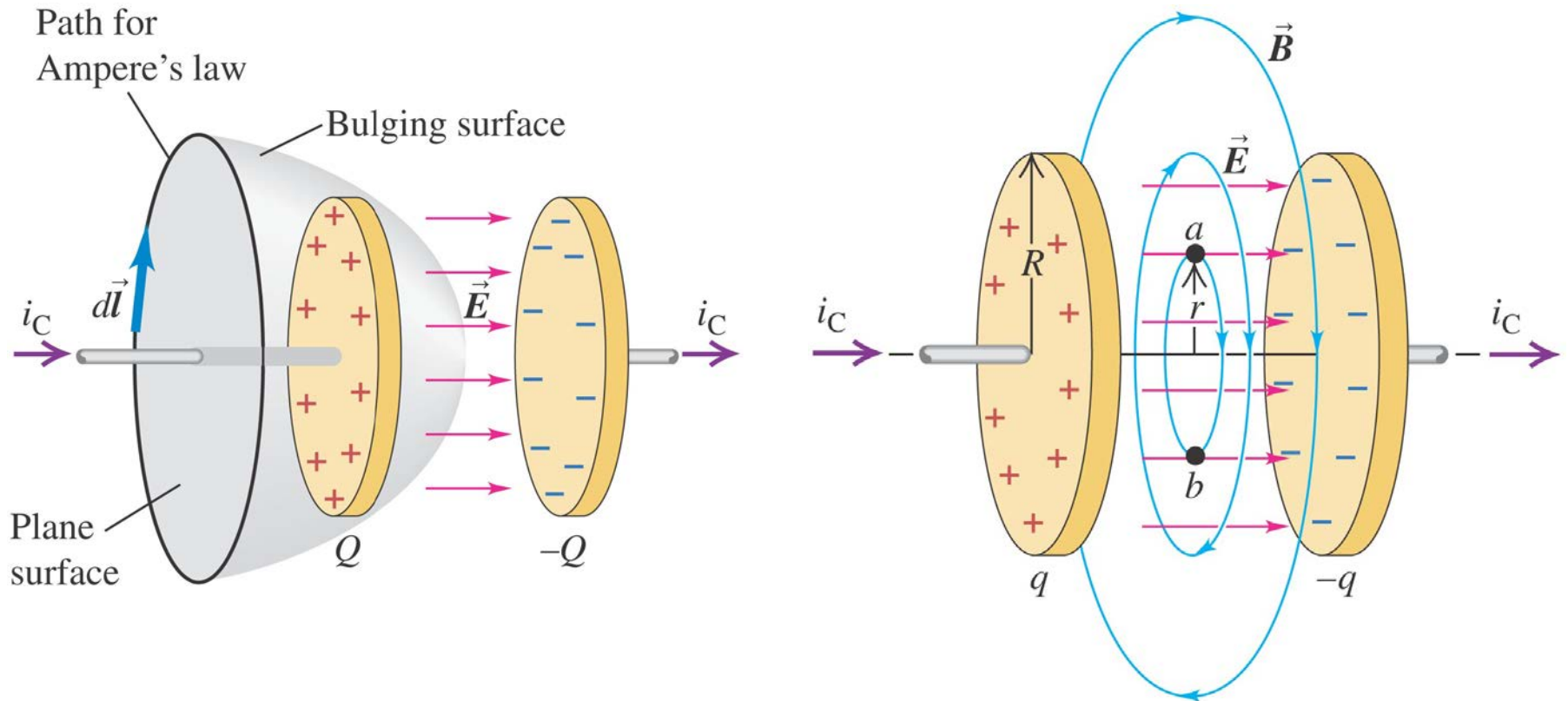
Using eddy currents

- 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.

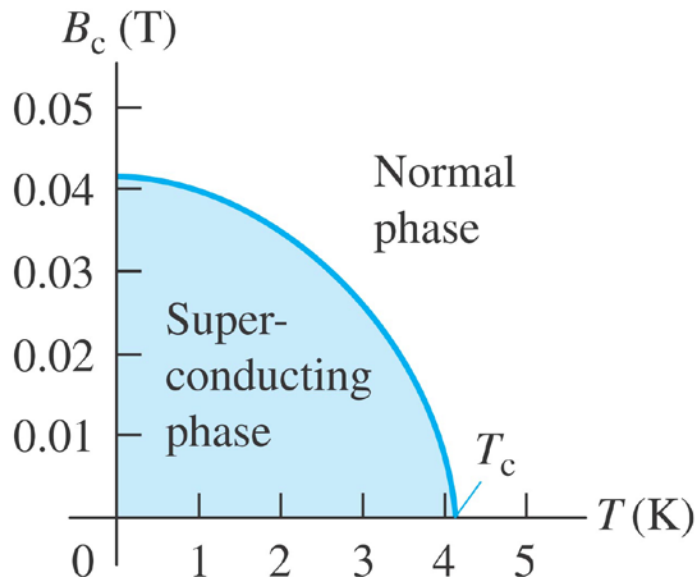


Maxwell's equations

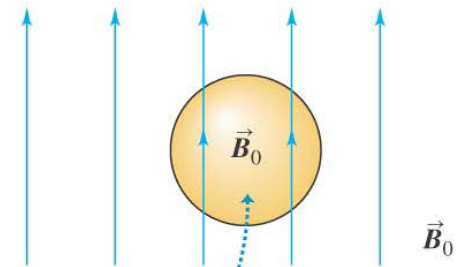
- *Maxwell's equations* consist of
 - ✓ Gauss's law for the electric field
 - ✓ Gauss's law for the magnetic field
 - ✓ Ampere's law
 - ✓ Faraday's law.
- Follow the text discussion for the mathematical form of these four fundamental laws.

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).

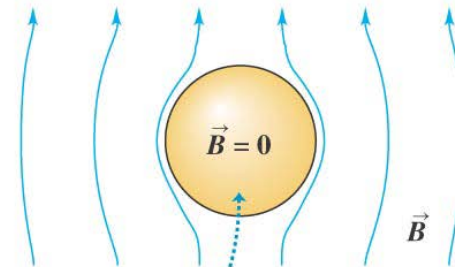


(a) Superconducting material in an external magnetic field \vec{B}_0 at $T > T_c$.



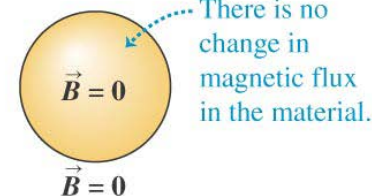
The field inside the material is very nearly equal to \vec{B}_0 .

(b) The temperature is lowered to $T < T_c$, so the material becomes superconducting.



Magnetic flux is expelled from the material, and the field inside it is zero (Meissner effect).

(c) When the external field is turned off at $T < T_c$, the field is zero everywhere.



There is no change in magnetic flux in the material.