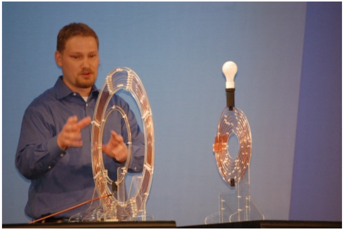
College Physics B - PHY2054C

Magnetic Forces & Induction



10/02/2023

My Office Hours:
Monday 1:00 - 3:00 PM

212 Keen Building

PHY2054C

Problems for this week's recitations:

5.1, 5.2, 5.5, 5.7

Outline

Magnetic Force on a Current

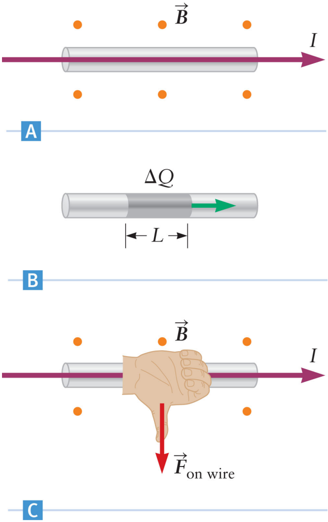
An electric current is a collection of moving charges:

➜ A force acts on a current.

$$F_B = q\,v \cdot B = (\Delta Q)\,v \cdot B$$

$$\text{Velocity of charge}: \; v = \frac{L}{\Delta t}$$

$$\text{Current}: \; I = \frac{\Delta Q}{\Delta t}$$



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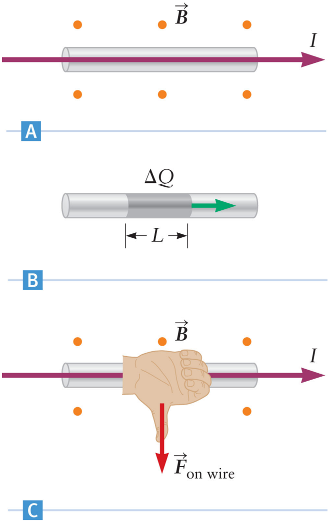
$$\text{Current}: \quad I = \frac{\Delta Q}{\Delta t}$$

$$F_B = (\Delta Q)\,v \cdot B = (\Delta Q)\,\frac{L}{\Delta t} \cdot B$$

$$\boxed{F_{\text{on wire}} = I\,L\,B}$$

If $\vec{B}$ is at an angle θ with the wire:

$$F_{\text{on wire}} = I\,L\,B\sin\theta$$



Electromagnetic Forces

$$\vec{F} = q\,\vec{E} + q\,\vec{v} \times \vec{B}$$

1. Electric Force depends on the electric field.
2. Magnetic Force depends on the magnetic field and the particle's velocity.

Question 1

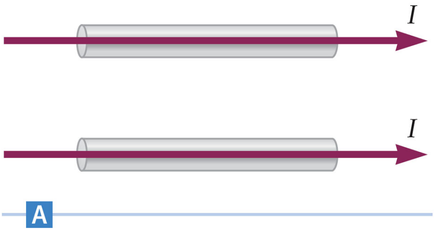
Two current-carrying wires are parallel as shown below; the current is the same in both wires. The current in both wires is flowing to the right. What is the effect of the magnetic force?

A The two wires attract each other.

B The two wires repel each other.

C There is no effect.

D I don't know.
(Not for credit)



Review Question 2

Two current-carrying wires are parallel as shown below; the current is the same in both wires. The current in both wires is flowing to the right. At the point P in the picture, the direction of the net magnetic field is

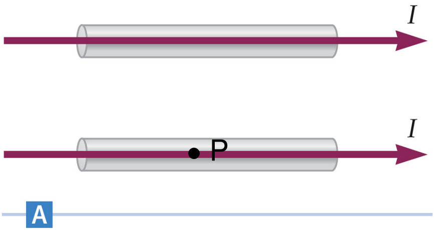
A to the right $\rightarrow$

B to the left $\leftarrow$

C into the screen

D out of the screen

E The field is zero.



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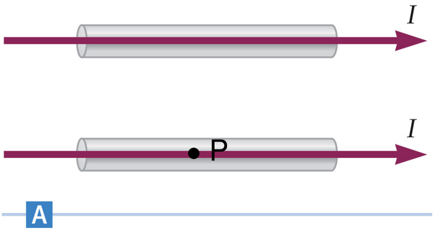
Right-Hand Rule I



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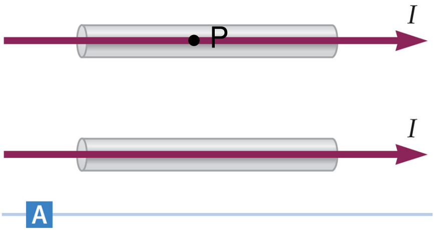
E The field is zero.



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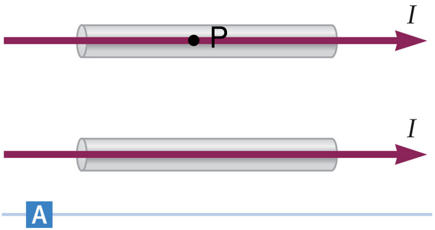
Right-Hand Rule I



Review Question 4

Two current-carrying wires are parallel as shown below; the current is the same in both wires. The current in both wires is flowing to the right. What is the effect of the magnetic force?

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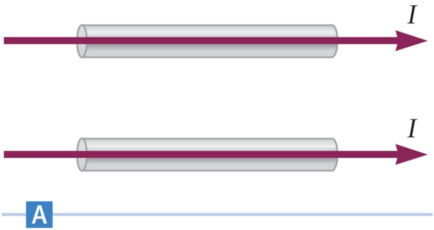

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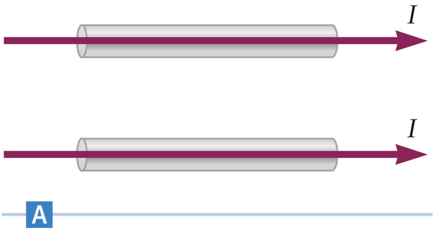
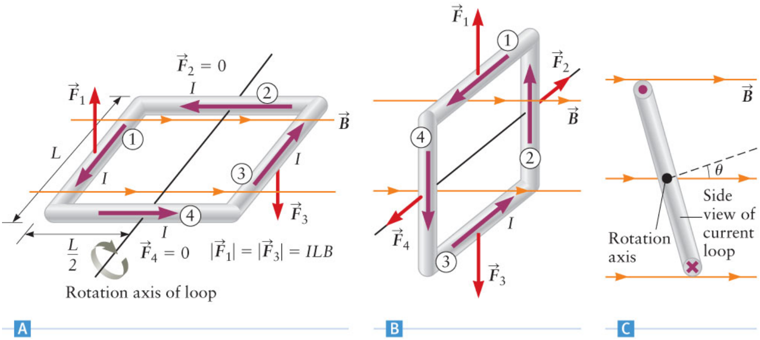


Torque on a Current Loop

A magnetic field can produce a torque on a current loop:

A On two sides, the current is parallel or antiparallel to the field, so the force is zero on those sides.

The forces on sides 1 and 3 are in opposite directions and produce a torque on the loop.



Torque on a Current Loop

A magnetic field can produce a torque on a current loop:

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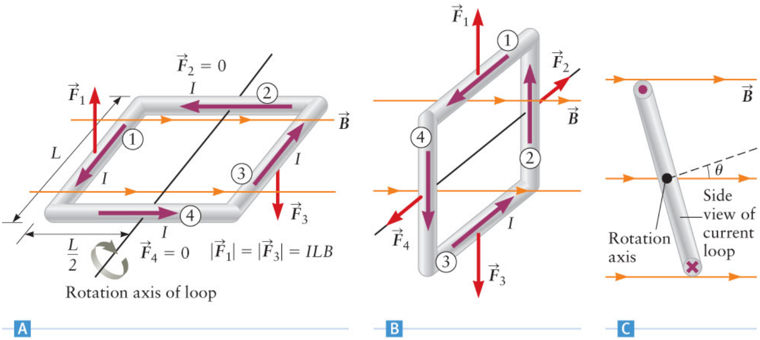
- When the angle between the loop and field is θ, the torque is:

$$\vec{\tau} = \vec{L}/2 \times \vec{F} \quad \rightarrow \quad |\tau| = I L^2 B \sin\theta$$



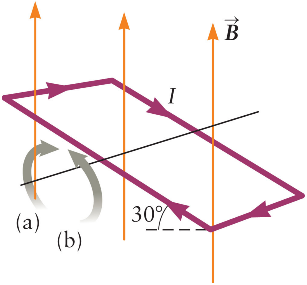
Question 5

The figure shows a current loop in a magnetic field. Is there a torque on the loop and, if so, in what direction?

A There is a torque that tends to rotate the loop in direction (a), clockwise.

B There is a torque that tends to rotate the loop in direction (b), counterclockwise.

C The torque is zero.



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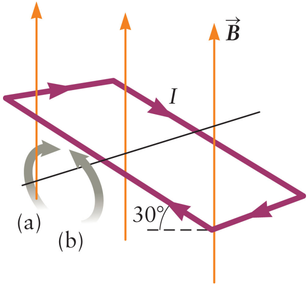


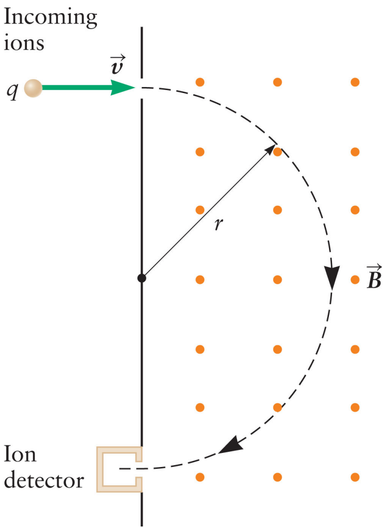
Outline

Mass Spectrometer

A mass spectrometer allows for the separation of ions according to their mass or charge.

- Ions enter spectrometer with some speed v.
- They pass into a region where magnetic field is perpendicular to velocity ➜ circles
- Measure v and B, then calculate q/m:

$$r = \frac{mv}{qB}$$



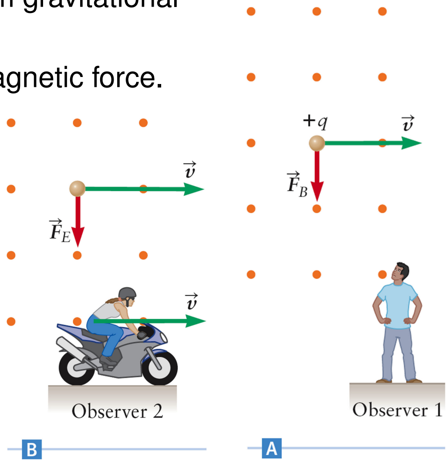
Velocity-Dependent Forces

The magnetic force exerted on a moving charged particle is dependent on its velocity.

- Differs substantially from gravitational and electrical forces.
- Observer 1 (A) sees magnetic force.

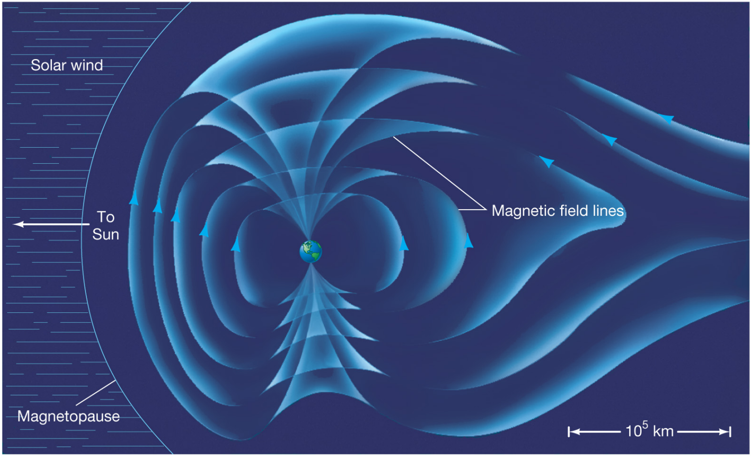
  Observer 2 (B) sees an electric force.
- Special relativity solves the dilemma.

  ➜ Chapter 28

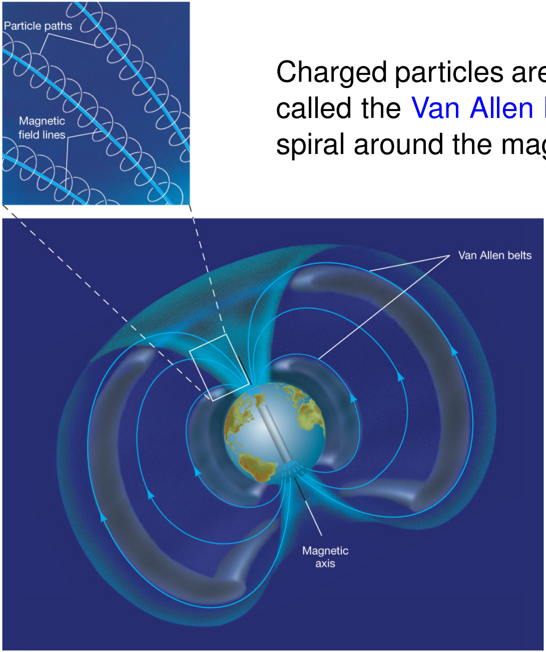


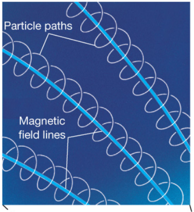
Earth's Magnetosphere

The magnetosphere is the region around Earth where charged particles from the solar wind are trapped.



Charged particles are trapped in areas called the Van Allen Belts, where they spiral around the magnetic field lines.





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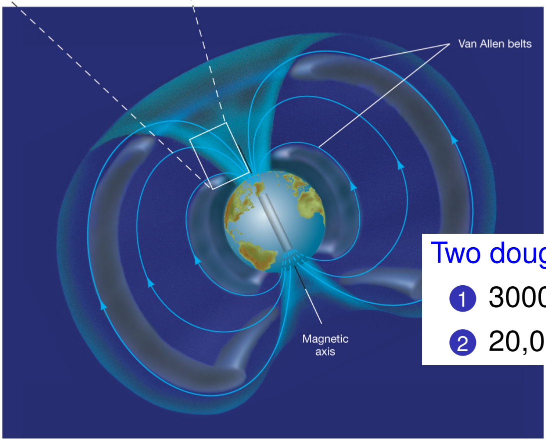
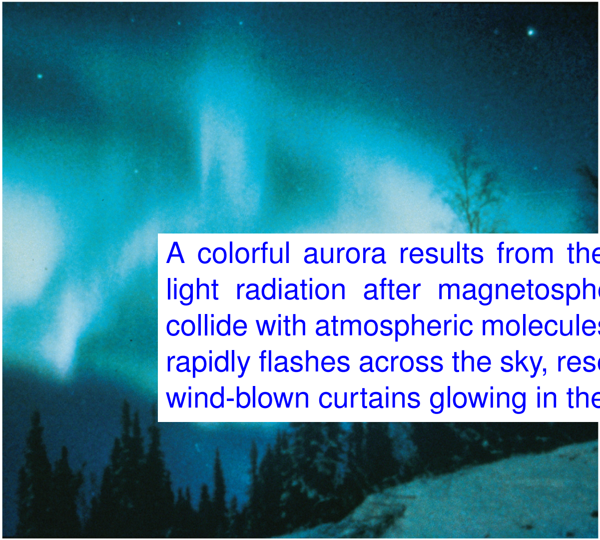


Two doughnut-shaped zones

1. 3000 km (protons)
2. 20,000 km (electrons)

Aurora Borealis



A colorful aurora results from the emission of light radiation after magnetospheric particles collide with atmospheric molecules. The aurora rapidly flashes across the sky, resembling huge wind-blown curtains glowing in the dark.

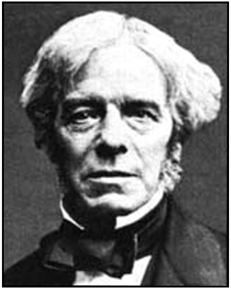
Aurora Borealis

Outline

Connection between Electricity and Magnetism

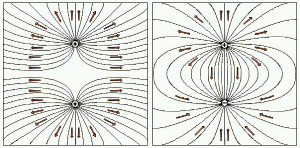
Sources of Electric Fields	Sources of Magnetic Fields
Electric Charge	

Electric Fields

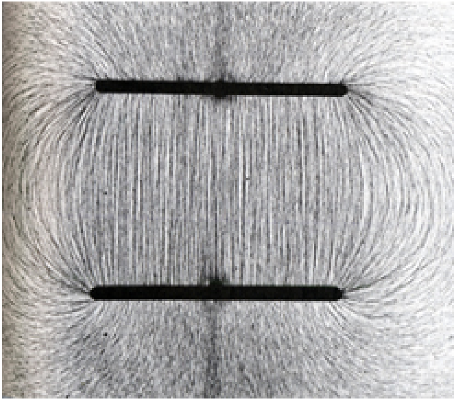


Michael Faraday (1791 - 1867)

Static Point Charges



Capacitor



Connection between Electricity and Magnetism

Sources of Electric Fields	Sources of Magnetic Fields
Electric Charge	Moving Electric Charge

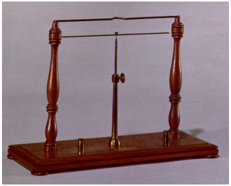
PBS | Einstein's Big Idea | Michael Faraday - Part 1

https://www.youtube.com/watch?v=TEVEBzNSwTU

Electromagnetism

Christian Oersted
(1777 - 1851)

Field around a current-carrying wire is fairly weak

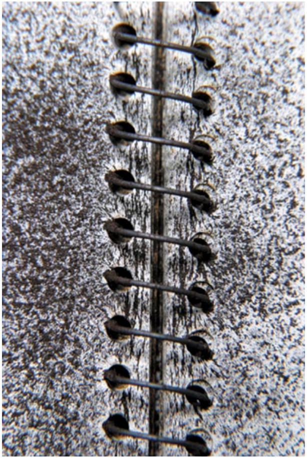


Electromagnetism

A coil concentrates and strengthens the field

Field around a current-carrying wire is fairly weak

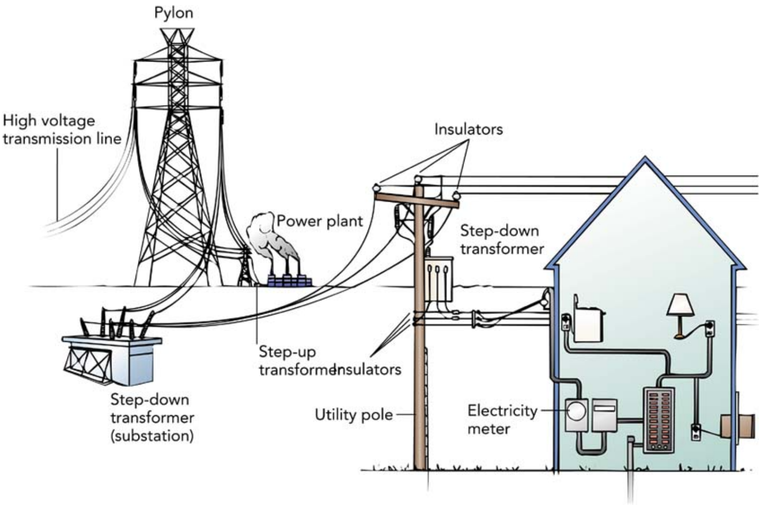
➜



Connection between Electricity and Magnetism

Sources of Electric Fields	Sources of Magnetic Fields
Electric Charge	Moving Electric Charge
Changing Magnetic Fields	

Why does the power company place large electric devices on the utility poles near homes or on the ground near neighborhoods?



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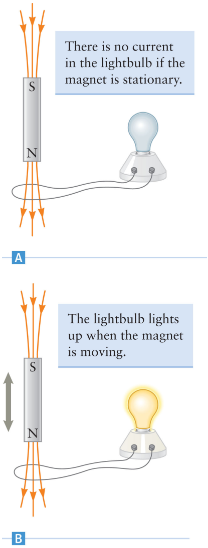
Faraday's Experiment

Michael Faraday attempted to observe an induced electric field.

➜ He did not use a light bulb.

A If the bar magnet is stationary, the current and the electric field are both zero.

B If the bar magnet was in motion, a current was observed.



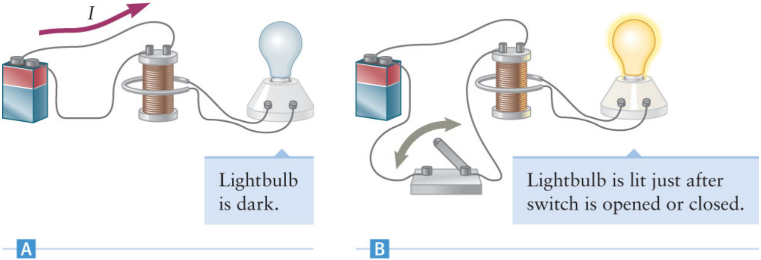
Faraday's Law:

phet.colorado.edu/sims/faradays-law/faradays-law_en.html

Another Faraday Experiment

A solenoid is positioned near a loop of wire with the light bulb. Now a current is passed through the solenoid by connecting it to a battery.

1. When the current through the solenoid is constant, there is no current in the wire.
2. When the switch is opened or closed, the bulb does light up.



Question 6

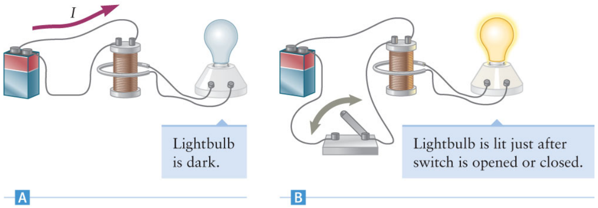
What is the conclusion from Faraday's Experiment? It shows that an electric current is produced in the wire loop only when

A the battery is directly connected to the light bulb.

B the magnetic field at the loop is constant.

C the magnetic field at the loop is changing.

D No electric current is produced. A magnetic field cannot produce an electric current to power the light bulb.



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A changing magnetic field produces an electric field.
➜ It is called *induced electric field*.

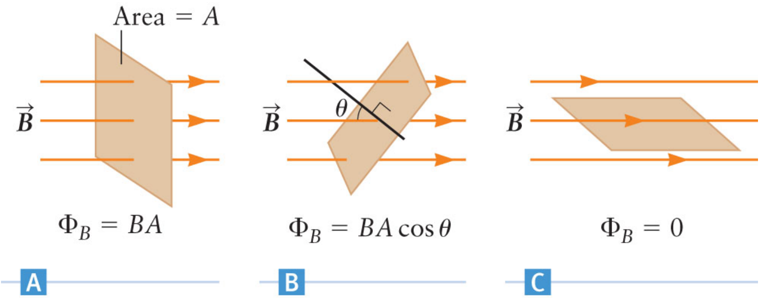
The phenomenon is called electromagnetic induction.

Magnetic Flux

Faraday developed a quantitative theory of induction now called *Faraday's Law:*

- It uses the concept of magnetic flux that is similar to the concept of electric flux:

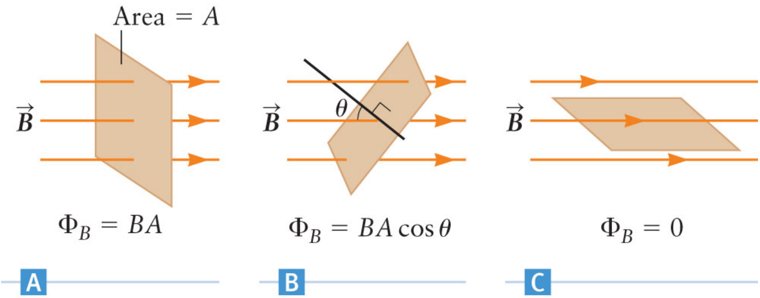
$$\Phi_B = A B \cos\theta \quad (\theta = \angle(\text{normal vector, magnetic field}))$$



Magnetic Flux

Faraday developed a quantitative theory of induction now called *Faraday's Law:*

- $\Phi_B = A\,B\cos\theta$
- The unit of magnetic flux is the *Weber* (Wb)
  ➜ $1\ \text{Wb} = 1\ \text{T}\cdot\text{m}^2$



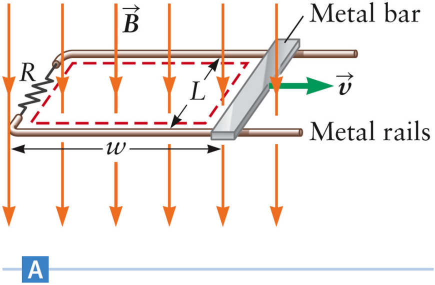
Faraday's Law

Faraday's Law indicates how to calculate the potential difference that produces the induced current:

$$|\mathcal{E}| = -\frac{\Delta\Phi_B}{\Delta t}$$

The magnitude of the induced emf equals the rate of change of the magnetic flux.

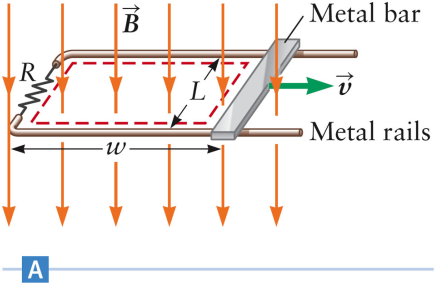
Example



A magnetic field *B* is constant and in a direction perpendicular to the plane of the rails and the bar. Assume the bar moves at constant speed:

$$\Phi_B = BA = BwL$$

Example



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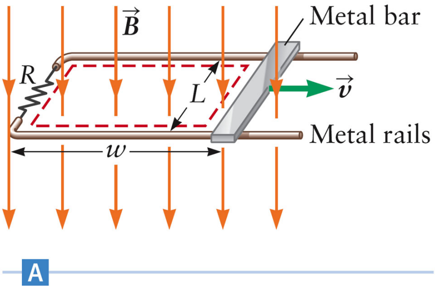
$$\Phi_B = BA = BwL$$

$$\frac{\Delta \Phi_B}{\Delta t} = |\mathcal{E}| = BL\frac{\Delta w}{\Delta t} = BLv$$

Example



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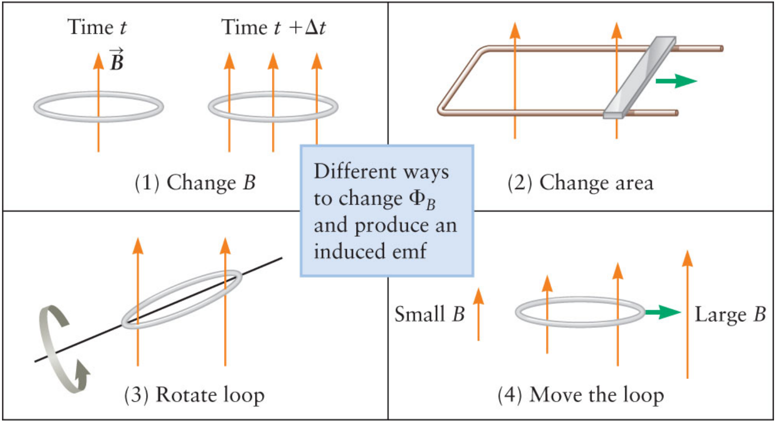
$$\Phi_B = BA = BwL$$

$$\frac{\Delta \Phi_B}{\Delta t} = |\mathcal{E}| = BL\frac{\Delta w}{\Delta t} = BLv$$

$$I = \frac{BLv}{R}$$

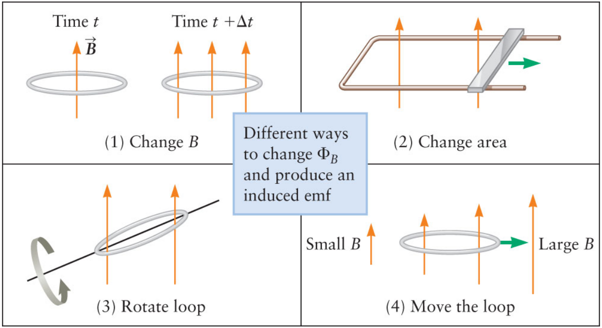
Faraday's Law



Faraday's Law

The mechanical power put into the bar by the external agent is equal to the electrical power delivered to the resistor:

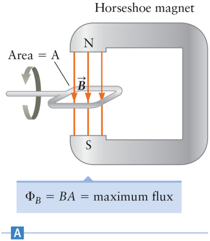
➜ Energy is converted from mechanical to electrical; total energy remains the same.

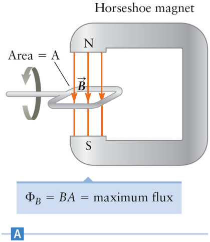


Electrical Generator

Need to make the rate of change of the flux large enough to give a useful emf:

- Use rotational motion instead of linear motion.
- A permanent magnet produces a constant magnetic field in the region between its poles.
- The angle between the field and the plane of the loop changes as the loop rotates.
- If the shaft rotates with a constant angular velocity, the flux varies sinusoidally with time.





Generator:

phet.colorado.edu/en/simulation/generator

Outline

Lenz's Law

Lenz's Law gives us an easy way to determine the sign of the induced emf.

Lenz's Law states that the magnetic field produced by an induced current always opposes any changes in the magnetic flux.