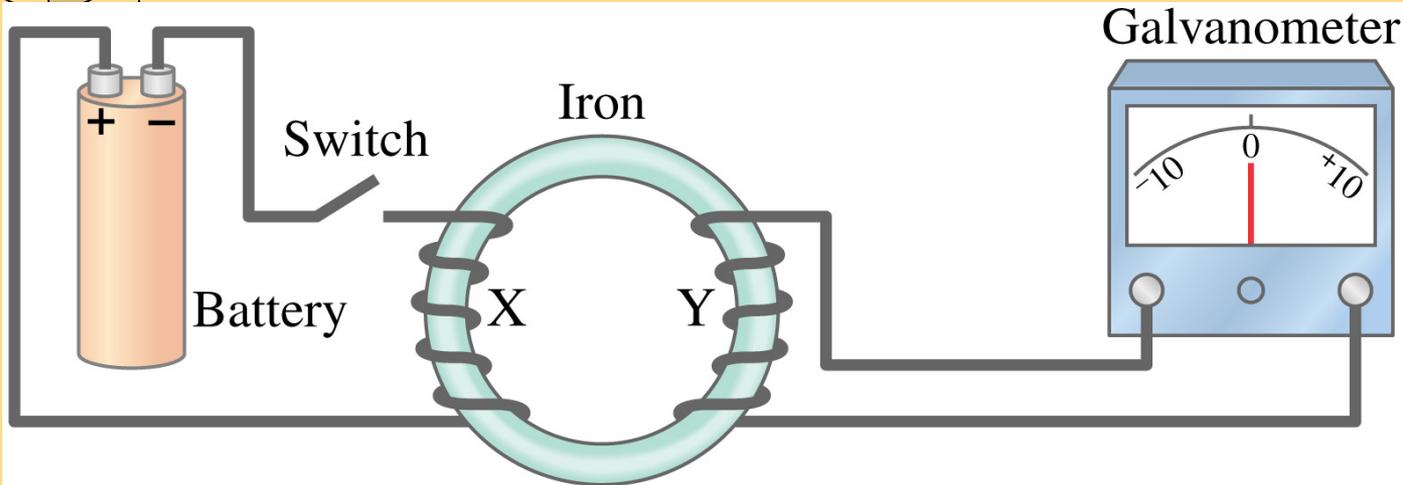


Chapter 21: Induction

Faraday looked for evidence that a magnetic field would induce an electric current with this apparatus:



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Remember that:

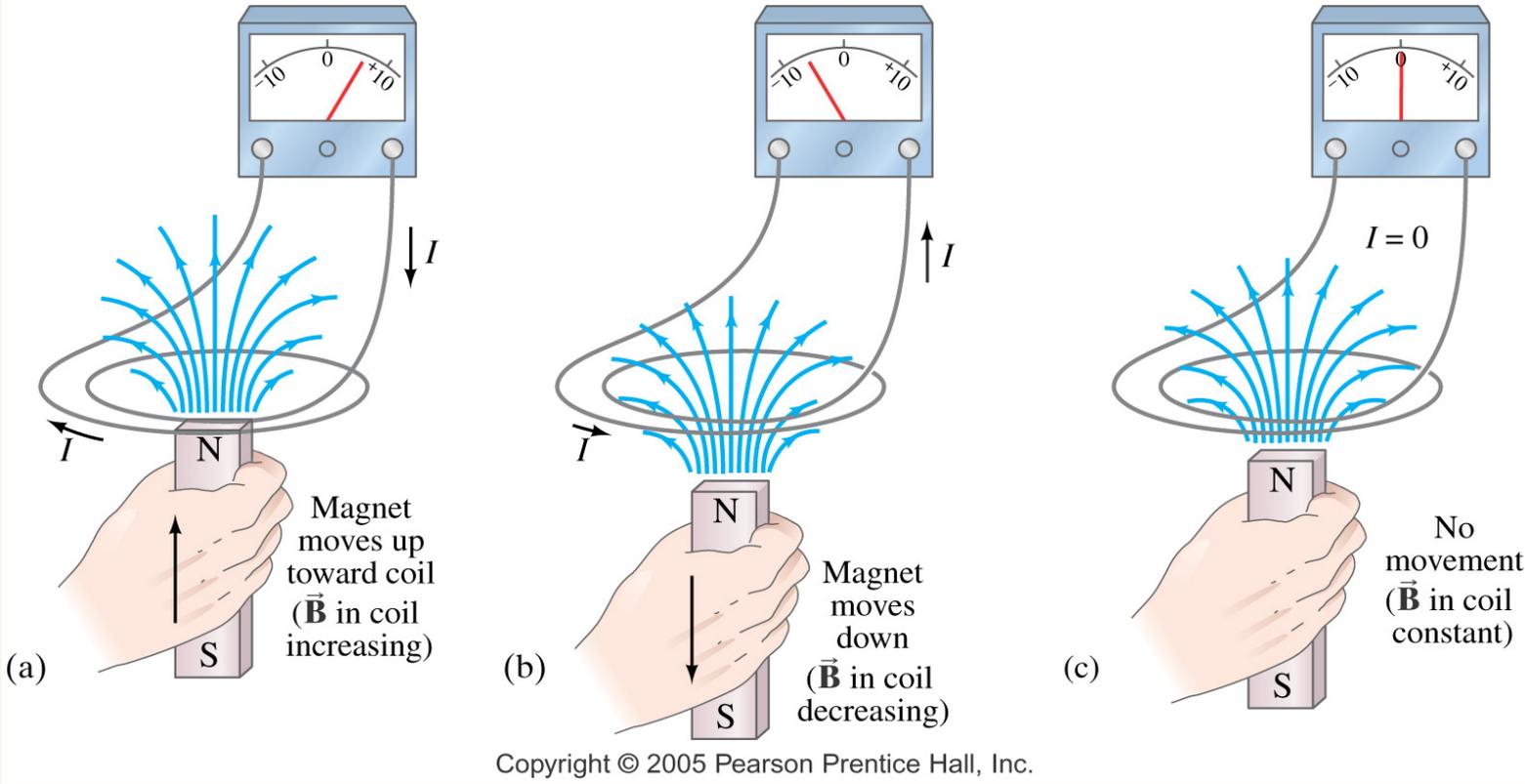
$$B = \frac{\mu_0 I}{2\pi r}$$

He noticed that a constant current in X produced a constant magnetic field which produced NO current in Y. BUT, when the current was starting or stopping, it did produce a current in Y.

Therefore: a **constant** magnetic field produces **NO** current, but **a changing magnetic field can produce an electric current – INDUCED CURRENT**

Induced EMF

Therefore, a changing magnetic field induces an emf.



Magnetic flux

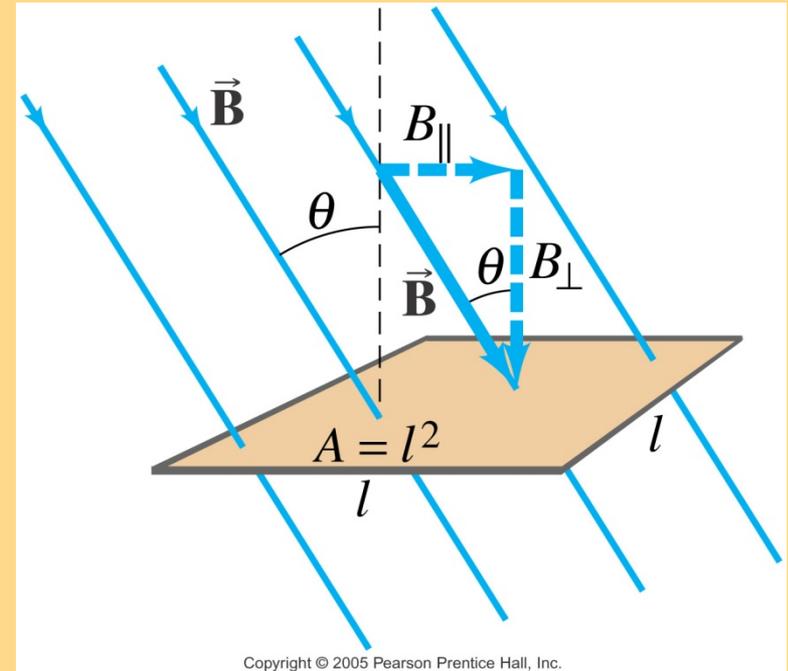
The induced emf in a wire loop is proportional to the rate of change of magnetic flux through the loop.

Magnetic flux:

$$\Phi_B = B_{\perp} A = BA \cos \theta$$

Unit of magnetic flux: weber, Wb.

$$1 \text{ Wb} = 1 \text{ T} \cdot \text{m}^2$$



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Ex. 21-2 A square loop of wire 10.0 cm on a side is in a 1.25-T magnetic field B . What are the maximum and minimum values of flux that can pass through the loop?

0.0125 Wb and 0

Faraday's Law and Lenz's Law

Faraday's law of induction:

[1 loop]

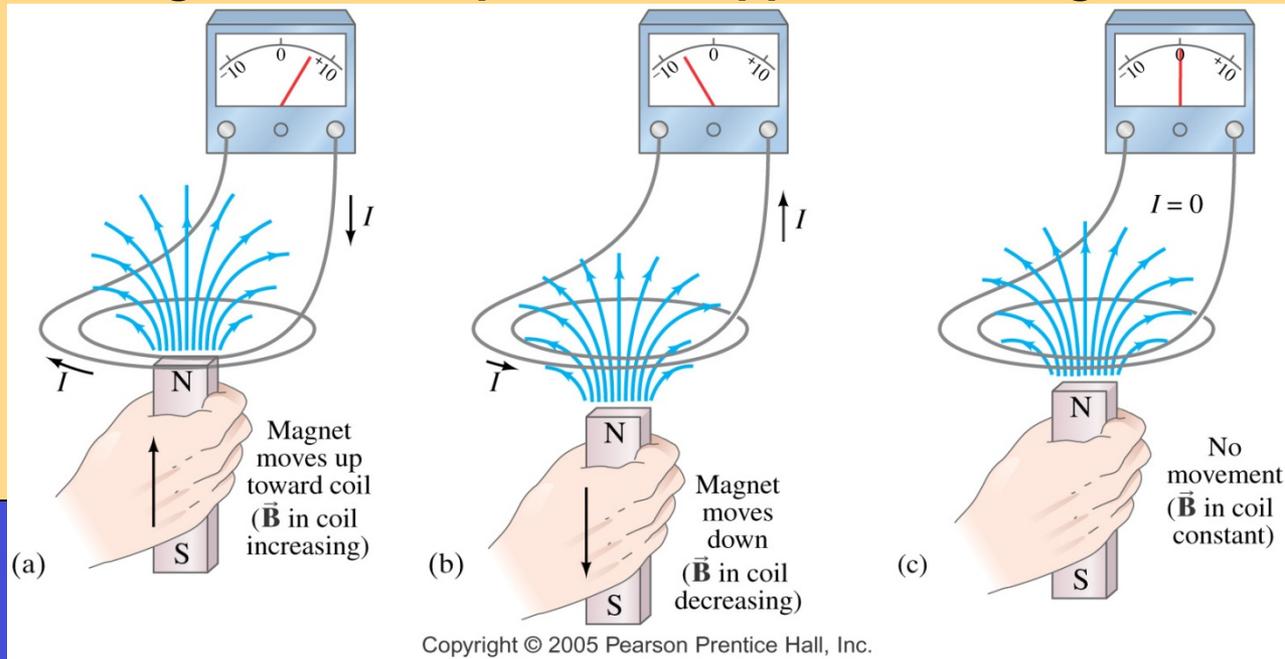
$$\mathcal{E} = - \frac{\Delta \Phi_B}{\Delta t}$$

[N loops]

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

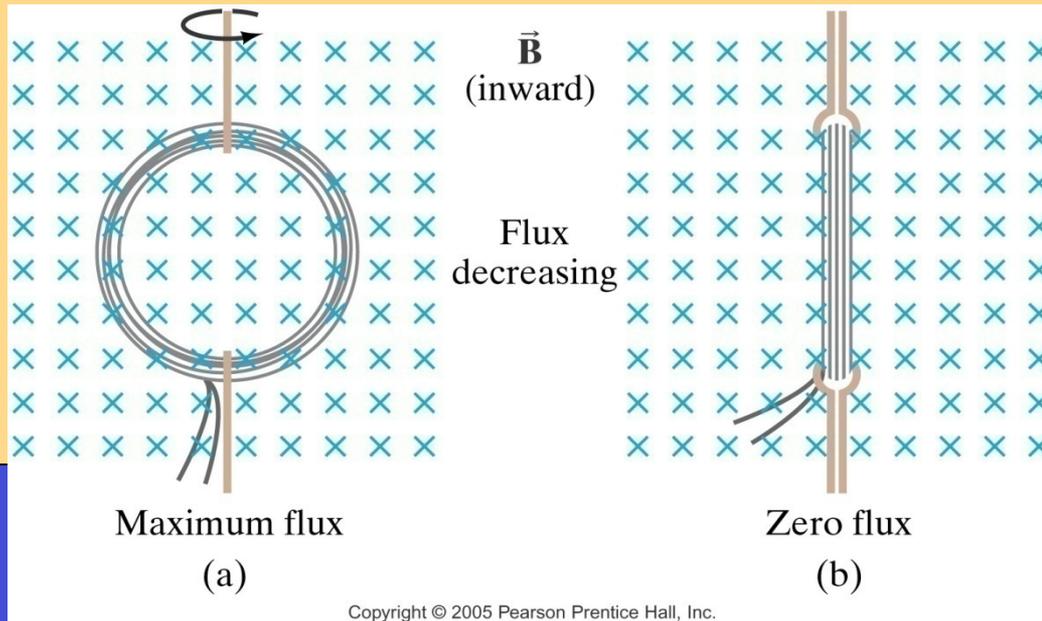
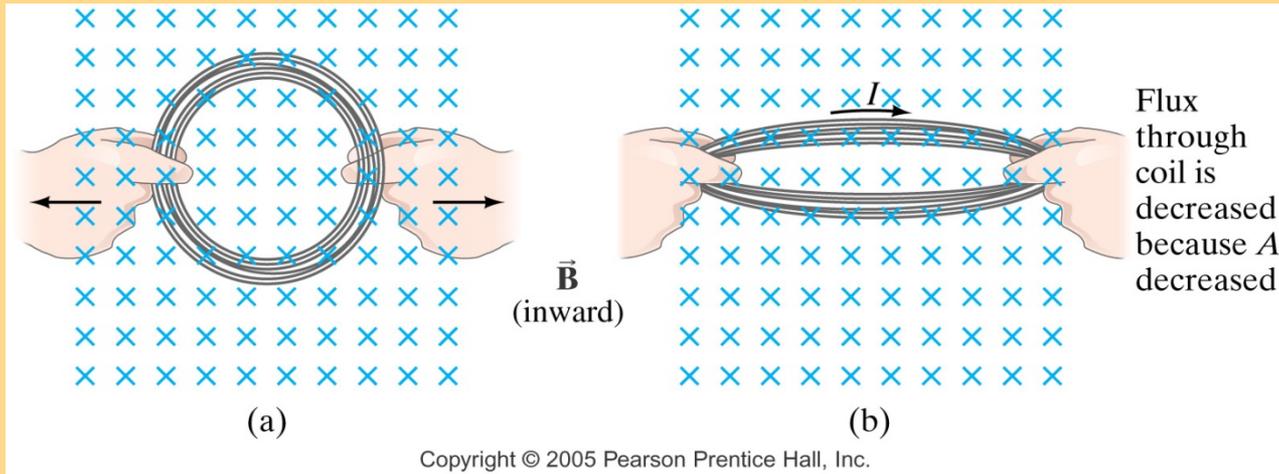
The minus sign gives the direction of the induced emf:

Lenz's Law: A current produced by an induced emf moves in a direction so that the magnetic field it produces opposes the original change in flux



Magnetic Flux

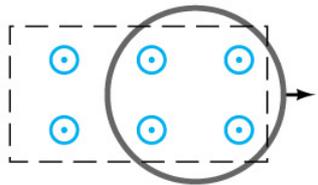
Magnetic flux will change if the area of the loop changes:



Magnetic flux will change if the angle between the loop and the field changes:

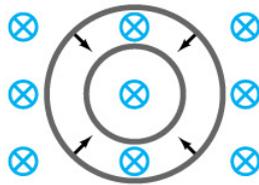
Lenz's Law

Ex. 21-4 In which direction is the current induced in the loop for each situation?



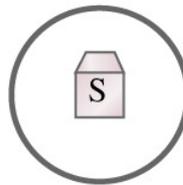
(a)

Pulling the loop to the right out of a magnetic field which points out of the page



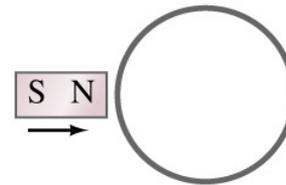
(b)

Shrinking a loop in a magnetic field pointing into the page



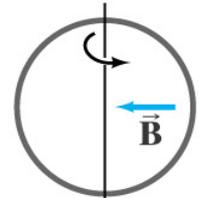
(c)

N magnetic pole moving toward loop into the page



(d)

N magnetic pole moving toward the loop in the plane of the page

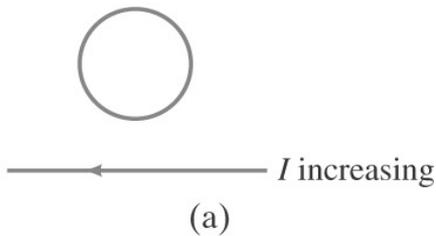


(e)

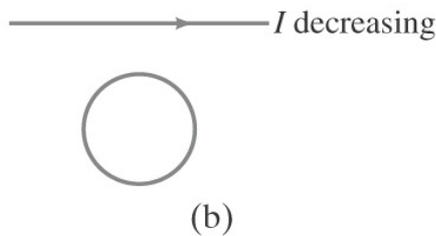
Rotating the loop by pulling the left side toward us and pushing the right side in; the magnetic field points from right to left

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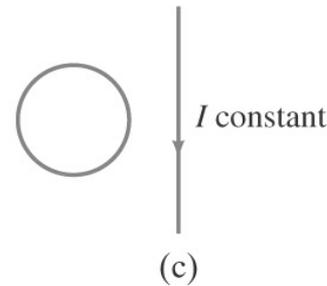
a) counterclockwise b) clockwise c) counterclockwise d) no current
e) counterclockwise



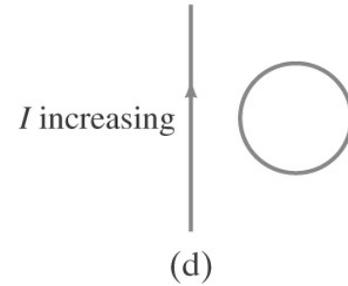
(a)



(b)



(c)



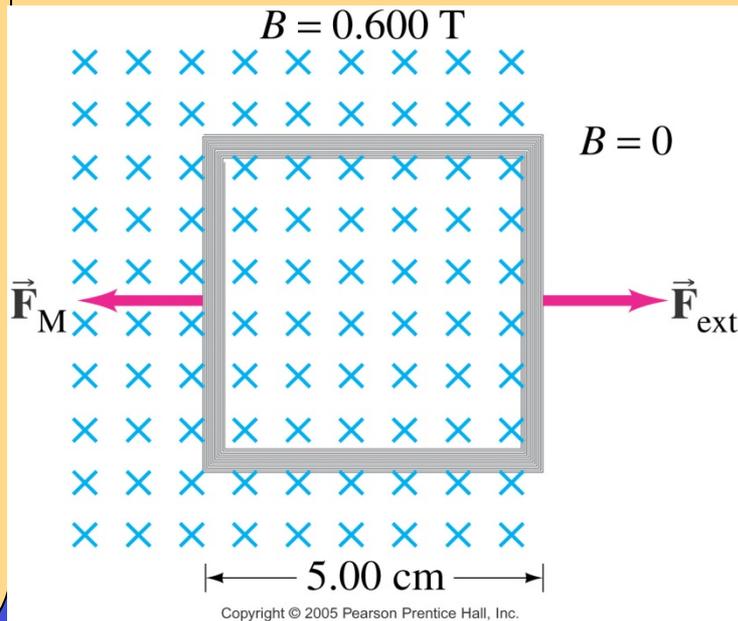
(d)

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a) counterclockwise b) clockwise c) no current d) counterclockwise

Emf and induce current

Ex. 21-5 A square coil of wire with side $l=5.00$ cm contains 100 loops and is positioned perpendicular to a uniform 0.600 -T magnetic field (see figure). It is quickly pulled from the field at constant speed (moving perpendicular to B) to a region where B drops abruptly to zero. At $t=0$, the right edge of the coil is at the edge of the field. It takes 0.100 s for the whole coil to reach the field-free region. The coil's total resistance is 100Ω . Find (a) the rate of change in flux through the coil and (b) the emf and current induced. (c) How much energy is dissipated in the coil? (d) What was the average force require?



a) $-1.50 \times 10^{-2} \text{ Wb} / \text{s}$

b) $emf = 1.50 \text{ V}, I = 15.0 \text{ mA}$

c) $E = Pt = (I^2 R)t = 2.25 \times 10^{-3} \text{ J}$

d) $F = W / d = 0.0450 \text{ N}$

EMF induced in a moving conductor

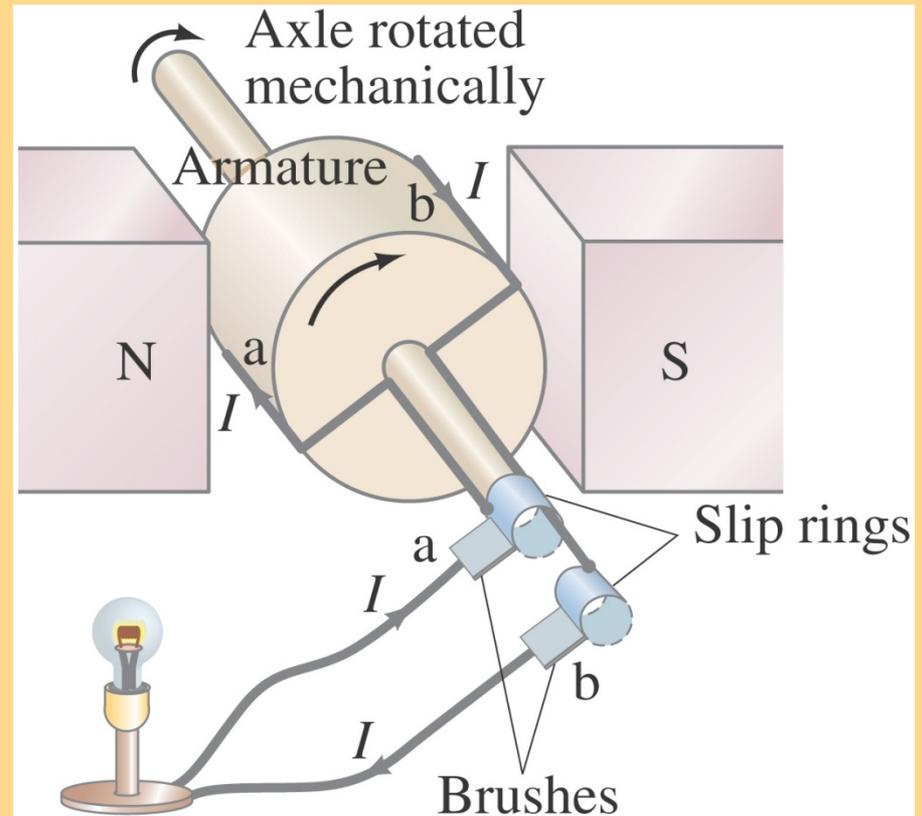
This is an **ac generator**:

A generator is the opposite of a motor – it transforms mechanical energy into electrical energy.

The axle is rotated by an external force such as falling water or steam.

An emf is induced in the rotating coil. A changing magnetic flux induces an electric current.

This is the most important application of Faraday's law.

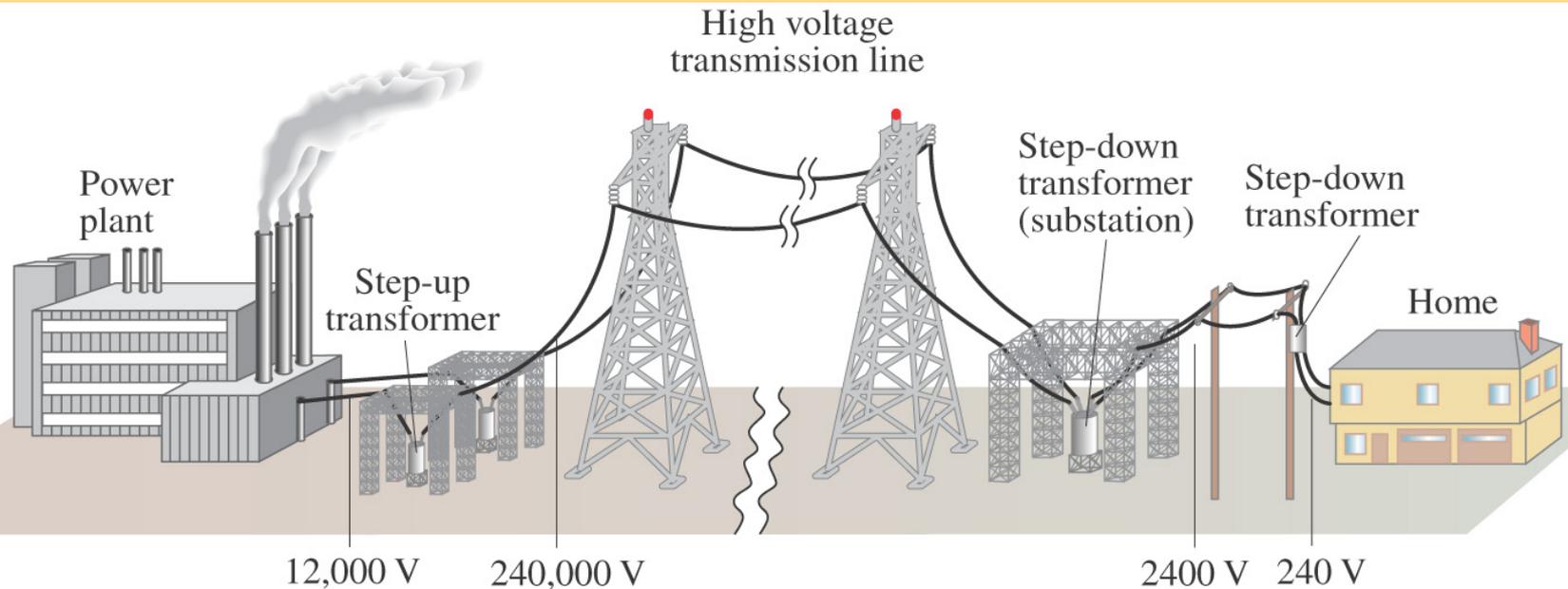


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Transformers & Transmission of Power

Transformers are important in the transmission of electricity. Power plants are far from metropolitan areas, electricity is transmitted over long distances. Power loss in the transmission lines can be **minimized** if the power is transmitted at **high voltage**.

Transformers work only if the current is changing; this is one reason why electricity is transmitted as ac.



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Transformers and Transmission

A transformer consists of two coils, either interwoven or linked by an iron core. A changing emf in one induces an emf in the other.

Ac voltage in primary coil – changing magnetic field induces ac voltage in the secondary coil

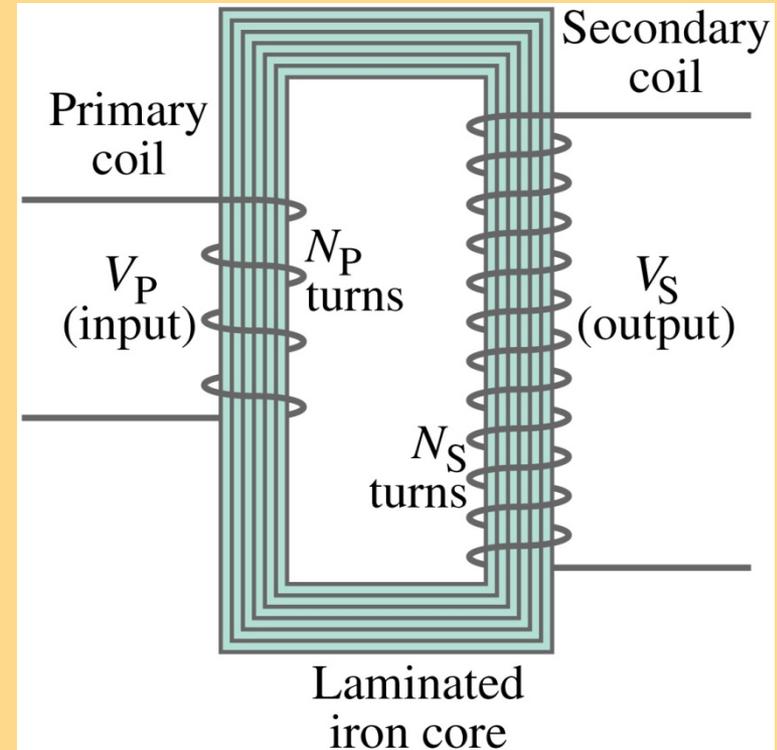
$$V_S = N_S \frac{\Delta\Phi_B}{\Delta t}, \quad V_P = N_P \frac{\Delta\Phi_B}{\Delta t}$$

$$\frac{V_S}{N_S} = \frac{V_P}{N_P} \Rightarrow \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Energy must be conserved; therefore power output is equal to the power input (if there is no loss)

$$V_P I_P = V_S I_S \Rightarrow$$

$$\frac{I_S}{I_P} = \frac{N_P}{N_S}$$



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Transformers and Transmission

Ex. 21-11 A transformer for home use of a portable radio reduces 120-V ac to 9.0-V ac. The secondary coil contains 30 turns and the radio draws 400 mA. Calculate (a) the number of turns in the primary coil, (b) the current in the primary and (c) the power transformed.

$$a) \frac{V_S}{N_S} = \frac{V_P}{N_P} \Rightarrow N_P = 400 \text{ turns}$$

$$b) \frac{I_S}{I_P} = \frac{N_P}{N_S} \Rightarrow I_P = 0.030 \text{ A}$$

$$c) P = I_S V_S = 3.6 \text{ W}$$

Transformers and Transmission

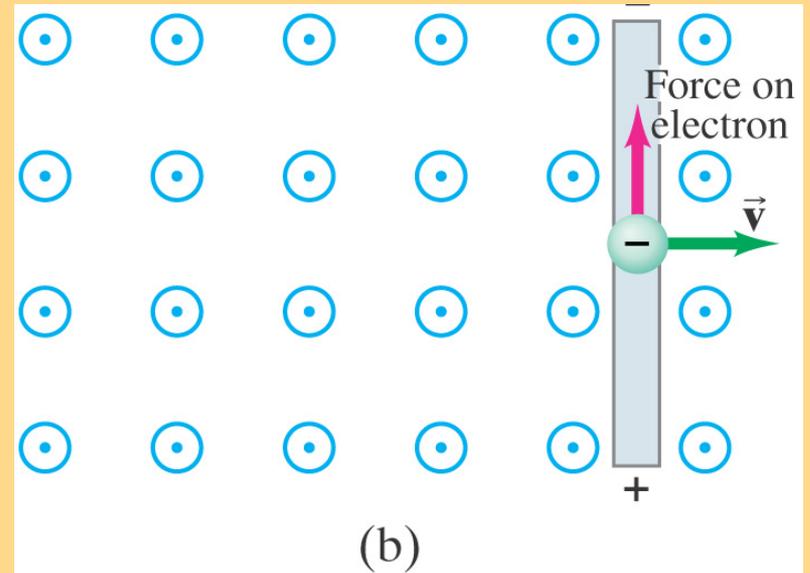
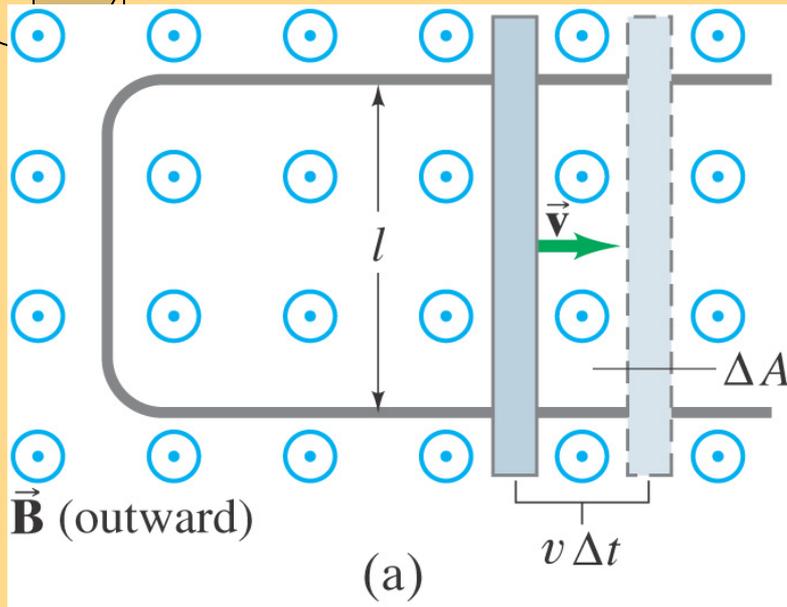
Ex. 21-11 An average of 120kW of electric power is sent to a small town from a power plant 10 km away. The transmission lines have a total resistance of 0.40 Ohms. Calculate the power loss if the power is transmitted at (a) 240 V and (b) 24,000 V

$$a) I = \frac{P}{V} = 500 A \Rightarrow P_{loss} = I^2 R = 100 kW$$

$$b) I = \frac{P}{V} = 5.0 A \Rightarrow P_{loss} = I^2 R = 10 W$$

EMF induced in a moving conductor

Another way the magnetic flux can change



$$\mathcal{E} = \frac{\Delta \Phi_B}{\Delta t} = \frac{B \Delta A}{\Delta t} = \frac{Blv \Delta t}{\Delta t} = Blv$$

The induced current is in a direction that tends to slow the moving bar – it will take an external force to keep it moving.

Exercise

Ex. 21-6 An airplane travels 1000 km/h in a region where the Earth's magnetic field is $5.0 \times 10^{-5} T$ and is nearly vertical. What is the potential difference induced between the wing tips that are 70 m apart?