Chapter 23   Magnetic Flux and Faraday's Law of induction

Outline

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23-2   Magnetic Flux
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23-5 Mechanical Work

Induced EMF (Voltage)

In a time interval Δt, the change of magnetic flux is

$$\Delta\Phi = B\Delta A = Blv\Delta t$$

The induced emf is

$$|\varepsilon| = N\left|\frac{\Delta\Phi}{\Delta t}\right| = (1)\frac{Blv\Delta t}{\Delta t} = Bvl \qquad (23-5)$$

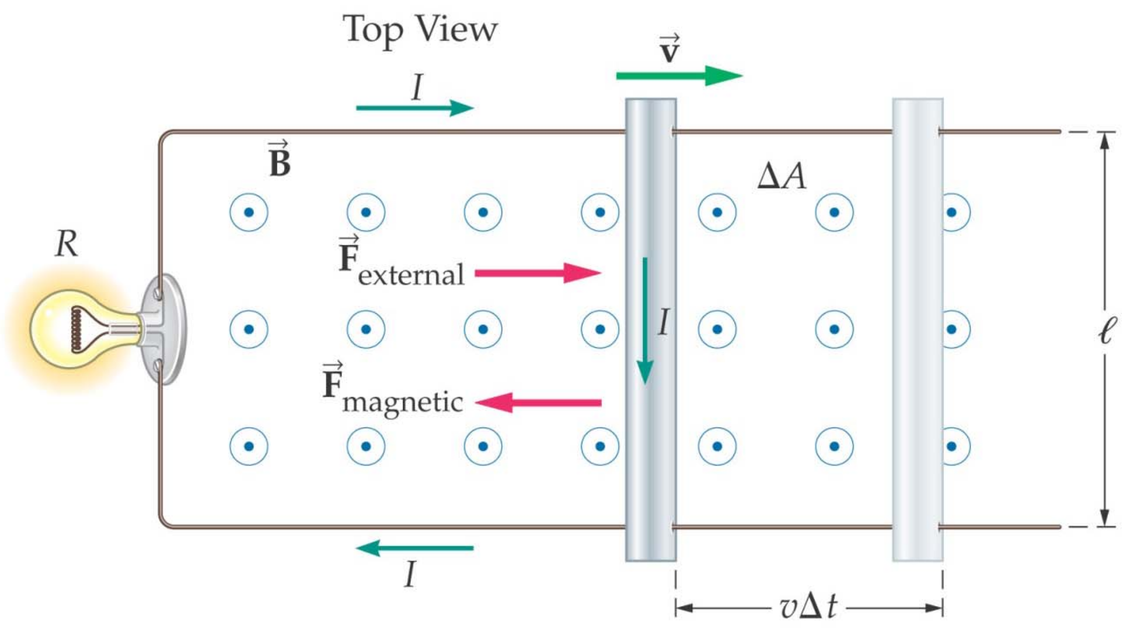


Figure 23-13
Force and Induced Current

For the induced electric field, since $V=E\,l$ along the rod. We have $Bvl = El$. Therefore,

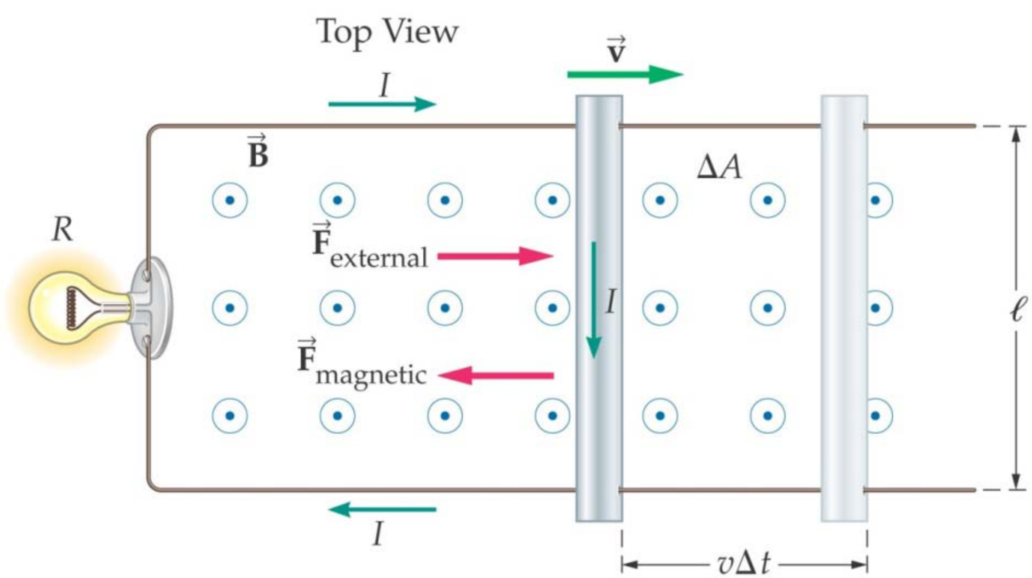
$$E = Bv \qquad (23-6)$$

According to Ohm's law, the induced current is

$$I = \frac{|\varepsilon|}{R} = \frac{Bvl}{R} \qquad (23-7)$$

Problem: Induced Potential Difference

As the rod in Figure 23-13 moves through a 0.445 T magnetic field, the 2-meter long rod moves with a constant speed of 1.8 m/s. What is the induced emf on the rod and the bulb, respectively?



Solution

The bulb and the rod are connected in parallel, and they have the same voltage:

$$|\varepsilon| = Bvl = 0.445 \times 1.8 \times 2$$

$$= 1.6 \quad V$$

Mechanical Work / Electrical Energy

Recalled that magnetic force applied on the motion rod is

$$F = IlB = \frac{Bvl}{R} lB = \frac{B^2 v l^2}{R} \qquad (23-8)$$

The mechanical power needed to move the rod is

$$P_{Me} = Fv = \frac{B^2 v^2 l^2}{R} \qquad (23-9)$$

The electric power provided to the resistor (bulb) is

$$P_{Elec} = I^2 R = (\frac{Bvl}{R})^2 R = \frac{B^2 v^2 l^2}{R} \qquad (23-10)$$

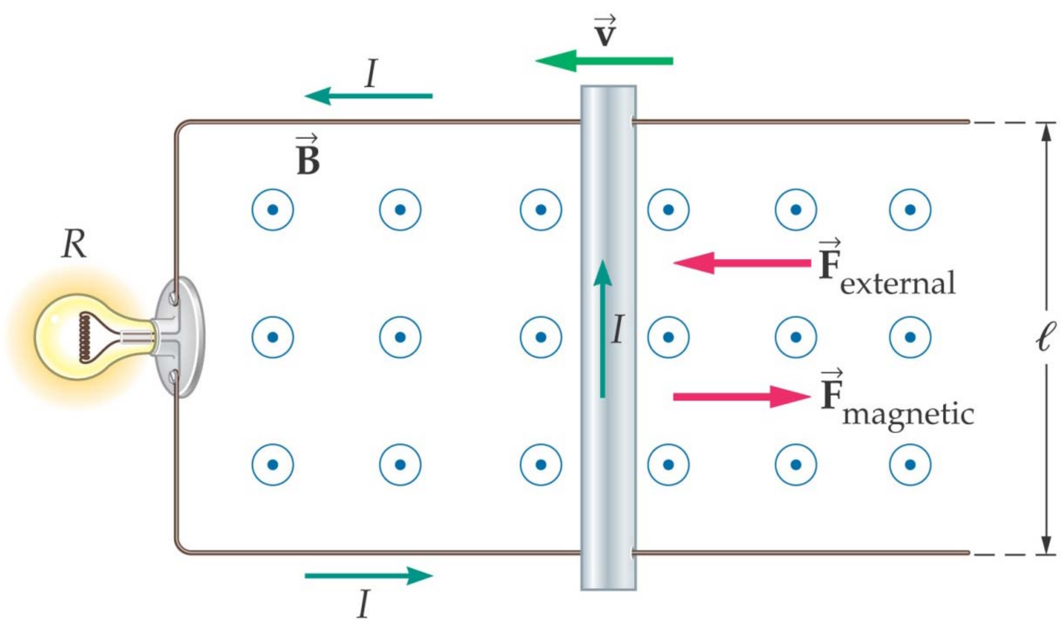
$P_{Me} = P_{Elc}$, Energy is conservative!

Example 23-3 Light Power

The light bulb in the circuit shown below has a resistance of 12 Ω and consume 5.0 W of power. The rod is 1.25 m long and moves to the left with a constant speed of 3.1 m/s.

(a) What is the strength of the magnetic field?

(b) What external force is required to maintain the rod's constant speed?



Solution

Part (a)

Since $P = (B^2 v^2 l^2)/R$, we have

$$B = \frac{\sqrt{PR}}{vl} = \frac{\sqrt{(5.0W)(12\Omega)}}{(3.1m/s)(1.25m)} = 2.0 \quad T$$

Part (b)

$$F = \frac{B^2 v l^2}{R}$$

$$= \frac{(2.0T)^2 (3.1m/s)(1.25m)^2}{12\Omega} = 1.6 \quad N$$

23-6 Electric Generators and Motors

Electric Generator

is a device that convert mechanical energy to electric energy.

Principle: the change of magnetic flux in the loop/coil create an emf, which can be expressed

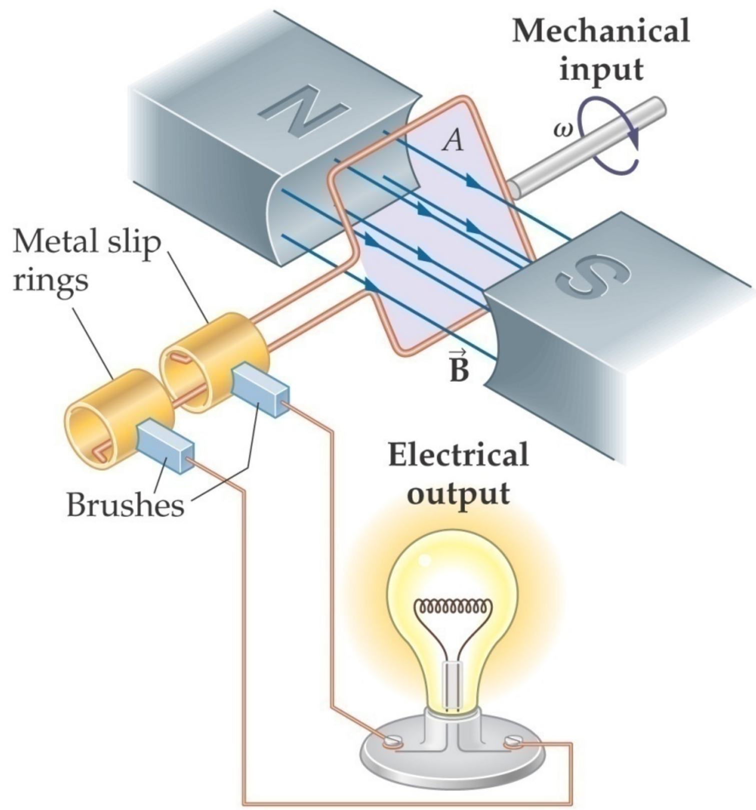


Figure 23-14
An Electric Generator

$$\varepsilon = NBA\omega \sin \omega t \qquad (23-11)$$

Where ω is the angular speed: radians /second.

N is the number of turns.

Since the ε change sign/direction, the generator is called an alternating current (AC) Generator.

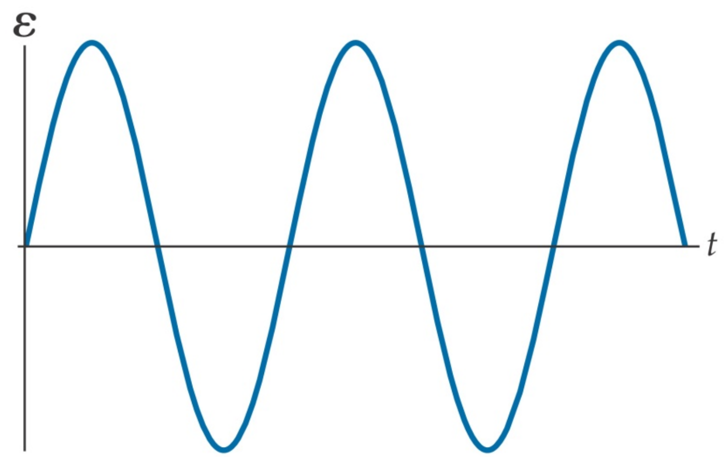


Figure 23-15
Induced emf of a Rotating Coil

Example 23-4

The coil of an electric generator has 100 turns and an area of $2.5x10^{-3}$ m^2. It has a maximum emf of 120V, when it rotates at the rate of 60.0 cycles per second. Find the strength of the magnetic field B that is required for this generator.

Solution

Find the angular speed,

$$\omega = 2\pi f = 2\pi\,(60\ Hz) = 377\ rad/s$$

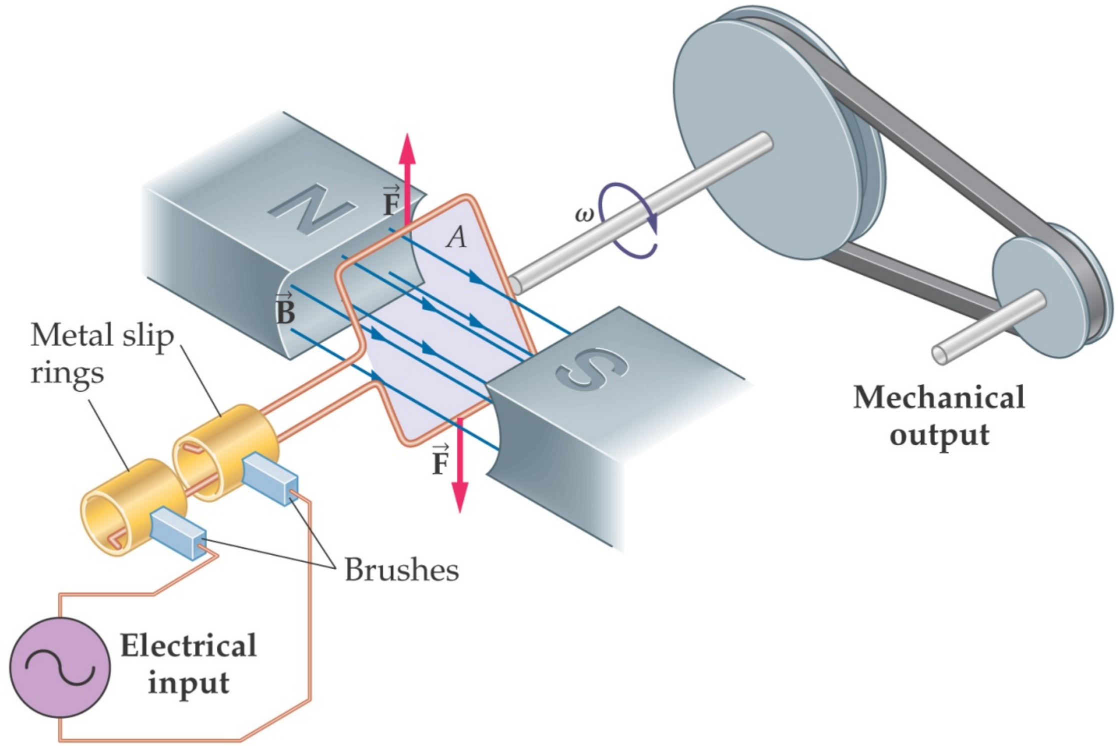
Since $\varepsilon_{\max} = NBA\omega$ *, we have*

$$B = \frac{\varepsilon_{\max}}{NA\omega} = \frac{120V}{(100)(2.5\times10^{-3}m^2)(377 rad/s)} = 1.3\ \ T$$

Alternating Electric Motors

The principle of the electric is the reverse of a generator.

It converts electric energy into mechanical energy.



Alternating current input

Figure 23-16
A Simple Electric Motor

Summary

1) Mechanical Work

How mechanical work is converted to electric energy.

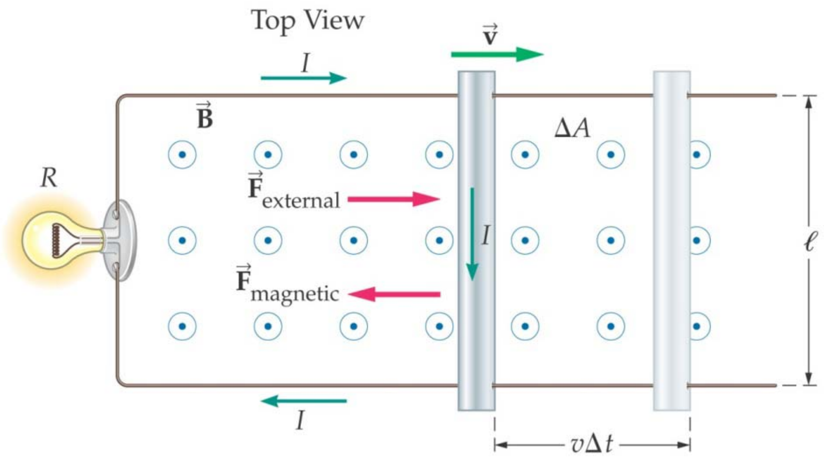
2) Generators and Motors

Exercise 23-2

As the rod in Figure 23-13 moves through a 0.445 T magnetic field, it experiences an induced electric field of 0.668 V/m. How fast is the rod moving ?

Solution

Since $E = B\,v$, we have



$$v = \frac{E}{B} = \frac{0.668 V/m}{0.445 T} = 1.50 \quad m/s$$