Electrodynamics

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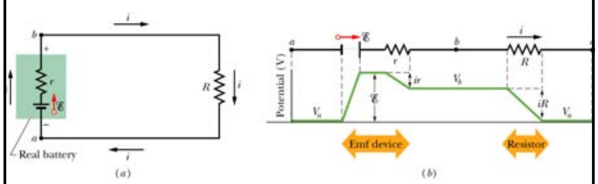
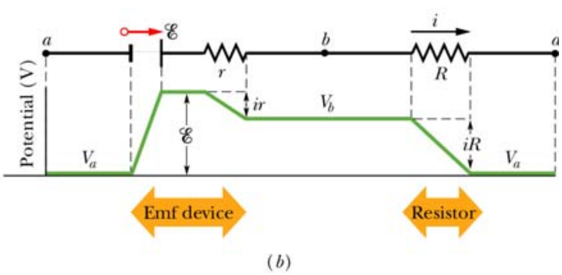
Currents and Circuits

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.

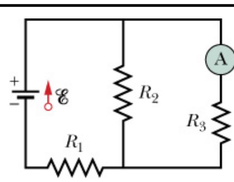
DC Circuit Rules

- *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

$$R_1 = R_2 = R_3 = 2\Omega$$



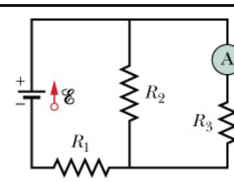
If ammeter reads 1A, what is emf of battery?

Give answer in volts.

(An integer between 0 and 9.)

Q.27-5

$$R_1 = R_2 = R_3 = 2\Omega$$



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

$$\text{So emf} = i_1 R_1 + i_3 R_3 = 4 + 2 = \underline{6V}$$

The Magnetic Force

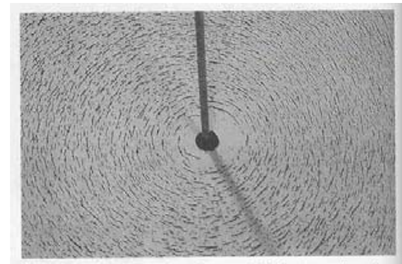
If a particle with electric charge q moves with velocity $\boldsymbol{v}$ through a magnetic field $\boldsymbol{B}$, then the force by the field on the particle is

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

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

$$\vec{F} = i\vec{L} \times \vec{B}$$

Field Due to a *Long Straight* Wire

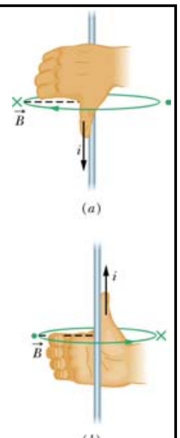


Lines of B make circles around wire!

Field of a long straight wire

1. Direction is given by the right-hand rule!
2. Magnitude is $B = \dfrac{\mu_0 i}{2\pi r}$
3. New universal constant:

$$\mu_0 = 4\pi \times 10^{-7}\ Tm/A$$



Ampere's Law

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

C = Any closed path

i_{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

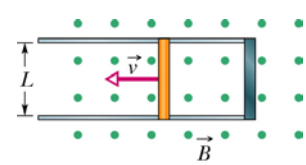
The ***direction*** of the emf is so as to create a current to ***oppose the change*** in the flux.

Inductance

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

Q.30-1

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

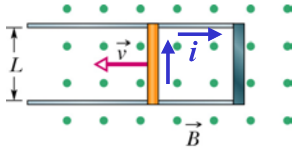


In which direction will electric current flow in the moving rod?

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

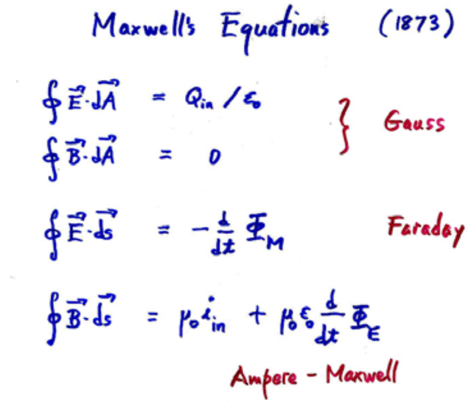
Q.30-1

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.

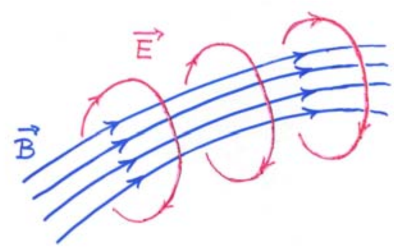
Gauss for B: Lines of *B* never begin or end.

Faraday: Changing *B* creates circular *E*.

Ampere: Current or changing *E* creates circular *B*.

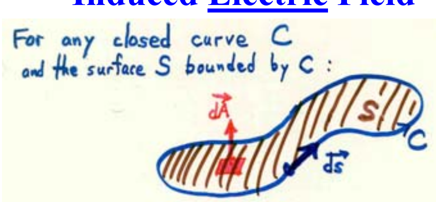
We now have the complete theory of the electromagnetic field.

Review: Induced E Fields



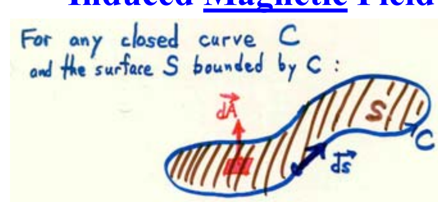
Lines of the *induced E* field make circles around the lines of the *changing B* field, just as lines of *B* circle around a wire.

Faraday: Induced Electric Field



$$\oint_C \vec{E}\cdot d\vec{s} = -\frac{d}{dt}\int_S \vec{B}\cdot d\vec{A}$$

Maxwell: Induced Magnetic Field

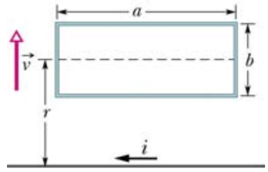


$$\oint_C \vec{B}\cdot d\vec{s} = \mu_0\varepsilon_0\frac{d}{dt}\int_S \vec{E}\cdot d\vec{A}$$

Example

Problem 30-24

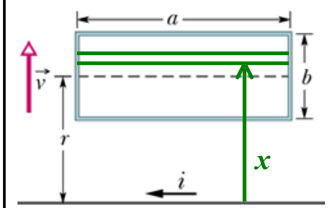
Rectangular loop of resistance R near long straight wire carrying current i.



Move rectangle away with constant speed $\mathbf{v}$: find magnetic flux, induced emf and current in the loop.

Step 1

First find magnetic flux Φ through the loop, as function of r.



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

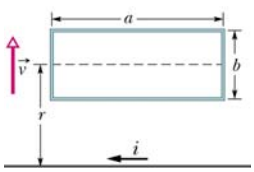
$$d\Phi = B(x)\, dA$$

$$= \frac{\mu_0 i}{2\pi x} a\, dx$$

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

Step 2

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



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

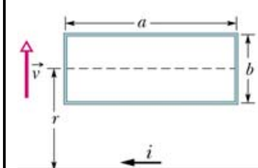
$$= -\frac{\mu_0 i a}{2\pi} \frac{d}{dt} \ln \frac{r+b/2}{r-b/2}$$

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

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

Step 3

Evaluate emf and find current.



$a = 2.2cm$

$b = 0.8cm$

$R = 0.4m\Omega$

$i = 4.7A$

$v = 3.2mm/s$

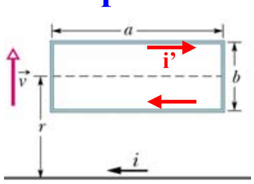
$r = 1.5b$

$$\mathcal{E} = \frac{4\mu_0 iabv}{2\pi\left(4r^2 - b^2\right)} = 8\times10^{-7} \frac{iav}{(4\times1.5^2 - 1)b}$$

$$8\times10^{-7} \frac{4.7\times.022\times.0032}{8\times.008} = 4\times10^{-9}V$$

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.

$$\mathcal{E} = 4\times10^{-9}V$$

$$i = \mathcal{E}/R = \frac{4\times10^{-9}V}{4\times10^{-4}\Omega} = 1\times10^{-5}A$$