# 25 Electromagnetic Induction

## 25.1 Generating Electricity

**Electromagnetic induction** occurs whenever a wire **cuts across magnetic field lines**. If the wire is part of a complete circuit, the **induced emf** forces electrons round the circuit. The

The induced emf is increased by

- Moving the wire **faster**.
- Using a **strong magnet**.
- Making the wire into a **coil**, and pushing the magnet in or out of the coil.

No emf is induced in the wire if the wire is parallel to the magnetic field lines - the wire must cut across the lines of magnetic field.

### Energy Changes

- When a magnet is moved relative to a conductor, an **emf is induced** in the conductor.
- If the conductor is part of a circuit, a **current passes** round the circuit.
- The electric current **transfer energy** from the source of the emf in a circuit to other components in the circuit - work must be done to keep the magnet moving.

$$\text{Rate of energy transfer} = I\varepsilon$$

**Fleming's right-hand rule** is used to work out the direction of the induced current.

## 25.2 The Laws of Electromagnetic Induction

A magnetic field is produced in and around a coil when it is connected to a battery and a current is passed through it.

- For a **solenoid**, the pattern of the magnetic field lines is like the pattern for a bar magnet.
- The field lines pass through the solenoid and loop round outside the solenoid from one end to another.

### Lenz's Law

Lenz's law states that the direction of the induced current is always such as to opposite the change that causes the current.

The explanation of Lenz's law is that energy is never created or destroyed - the induced current could never be in a direction to help the change that causes it, as it would produce electrical energy from nowhere.

**Faraday's Law of Electromagnetic Induction**

$$\text{Magnetic flux } \phi = BA$$
$$\text{Magnetic flux linkage } \Phi = N\phi$$

where $B$ is the magnetic flux density perpendicular to area $A$. When the magnetic field is at angle $\theta$ to the normal at the coil face, the flux linkage through the coil is $N\phi = BAN\cos\theta$.

The unit of magnetic flux is the **weber**, equal to $1\text{TM}^2$.

**Faraday's law of electromagnetic induction** states that the induced emf in a circuit is equal to the rate of change of flux linkage through the circuit.

$$\varepsilon = -\frac{d\Phi}{dt}$$

The minus sign represents the fact that the induced emf acts in a way such that the direction is opposite to the change that caused it (Lenz's law).

For a moving conductor at right angles to the field lines

$$\varepsilon = Blv$$

## 25.3 The Alternating Current Generator

The simple AC generator consists of a **rectangular coil** that spins in a uniform magnetic field.

- When the coil spins at a steady rate, the flux linkage changes continuously.
- At an instant where the normal to the plane of the coil is at an angle $\theta$ to the field lines, the flux linkage through the coil is

$$\Phi = BAN\cos\theta$$

- For a coil spinning at steady frequency, $\theta = 2\pi ft$.

$$\begin{aligned}\Phi &= BAN\cos 2\pi ft\\ \varepsilon = \frac{d\Phi}{dt} &= -2\pi fBAN\sin 2\pi ft\\ &= \varepsilon_0 \sin 2\pi ft\\ &= \varepsilon_0 \sin\omega t\end{aligned}$$

The peak emf can be increased by increasing the **speed**, or using a **stronger magnet**, a **bigger coil**, or a **coil with more turns**.

**Back Emf**

An emf is induced in the spinning coil of an electric motor because the flux linkage through the coil changes.

The induced emf is referred to as a back emf because it **acts against the pd** applied to the motor in accordance with Lenz's law.

$$V - \varepsilon = IR$$

## 25.4 Alternating Current and Power

The alternating current is a current that **repeatedly reverses its direction**.

- Mains electricity has a frequency of 50Hz.
- Peak current depends on peak pd of the alternating current source.
- Peak pd of mains is 325V.

The power supplied to the heater is given by $P = I^2 R$

- At **peak current** $I_0$, maximum power supplied is equal to $I_0^2 R$.
- At zero current, zero power is supplied.

The **root mean square** value of an alternating current is the value of direct current that would give the same heating effect as the alternating current in the same resistor.

$$I_{\text{rms}} = \frac{1}{\sqrt{2}} I_0$$
$$V_{\text{rms}} = \frac{1}{\sqrt{2}} V_0$$

The mean power is therefore $\frac{1}{2} I_0^2 R$

## 25.5 Transformers

A transformer changes an alternating pd to a different peak value.

- Consists of the **primary coil** and the **secondary coil**.
- The two coils have the **same iron coil**.

When the primary coil is connected to a source of alternating pd.

1. An **alternating magnetic field** is produced in the core.
2. The field passes through the secondary coil, so an **alternating emf** is induced in the secondary coil by the changing magnetic field.

A transformer is designed so that all the magnetic flux produced by the primary coil passes through the secondary coil.

The **transformer rule**

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- A **step-up transformer** has $N_s > N_p$ so $V_s > V_p$.
- A **step-down transformer** has $N_s < N_p$ so $V_s < V_p$.

**Transformer Efficiency**

Transformers are almost 100% efficient because they are designed with

- **Low-resistance** windings to reduce power wasted due to the heating effect of the current.
- A **laminated core** which consists of layers of iron separated by layers of insulator. **Eddy currents** are reduced so the magnetic flux is as high as possible - heating effect in the core is reduced.
- The **soft iron core** can be easily magnetised and demagnetised, reduces power wasted through repeated magnetisation and demagnetisation of the core.

$$\text{Efficiency} = \frac{I_s V_s}{I_p V_p}$$

**The Grid System**

The National Grid is a network of transformers and cables which covers all regions of the UK.

1. **Power stations** generates alternating current of 50Hz and 25kV.
2. **Step-up transformers** at the power station increases the alternating voltage to 400kV for long-distance transmission via the grid.
3. Homes are supplied via a **local transformer substation** at 230V.

Transmission of electrical power over long distances is much more efficient at high voltages than at low voltages.