Electrodynamics

- Ch. 26,27  Currents and DC Circuits
- Ch. 28  Magnetic Fields and Forces
- Ch. 29  Ampere’s Law
- Ch. 30  Faraday’s Law
- Ch. 31  AC Circuits
- Ch. 32  Maxwell’s Equations
- Ch. 32  Magnetic Materials

Currents and Circuits

Study Fig. 27-4 in the text to see how the potential changes from point to point in a circuit.

Following the Potential

Note the net change around the loop is zero.

DC Circuit Rules

- The net voltage change around any loop is zero. “Energy conservation”
- The net current into any junction is zero. “Charge conservation”

Using these two rules we can always get enough equations to solve for the currents if we are given the emfs and resistances.

Q.27-5

\[ R_1 = R_2 = R_3 = 2\Omega \]

If ammeter reads 1A, what is emf of battery?
Give answer in volts.
(An integer between 0 and 9.)

Q.27-5

\[ R_1 = R_2 = R_3 = 2\Omega \]

\[ i_3 = 1A \text{ and } R_2 = R_3 \text{ so } i_1 = 2A \]

\[ \text{So emf} = i_1 R_1 + i_3 R_3 = 4 + 2 = 6V \]
The Magnetic Force

If a particle with electric charge $q$ moves with velocity $v$ through a magnetic field $B$, then the force by the field on the particle is

$$\vec{F} = q \vec{v} \times \vec{B}$$

If a wire of length $L$ carries a current $i$ through a field $B$, the force by the field on the wire is

$$\vec{F} = iL \times \vec{B}$$

Field Due to a Long Straight Wire

Lines of $B$ make circles around wire!

Field of a long straight wire

1. Direction is given by the right-hand rule!
2. Magnitude is $B = \frac{\mu_0 i}{2\pi r}$
3. New universal constant: $\mu_0 = 4\pi \times 10^{-7} \text{Tm} / \text{A}$

Ampere’s Law

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 i_{\text{enc}}$$

$C =$ Any closed path

$i_{\text{enc}} =$ Net current linking $C$ (Right-hand rule)

$B =$ The total magnetic field

$ds =$ A short step along the path

Faraday’s Law

$$\mathcal{E} = -\frac{d\Phi}{dt}$$

The emf induced in a loop equals the negative rate of change of the magnetic flux through that loop.

Lenz’s Law

The direction of the emf is so as to create a current to oppose the change in the flux.

Inductance

$$\mathcal{E} = -L \frac{di}{dt}$$

Q.30-1

I push a rod along metal rails through a uniform magnetic field.

In which direction will electric current flow in the moving rod?

(1) Up   (2) Down   (3) Right   (4) Left
Q.30-1
In which direction will current flow in the moving rod?

• Lenz: Try to oppose change in flux.
• Motion increases flux outward.
• Current will try to create downward flux.
• RH rule: CW current will do that.

(1) Up  (2) Down  (3) Right  (4) Left

Summary

Gauss for E: Lines of E begin and end on charges.
Gauss for B: Lines of B never begin or end.
Faraday: Changing B creates circular E.
Ampere: Current or changing E creates circular B.

We now have the complete theory of the electromagnetic field.

Review: Induced E Fields

Lines of the induced E field make circles around the lines of the changing B field, just as lines of B circle around a wire.

Faraday: Induced Electric Field

For any closed curve, C, on the surface, S, bounded by C:

\[ \oint_C \mathbf{E} \cdot d\mathbf{s} = -\frac{d}{dt} \int_S \mathbf{B} \cdot d\mathbf{A} \]


Maxwell: Induced Magnetic Field

For any closed curve, C, on the surface, S, bounded by C:

\[ \oint_C \mathbf{B} \cdot d\mathbf{s} = \mu_0 \varepsilon_0 \frac{d}{dt} \int_S \mathbf{E} \cdot d\mathbf{A} \]
Example

Problem 30-24

Rectangular loop of resistance \( R \) near long straight wire carrying current \( i \).

Move rectangle away with constant speed \( v \): find magnetic flux, induced emf and current in the loop.

Step 1

First find magnetic flux \( \Phi \) through the loop, as function of \( r \).

\[
B(x) = \frac{\mu_0 i}{2\pi x}
\]

\[
d\Phi = B(x)\,dA
\]

\[
\Phi = \int d\Phi = \frac{\mu_0 i}{2\pi} \int_{r-b/2}^{r+b/2} \frac{dx}{x} - \frac{\mu_0 i}{2\pi} \ln\frac{r+b/2}{r-b/2}
\]

Step 2

Next find emf in loop, which is time derivative of flux.

\[
\mathcal{E} = -\frac{d\Phi}{dt} = -\frac{\mu_0 i a}{2\pi} \ln\frac{r+b/2}{r-b/2}
\]

Work out derivative using \( \frac{d}{dt} \ln u = \frac{1}{u} \frac{du}{dt} \)

Get

\[
\mathcal{E} = -\frac{\mu_0 i a}{2\pi} \left[ -\frac{bv}{r^2-b^2/4} \right] = \frac{4\mu_0 i abv}{2\pi(4r^2-b^2)}
\]

Step 3

Evaluate emf and find current.

\[
a = 2.2\,cm
\]

\[
b = 0.8\,cm
\]

\[
R = 0.4m\Omega
\]

\[
i = 4.7\,A
\]

\[
v = 3.2\,mm/s
\]

\[
r = 1.5\,b
\]

\[
\mathcal{E} = \frac{4\mu_0 i abv}{2\pi(4r^2-b^2)} = 8 \times 10^{-7} \frac{ia v}{(4 \times 1.5^2 - 1)b}
\]

\[
= 8 \times 10^{-7} \times \frac{4.7 \times 0.022 \times 0.0032}{8 \times 0.008} = 4 \times 10^{-9} V
\]

Step 4

Evaluate emf and find current.

Lenz's Law:

\( B \) into screen but flux is decreasing.

Induce \( i' \) to resist decrease, i.e. to increase \( B \).

RH rule gives \( i' \) clockwise.

\[
\mathcal{E} = 4 \times 10^{-9} V
\]

\[
i = \mathcal{E} / R = \frac{4 \times 10^{-9} V}{4 \times 10^{-4} \Omega} = 1 \times 10^{-5} A
\]