Chapter 34. Electromagnetic Induction

Electromagnetic induction is the scientific principle that underlies many modern technologies, from the generation of electricity to communications and data storage.

Chapter Goal: To understand and apply electromagnetic induction.

Chapter 34. Electromagnetic Induction

Topics:

- Induced Currents
- Motional emf
- Magnetic Flux
- Lenz's Law
- Faraday's Law
- Induced Fields

Chapter 34. Reading Quizzes

Electromagnetic induction was discovered by

A. Faraday.
B. Henry.
C. Maxwell.
D. Both Faraday and Henry.
E. All three.

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The direction that an induced current flows in a circuit is given by

A. Faraday’s law.
B. Lenz’s law.
C. Henry’s law.
D. Hertz’s law.
E. Maxwell’s law.

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A. Faraday's law.
✔ **B. Lenz's law.**
C. Henry's law.
D. Hertz's law.
E. Maxwell's law.

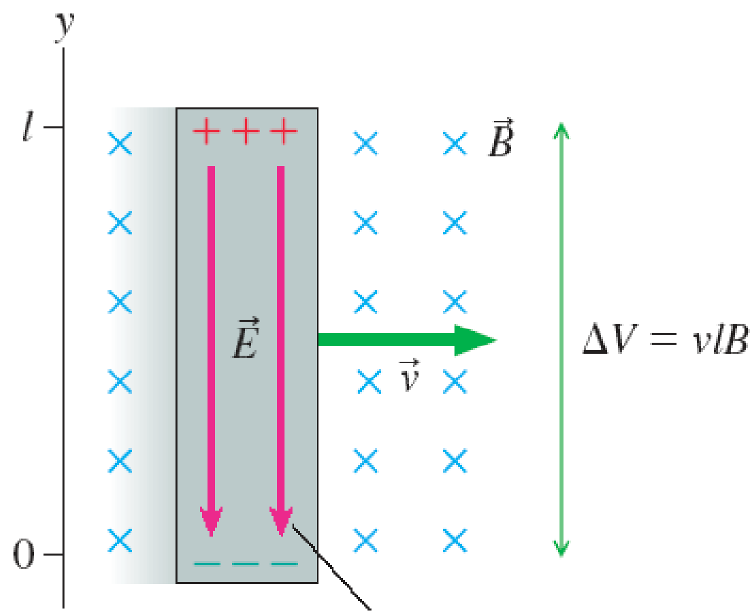
Chapter 34. Basic Content and Examples

Faraday's Discovery

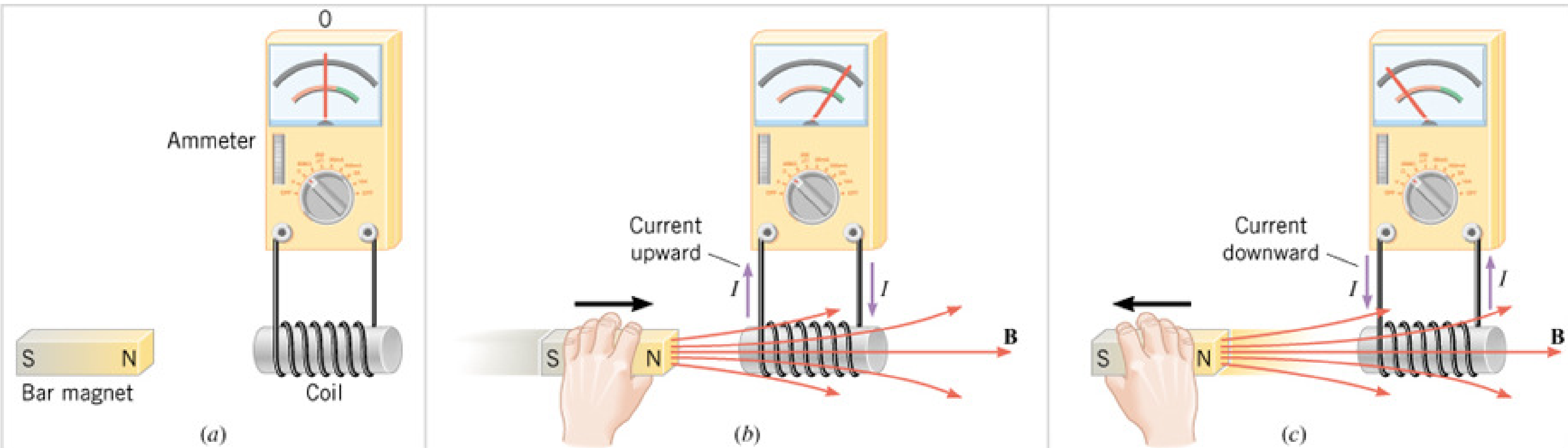
Faraday found that there is a current in a coil of wire if and only if the magnetic field passing through the coil is *changing*. This is an informal statement of *Faraday's law.*

FIGURE 34.3 Two different ways to generate an emf.

(a) Magnetic forces separate the charges and cause a potential difference between the ends. This is a motional emf.

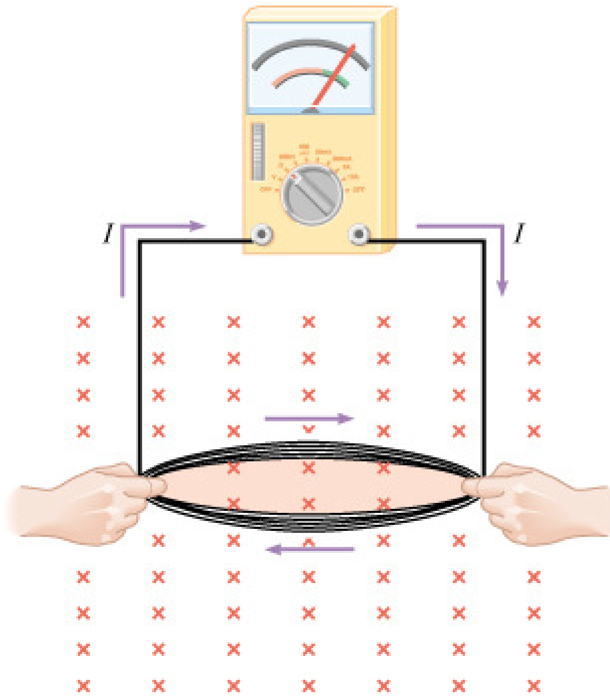


There are a number of ways a magnetic field can be used to generate an electric current.



It is the ***changing*** field that produces the current.

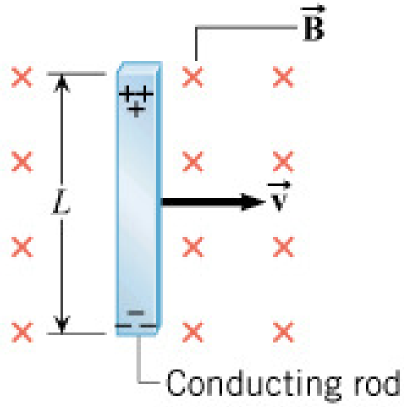
An emf can be induced by changing the area of a coil in a constant magnetic field



In each example, both an emf and a current are induced because the coil is part of a complete circuit. If the circuit were open, there would be no induced current, but there would be an induced emf.

The phenomena of producing an induced emf with the aid of a magnetic field is called ***electromagnetic induction.***

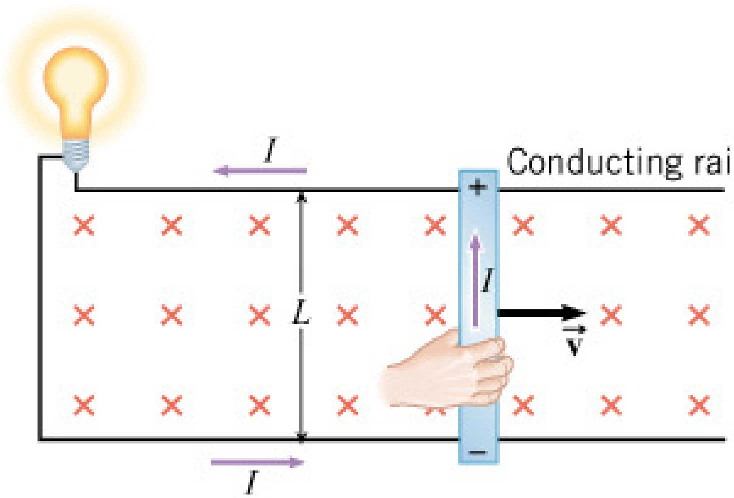
THE EMF INDUCED IN A MOVING CONDUCTOR



(a)

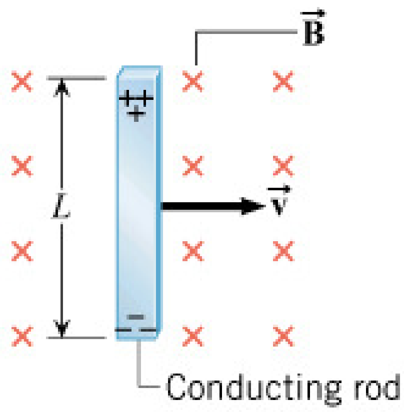
Each charge within the conductor is moving and experiences a magnetic force

$$F = qvB$$

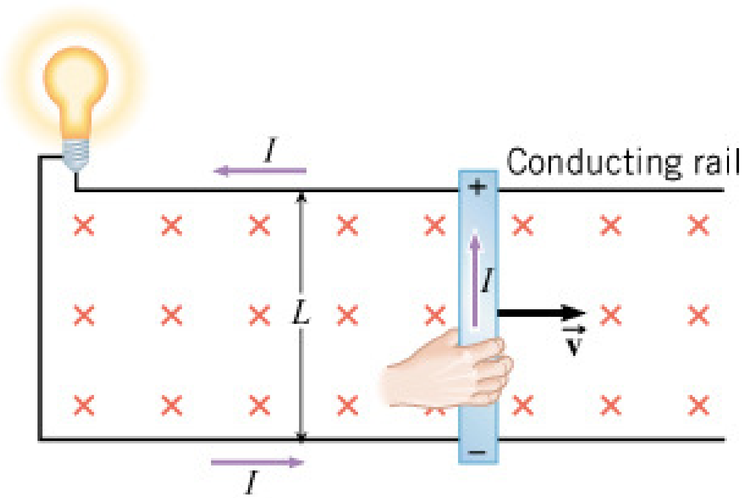


(b)

The separated charges on the ends of the conductor give rise to an induced emf, called a ***motional emf.***



(*a*)



(*b*)

Motional emf when v, B, and L are mutually perpendicular

$$\mathcal{E} = vBL$$

Motional emf

The motional emf of a conductor of length l moving with velocity v perpendicular to a magnetic field B is

$$\mathcal{E} = vlB$$

EXAMPLE 34.1 Measuring the earth's magnetic field

QUESTION:

EXAMPLE 34.1 Measuring the earth's magnetic field

It is known that the earth's magnetic field over northern Canada points straight down. The crew of a Boeing 747 aircraft flying at 260 m/s over northern Canada finds a 0.95 V potential difference between the wing tips. The wing span of a Boeing 747 is 65 m. What is the magnetic field strength there?

EXAMPLE 34.1 Measuring the earth's magnetic field

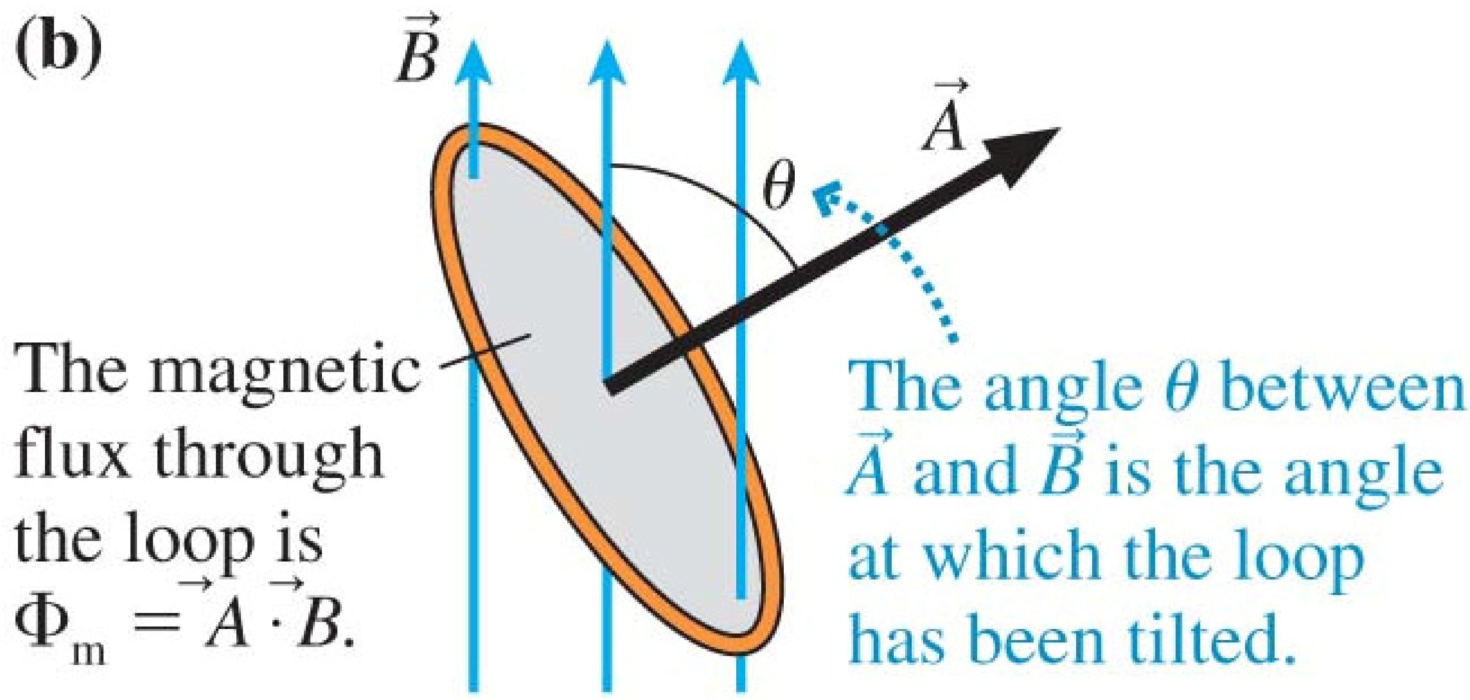
MODEL The wing is a conductor moving through a magnetic field, so there is a motional emf.

EXAMPLE 34.1 Measuring the earth's magnetic field

SOLVE The magnetic field is perpendicular to the velocity, so we can use Equation 34.3 to find

$$B = \frac{\mathcal{E}}{vL} = \frac{0.95\ \text{V}}{(260\ \text{m/s})(65\ \text{m})} = 5.6 \times 10^{-5}\ \text{T}$$

Magnetic flux can be defined in terms of an area vector



Magnetic Flux

$$\Phi_m = A_{eff}B = AB\cos\theta$$

The magnetic flux measures the amount of magnetic field passing through a loop of area A if the loop is tilted at an angle θ from the field, B. As a dot-product, the equation becomes:

$$\Phi_m = \vec{A} \cdot \vec{B}$$

Lenz's Law

There is an induced current in a closed, conducting loop if and only if the magnetic flux through the loop is changing. The direction of the induced current is such that the induced magnetic field opposes the *change* in the flux.

FIGURE 34.20 The induced current is ccw.

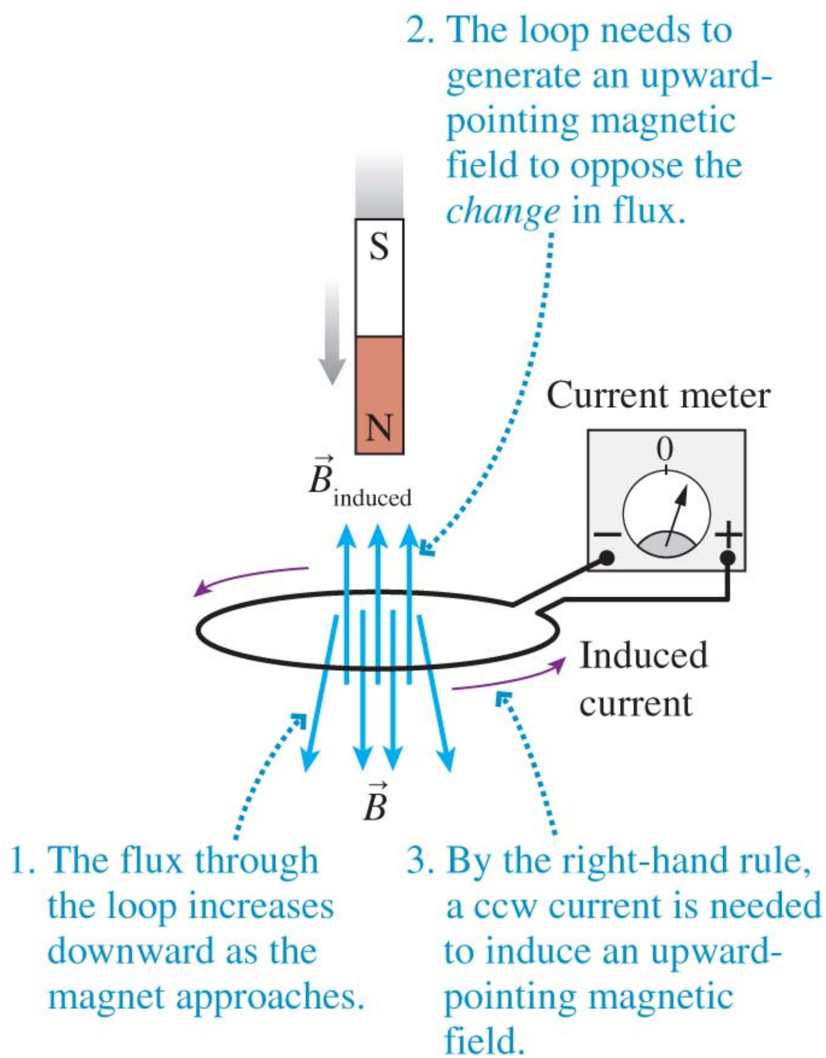
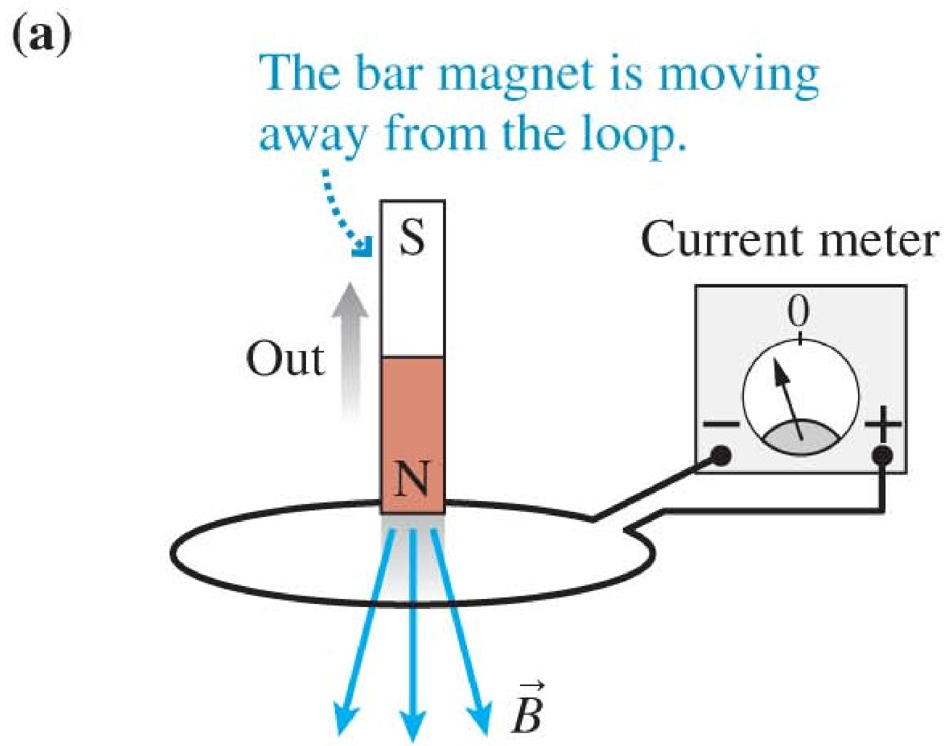
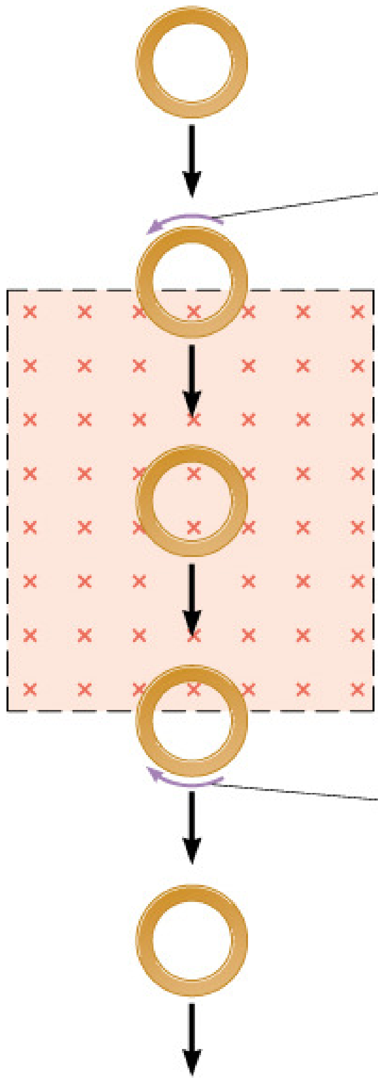


FIGURE 34.21 Pulling the magnet away induces a cw current.





The Emf Produced by a Moving Copper Ring.

There is a constant magnetic field directed into the page in the shaded region. The field is zero outside the shaded region. A copper ring slides through the region.

For each of the five positions, determine whether an induced current exists and, if so, find its direction.

Tactics: Using Lenz's Law

TACTICS BOX 34.1 **Using Lenz's law**

MP

1. **Determine the direction of the applied magnetic field.** The field must pass through the loop.
2. **Determine how the flux is changing.** Is it increasing, decreasing, or staying the same?
3. **Determine the direction of an induced magnetic field that will oppose the *change* in the flux.**
   - Increasing flux: the induced magnetic field points opposite the applied magnetic field.
   - Decreasing flux: the induced magnetic field points in the same direction as the applied magnetic field.
   - Steady flux: there is no induced magnetic field.
4. **Determine the direction of the induced current.** Use the right-hand rule to determine the current direction in the loop that generates the induced magnetic field you found in step 3.

Exercises 10–14

Faraday's Law

An emf is induced in a conducting loop if the magnetic flux through the loop changes. The magnitude of the emf is

$$\mathcal{E} = \left| \frac{d\Phi_m}{dt} \right|$$

and the direction of the emf is such as to drive an induced current in the direction given by Lenz's law.

Problem-Solving Strategy: Electromagnetic Induction

PROBLEM-SOLVING STRATEGY 34.1 **Electromagnetic induction**

MODEL Make simplifying assumptions about wires and magnetic fields.

VISUALIZE Draw a picture or a circuit diagram. Use Lenz's law to determine the direction of the induced current.

SOLVE The mathematical representation is based on Faraday's law

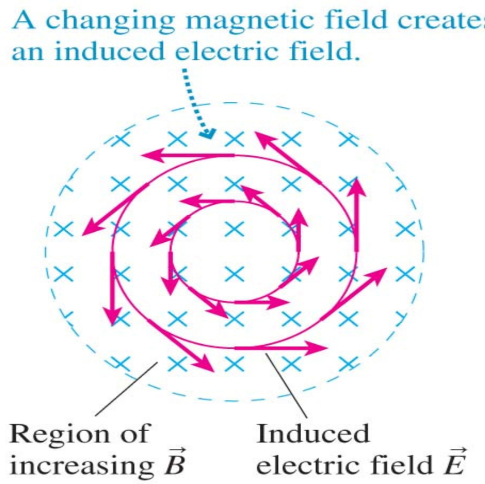
$$\mathcal{E} = \left|\frac{d\Phi_m}{dt}\right|$$

For an N-turn coil, multiply by N. The size of the induced current is $I = \mathcal{E}/R$.

ASSESS Check that your result has the correct units, is reasonable, and answers the question.

Electromagnetic Waves

FIGURE 34.35 Maxwell hypothesized the existence of induced magnetic fields.



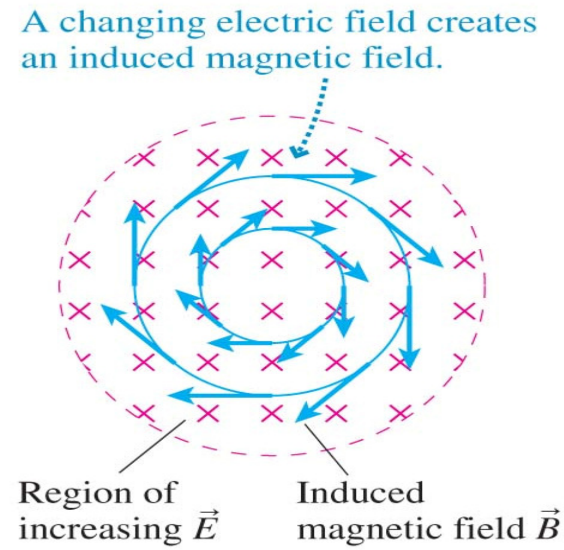
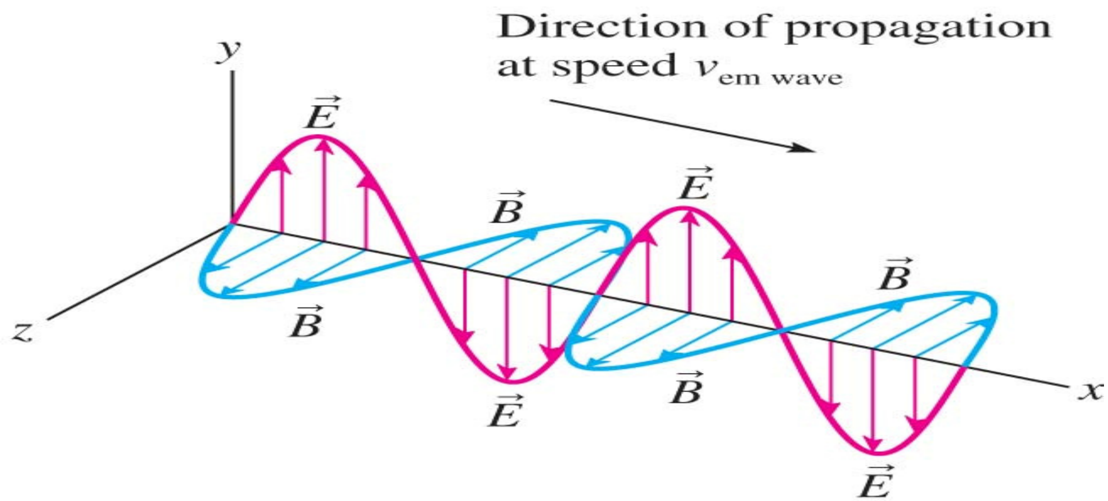
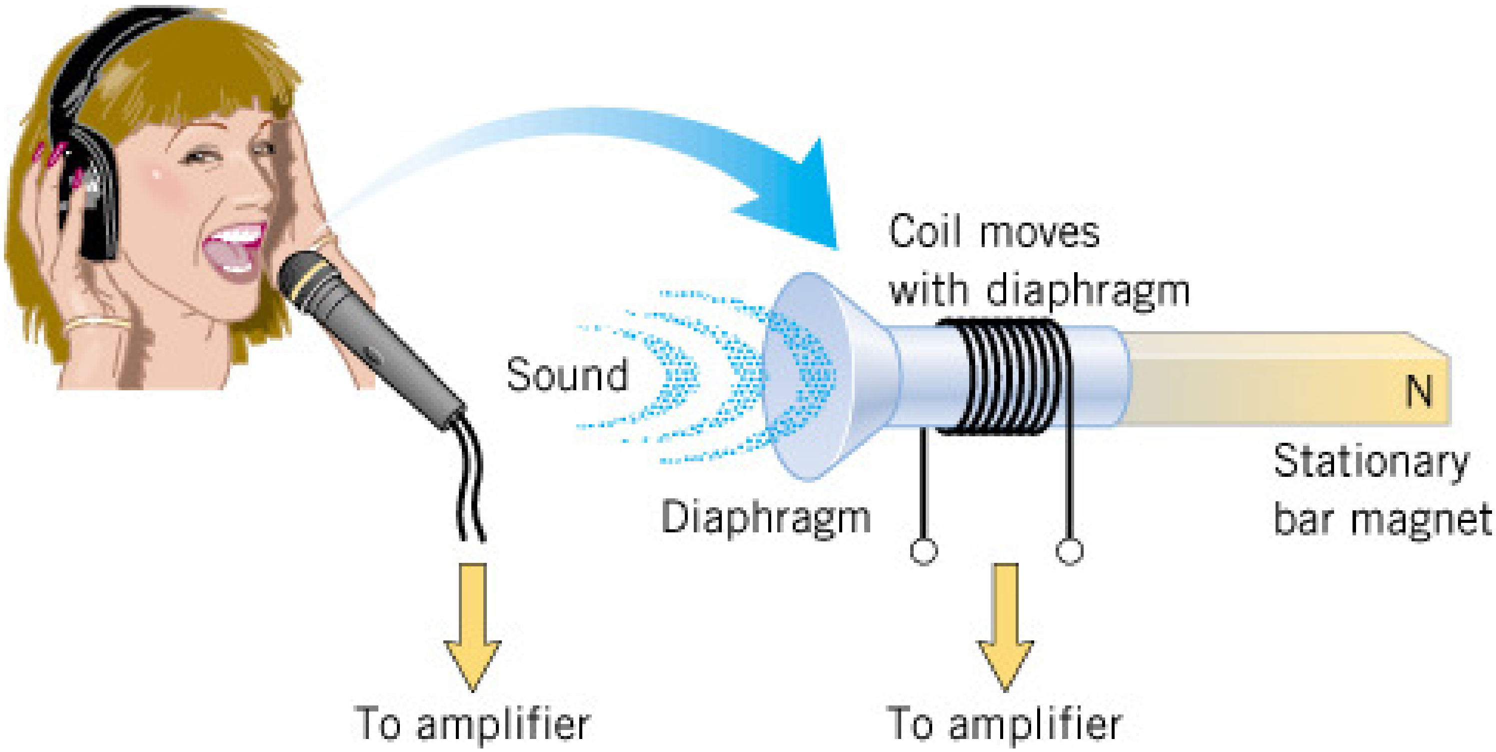
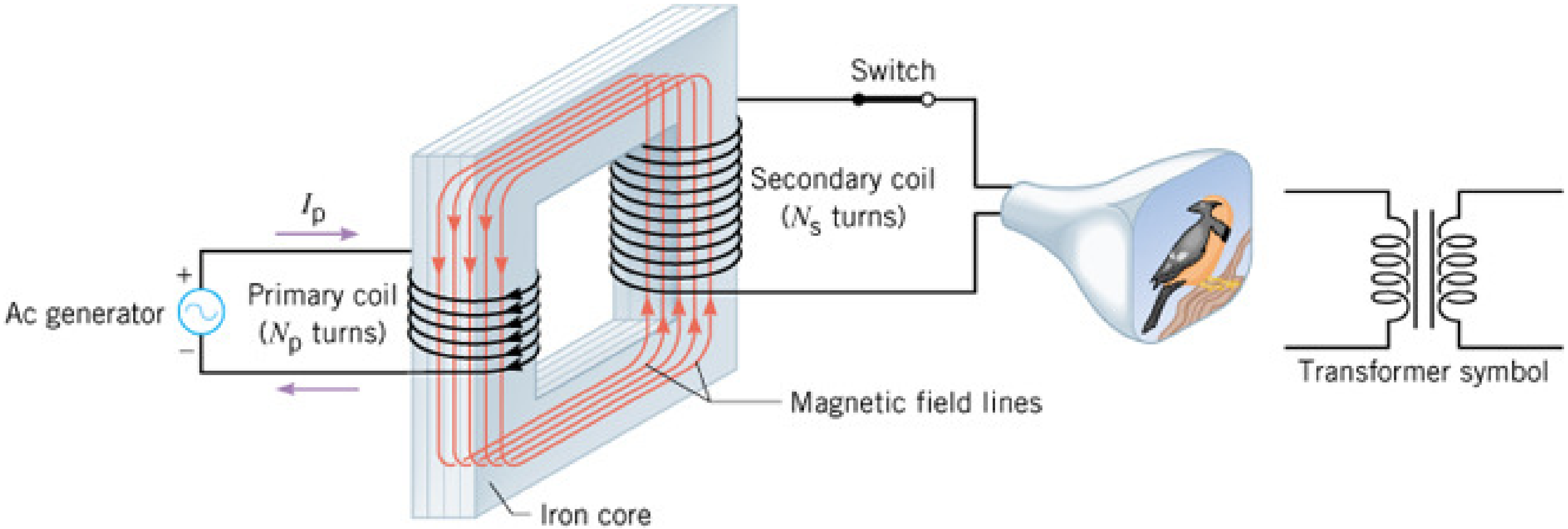


FIGURE 34.36 A self-sustaining electromagnetic wave.



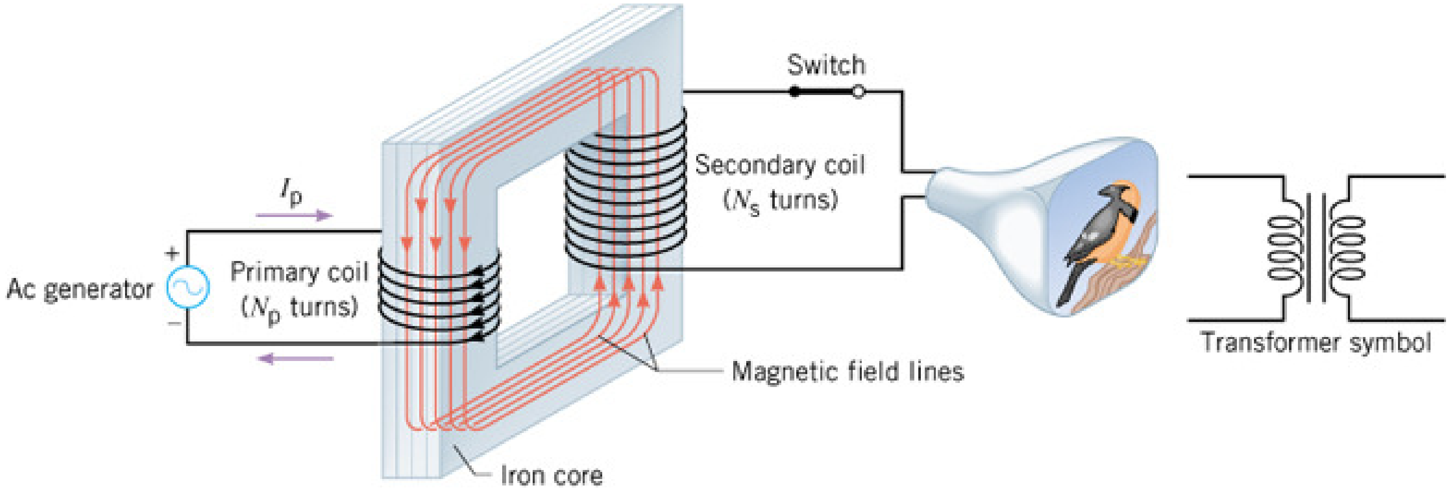

Coil moves
with diaphragm
Sound
N
Stationary
bar magnet
Diaphragm
To amplifier
To amplifier

A ***transformer*** is a device for increasing or decreasing an ac voltage.



$$\mathcal{E}_s = -N_s \frac{\Delta\Phi}{\Delta t} \qquad \mathcal{E}_p = -N_p \frac{\Delta\Phi}{\Delta t}$$

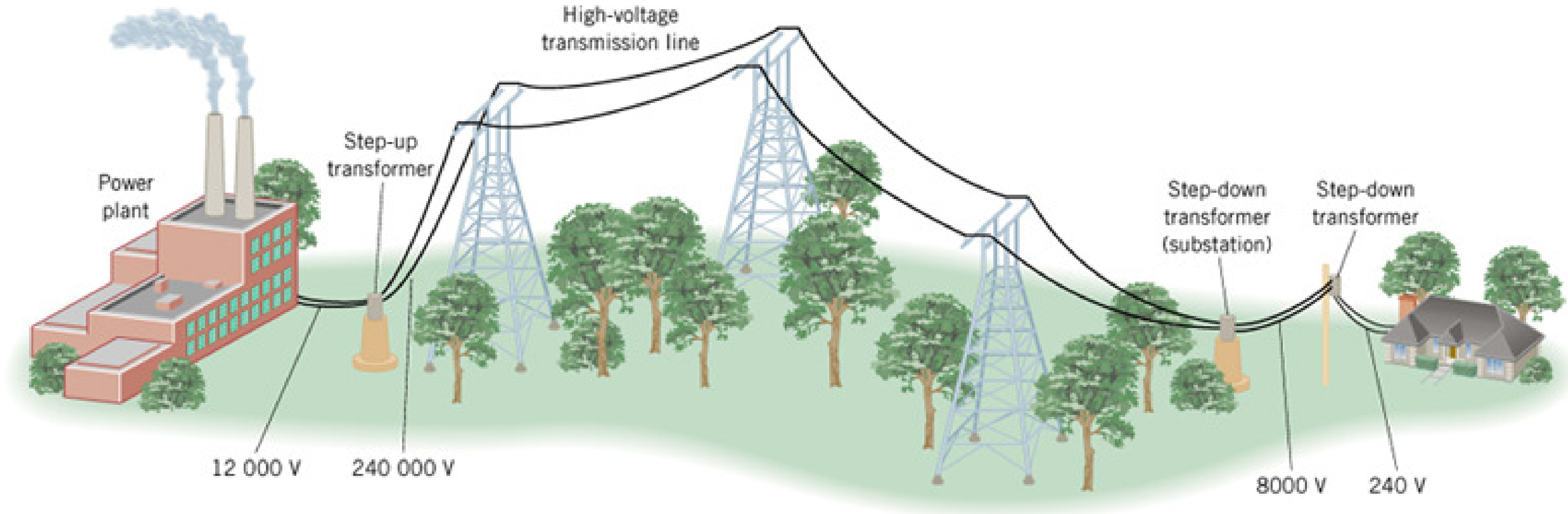
$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{N_s}{N_p}$$



$$\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$$

A transformer that steps up the voltage simultaneously steps down the current, and a transformer that steps down the voltage steps up the current.

Transformers



Chapter 34. Summary Slides

General Principles

Faraday's Law

MODEL Make simplifying assumptions.

VISUALIZE Use Lenz's law to determine the direction of the **induced current.**

SOLVE The **induced emf** is

$$\mathcal{E} = \left| \frac{d\Phi_m}{dt} \right|$$

Multiply by N for an N-turn coil.
The size of the induced current is $I = \mathcal{E}/R$.

ASSESS Is the result reasonable?

General Principles

Lenz's Law

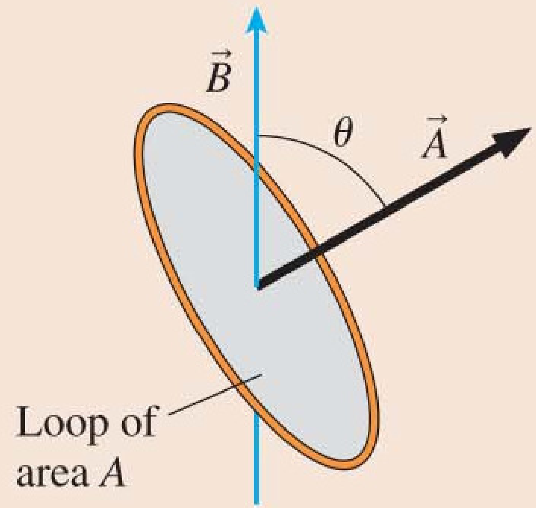
There is an induced current in a closed conducting loop if and only if the magnetic flux through the loop is changing. The direction of the induced current is such that the induced magnetic field opposes the *change* in the flux.

General Principles

Magnetic flux

Magnetic flux measures the amount of magnetic field passing through a surface.

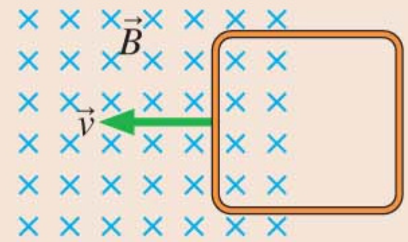
$$\Phi_m = \vec{A} \cdot \vec{B} = AB\cos\theta$$



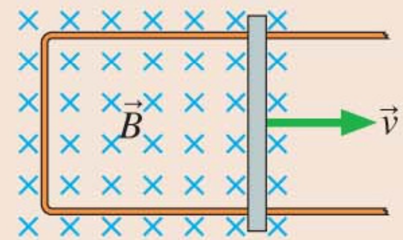
Important Concepts

Three ways to change the flux

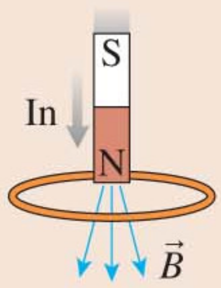
1. A loop moves into or out of a magnetic field.



2. The loop changes area or rotates.



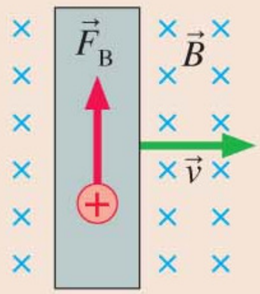
3. The magnetic field through the loop increases or decreases.



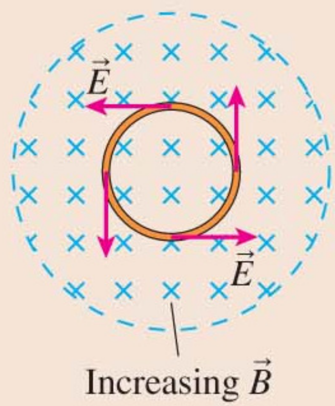
Important Concepts

Two ways to create an induced current

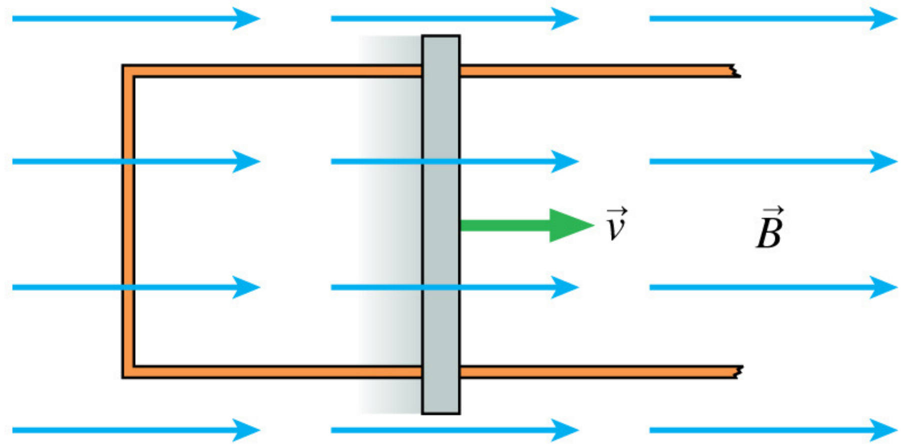
1. A **motional emf** due to magnetic forces on moving charge carriers.



2. An induced electric field due to a changing magnetic field.

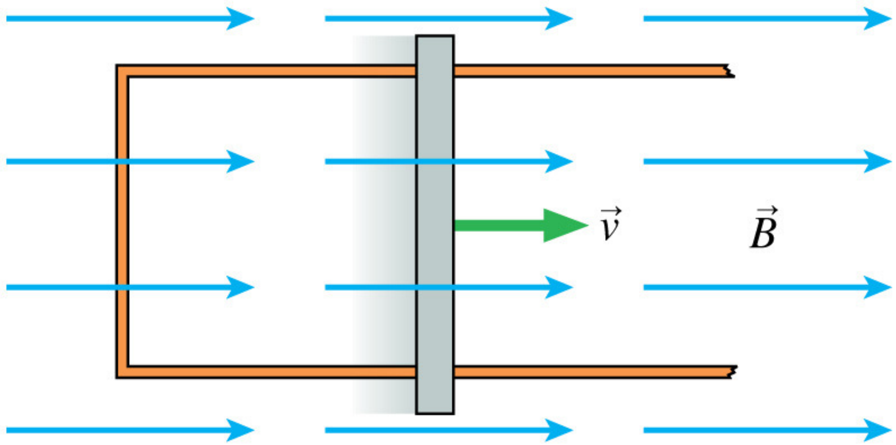


Chapter 34. Questions



Is there an induced current in this circuit? If so, what is its direction?

A. No
B. Yes, clockwise
C. Yes, counterclockwise



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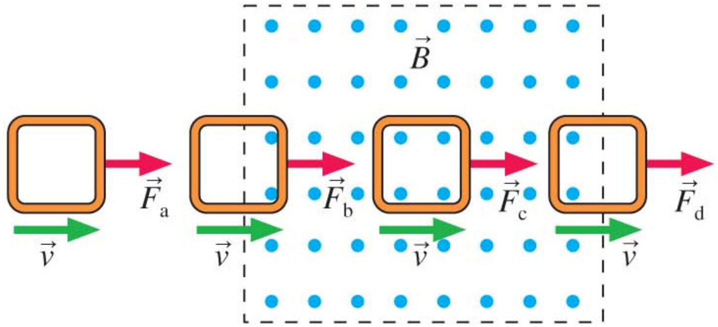
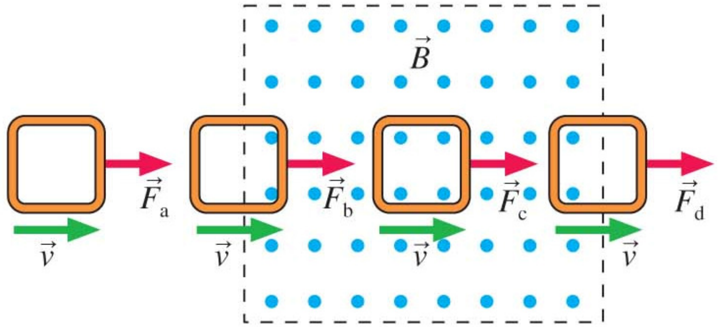


A square loop of copper wire is pulled through a region of magnetic field. Rank in order, from strongest to weakest, the pulling forces F_a, F_b, F_c and F_d that must be applied to keep the loop moving at constant speed.

A. $F_b = F_d > F_a = F_c$
B. $F_c > F_b = F_d > F_a$
C. $F_c > F_d > F_b > F_a$
D. $F_d > F_b > F_a = F_c$
E. $F_d > F_c > F_b > F_a$



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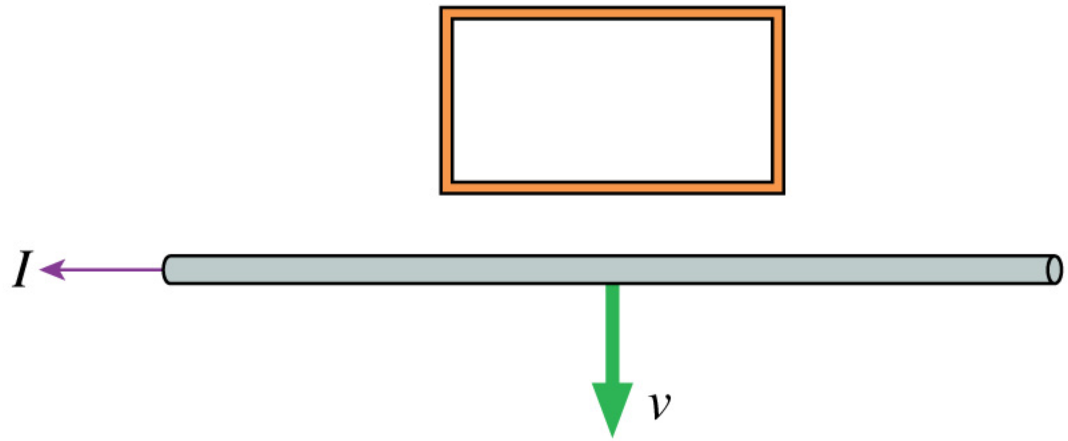
B. $F_c > F_b = F_d > F_a$

C. $F_c > F_d > F_b > F_a$

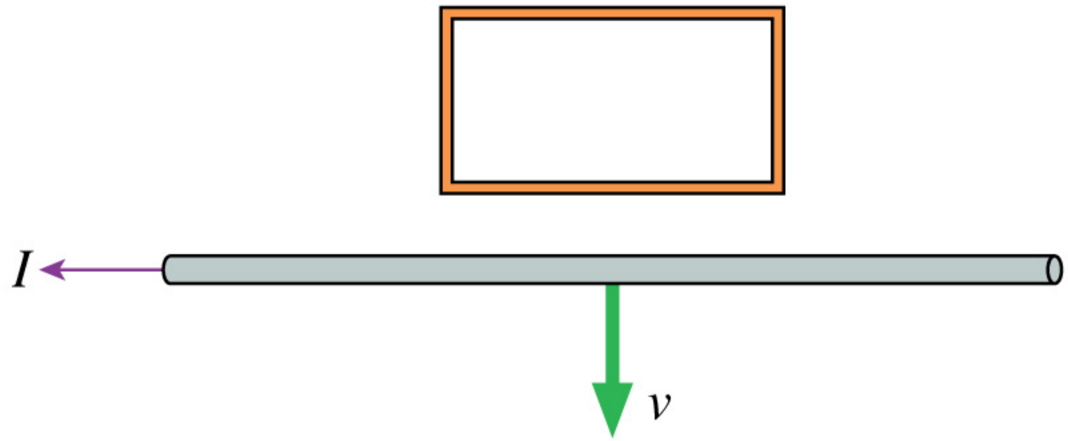
D. $F_d > F_b > F_a = F_c$

E. $F_d > F_c > F_b > F_a$



A current-carrying wire is pulled away from a conducting loop in the direction shown. As the wire is moving, is there a cw current around the loop, a ccw current or no current?

A. There is no current around the loop.
B. There is a clockwise current around the loop.
C. There is a counterclockwise current around the loop.



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