Chapter 23  Magnetic Flux and Faraday’s Law of induction

Outline

23-1  Induced Electromotive Force
23-2  Magnetic Flux
23-3  Faraday’s Law of Induction
23-4  Lens’s Law
23-5  Mechanical Work (Energy Conservation)
23-6  Electric Generators and Motors
23-10 Transformers
In a time interval $\Delta t$, the change of magnetic flux is

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

The induced emf is

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

(23–5)
For the induced electric field, since $V = E l$ along the rod. We have $Bvl = El$. Therefore,

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

According to Ohm’s law, the induced current is

$$I = \frac{|\mathcal{E}|}{R} = \frac{Bvl}{R} \quad \quad (23-7)$$
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:

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

$$= 1.6 \ V$$
Mechanical Work / Electrical Energy

Recalled that magnetic force applied on the motion rod is

\[ F = IlB = \frac{Bvl}{R} lB = \frac{B^2vl^2}{R} \]  \hspace{1cm} (23–8)

The mechanical power needed to move the rod is

\[ P_{Me} = Fv = \frac{B^2v^2l^2}{R} \]  \hspace{1cm} (23–9)

The electric power provided to the resistor (bulb) is

\[ P_{Elec} = I^2R = \left(\frac{Bvl}{R}\right)^2 R = \frac{B^2v^2l^2}{R} \]  \hspace{1cm} (23–10)

\[ P_{Me} = P_{Elec}, \quad \text{Energy is conservative!} \]
Example 23-3  Light Power

The light bulb in the circuit shown below has a resistance of $12 \, \Omega$ 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 \( P = \frac{(B^2 \nu^2 l^2)}{R} \), we have

\[
B = \frac{\sqrt{PR}}{\nu l} = \frac{\sqrt{(5.0W)(12\Omega)}}{(3.1m/s)(1.25m)} = 2.0 \ \text{T}
\]

Part (b)

\[
F = \frac{B^2\nu l^2}{R}
= \frac{(2.0T)^2(3.1m/s)(1.25m)^2}{12\Omega} = 1.6 \ \text{N}
\]
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
\[ \varepsilon = NBA \omega \sin \omega t \]  

(23–11)

Where \( \omega \) is the angular speed: radians /second.

\( N \) is the number of turns.

Since the \( \varepsilon \) 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 $2.5 \times 10^{-3}$ 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,

\[ \omega = 2\pi f = 2\pi (60 \text{ Hz}) = 377 \text{ rad/s} \]

Since \( \varepsilon_{\text{max}} = NBA \omega \), we have

\[
B = \frac{\varepsilon_{\text{max}}}{NA\omega} = \frac{120V}{(100)(2.5 \times 10^{-3} \text{ m}^2)(377 \text{ rad} / \text{s})} = 1.3 \text{ T}
\]
Alternating Electric Motors

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

It converts electric energy into mechanical energy.

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 $E = B \nu$, we have

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