Electromagnetic Induction

Induced emf

emf → energy per unit charge supplied by a source of electric current

→ increase in the potential energy of charges circulating in a circuit

→ potential difference = Voltage

→ emf = Voltage

Induced emf

- We have seen that an electric field can produce a magnetic field.
- The reverse is also true: a magnetic field can give rise to an electric field.
- A conductor that is caused to move relative to a magnetic field generates an electric field.

Induced emf

A rotating coil in a magnetic field induces an alternating **emf**, which produces an *alternating current* (**ac**).

This process is called **electromagnetic induction** and is the operating principle behind many electrical devices.

Electromagnetic Induction

- Faraday discovered that when a conductor cuts magnetic flux lines, an **emf** is produced.
- He did this by passing a magnet through a loop of wire
- The induced emf and current are largest when the plane of the loop is perpendicular to the magnetic field and zero when parallel to the magnetic field

Electromagnetic Induction

From experiments performed it can be stated that:

Relative motion between a conductor and a magnetic field induces an **emf** in the conductor.

The direction of the induced **emf** depends upon the direction of motion of the conductor with respect to the field.

The magnitude of the **emf** is directly proportional to the rate at which the conductor cuts magnetic flux lines.

The magnitude of the **emf** is directly proportional to the number of turns of the conductor crossing the flux lines.

Motional emf

To be used when v, B, and L are all mutually perpendicular

$\mathcal{E} = vBL$

E → induced emf

v → velocity

B → magnetic field strength

L → length of rod on the rails

Lenz's Law

The magnetic field of the induced current opposes the change in the applied magnetic field

The induced magnetic field is therefore in the direction opposite that of the approaching magnetic field

As the applied field changes the induced field attempts to keep total field strength constant → *Conservation of Energy*

Magnetic Flux

By crossing magnetic field lines, or lines of varying magnetic force we create magnetic flux

$\Phi = BA \cos\theta$

→ Φ = magnetic flux

→ B = magnetic field strength

→ A = Area of loop

→ θ = orientation of loop to the field

Faraday’s Law of Induction

$$emf = -N\frac{\Delta\phi}{\Delta t} \qquad \Delta\phi = AB\cos\theta$$

emf = voltage in volts (**V**)

N = number of turns or loops in a circuit

$\Delta\phi$ = change in flux in *Webers* (**Wb**)

A = area (**m**^{2})

B = magnetic field (**T**)

Generators

- Another way to induce current is to change the orientation of the loop with respect to the magnetic field
- Mechanical energy used to turn the loop is converted to electrical energy
- A device that does this is called an electric ***generator***

Generators

- Generators produce a continuously changing emf
- As the loop turns in the magnetic field the polarity of the induced emf and the direction of the current are reversed
- The output current from the generator changes its direction at regular intervals
- Alternating Current (AC) is produced

Generators

Maximum emf = $NAB\omega$

N → number of turns

A → circuit area (m^2)

B → magnetic field strength (T)

ω → angular frequency of rotation

$$\omega = 2 \times \pi \times \text{frequency}$$

Motors

- Motors are devices that convert electrical energy into mechanical energy
- A current is supplied to a loop by an emf source
- The magnetic force on the current loop causes it to rotate
- ***Back emf*** → the emf induced in a motor's coil that tends to reduce the current powering the motor

Mutual Inductance

- A measure of the ability of one circuit carrying a changing current to induce an emf in a nearby circuit
- As long as the coils remain unchanged with respect to each other the mutual inductance is constant
- By changing the number of turns of wire in the secondary coil, the induced emf in the secondary circuit can be changed

Transformers

- Devices that are used to increase or decrease an *ac* voltage
- It consists of two coils or wire, known as the *primary* and *secondary* coils.
- The advantage of a transformer is that it is possible to produce a higher or lower voltage in the secondary as compared to the primary. This is accomplished by having different numbers of turns of wire in the two coils.

Transformers

Step Down Transformer - number of turns of wire in the primary is greater in the primary than the secondary, then the voltage in the the secondary is lower than in the primary

Step Up Transformer - number of turns in the primary is less than the secondary, then the voltage in the secondary is higher than in the primary

Transformers

$$\frac{V_s}{V_P} = \frac{N_S}{N_P} \qquad I_P V_P = I_S V_S$$

V → voltage in volts (V)

N → number of coils

I → current in amperes (A)

Note → power input = power output