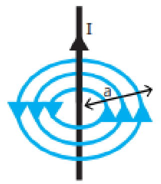
Module 6 Section 3: Electromagnetism

Magnetic Fields

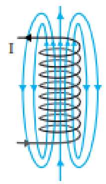
Magnetic fields are created by current carrying wires, the shape of the field can be predicted by the right-hand grip rule.

Long straight wire



Thumb in the direction of the current, fingers in the direction of the field.

Solenoid



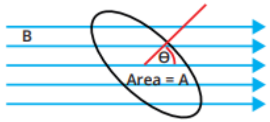
Fingers in the direction of the current, thumb in the direction of the field inside the coil.

Magnetic Flux and Flux Linkage

Magnetic flux can be thought of as the number of field lines passing through an area. It is very important in calculating the emf induced by electromagnetism.

Magnetic flux, ϕ, is calculated using this equation:

$$\phi = AB\cos\theta$$



Where θ is the angle between the field and the **normal to the surface**.

If a coil rather than a single loop is used, the **flux linkage** must be calculated.

$$\text{Flux linkage} = N\phi = BAN\cos\theta$$

Lenz's Law

The direction of an induced e.m.f. (and current) are given by **Lenz's law**:

> The induced e.m.f. is always in such a direction as to oppose the change that caused it.

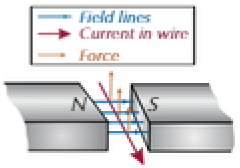
A changing magnetic field induces an e.m.f. in a coil (see page 395). If the coil is part of a complete circuit, a current is induced in the same direction as the induced e.m.f. The induced current then produces its own magnetic field (p.381). Lenz's law says:

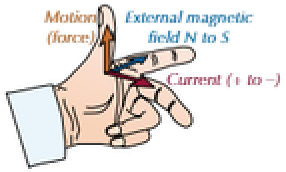
- If the original magnetic field is getting stronger, the current will be induced in the direction that generates a magnetic field in the opposite direction to the external field, to try to weaken it.
- If the original magnetic field is getting weaker (collapsing), the current will be induced in the direction that generates a magnetic field in the same direction as the external field, to try to maintain it.

Flemings Left Hand Rule

You can use your left hand to find the direction of the current, the direction of the external magnetic field or the direction of the force on the wire (as long as you know the other two). Stretch your thumb, forefinger and middle finger out, as shown in Figure 8, and use the following rules:

- The First finger points in the direction of the uniform magnetic Field.
- The seCond finger points in the direction of the conventional Current.
- The thuMb points in the direction of the force (the direction of Motion).





Faraday's Law

Faraday's law links the rate of change of flux linkage with e.m.f.:

> Induced e.m.f. is directly proportional to the rate of change of flux linkage.

It can be written as:

$$\varepsilon = -\frac{\Delta(N\phi)}{\Delta t} = -\frac{N\Delta\phi}{\Delta t}$$

- $\Delta(N\phi)$ = change in flux linkage in Wb
- N = number of turns on the coil cutting the flux
- ε = induced e.m.f. in V
- $\Delta\phi$ = change in magnetic flux in Wb
- Δt = time taken for flux linkage to change in s

For a coil, induced e.m.f. depends on the number of turns and how fast flux through the coil is changing. The unit of flux, the weber (Wb), is defined in terms of the e.m.f. induced:

> A change in flux linkage of one weber per second will induce an electromotive force of 1 volt in a loop of wire.

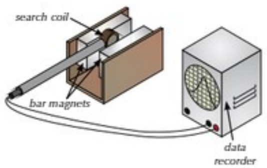


Figure 3: Set-up for experiment to investigate magnetic flux.

Magnetic Flux Density

> The force on one metre of wire carrying a current of one amp at right angles to the magnetic field.

Magnetic flux density is a vector quantity with both a direction and a magnitude. It is measured in teslas, T. One tesla is equal to one newton per amp per metre:

$$1 \text{ tesla} = 1\ \frac{\text{N}}{\text{Am}}$$

When a current-carrying wire is at 90° to a magnetic field, the size of the force on the wire, F, is proportional to the current, I, the length of wire in the field, L, and the flux density, B, of the external magnetic field. This gives the equation:

$$F = BIL$$

- F = force on a current-carrying wire in N
- I = current through the wire in A
- B = magnetic flux density in T
- L = length of the wire in m

So, for a wire at an angle θ to the field, the force acting on the wire is given by:

$$F = BIL\sin\theta$$

- F = force on a current-carrying wire in N
- I = current through the wire in A
- θ = angle between wire and field
- B = magnetic flux density in T
- L = length of the wire in m

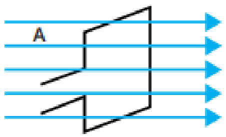
Module 6 Section 3: Electromagnetism

Uses of Electromagnetic Induction

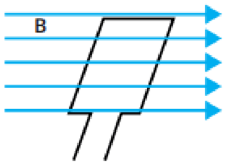
A generator uses a rotating coil in a magnetic field to induce an emf. The magnitude is given by Faraday's law. The average emf for a time *t* can be calculated as described, by subtracting the flux linkage at the end from the stars and dividing by the time. However, the instantaneous emf must be considered.

The factors that affect the instantaneous emf are:

1. **The flux density**
   Larger flux density means a larger flux linkage, this means in a given time the change in flux density would be larger. Therefore, the induced emf would be greater.
2. **The area of the coil**
   As above, a larger area means a larger flux linkage. Therefore, the induced emf would be larger.
3. **The angular velocity of the rotation**
   Larger angular velocity means the change in flux linkage would happen is a smaller time. Therefore, the induced emf would be larger but the frequency of the emf would also be larger.
4. **The position of the coil**
   At position A, the coil is vertical, therefore θ = 0° and cosθ = 1. The flux linkage is a maximum at that point; therefore, the rate of change of flux linkage is at its minimum. Emf = 0



   At position B, the coil is vertical, therefore θ = 90° and cosθ = 0. The flux linkage is 0 at that point; therefore, the rate of change of flux linkage is at its maximum.



Transformers

Transformers are devices that make use of electromagnetic induction to change the size of the voltage for an alternating current. They consist of two coils of wire wrapped around an iron core — see Figure 5.

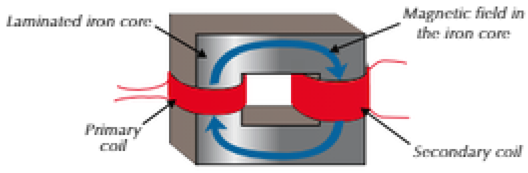


Figure 5: The basic structure of a (step-up) transformer.

Which gives the transformer equation: