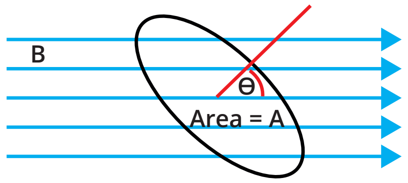
GCE Physics Unit 4.5 Electromagnetic Induction

Magnetic flux:

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.

$$Flux\ linkage = N\phi = BAN\cos\theta$$

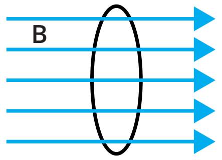
Faraday and Lenz:

Flux and flux linkage are linked to the emf induced by Faraday's law. This states that the emf induced is equal to the **rate of change of flux linkage**. This can be written as the following:

$$V = -\frac{\Delta N\phi}{\Delta t}$$

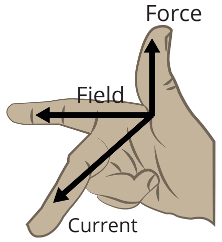
The – sign in the equation is as a result of **Lenz's** law. This states that the direction of the current resulting from an induced emf is such as to oppose the change in flux linkage that is causing the current.

For example, if a current were induced in this loop by the magnetic field shown, the current would flow so that the magnetic field is created would be in the opposing direction.



Fleming's Right-Hand Rule:

As a result of Lenz's law, the direction of the induced current can be predicted using Fleming's Right-Hand Rule.



Applying Faraday's law:

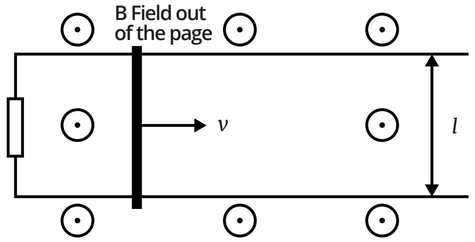
The simplest way to calculate the induced emf is to calculate the flux linkage at time = 0 and the flux linkage at time = t, subtract one from the other and divide by t. This will give you the average emf induced over that time.

There are two common ways of inducing an emf:

1. **Changing area over time**
2. **Changing flux density over time**

Faraday's law can be applied to calculate the emf to both examples.

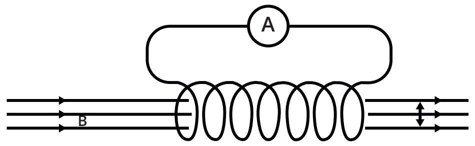
1. Changing area over time



Consider this conducting rod, moving along a trac made of 2 metal rails. The area of the loop is increasing; therefore, the flux linkage is increasing. As it is rectangular, the area is increasing by $lv\Delta t$. This can be substituted into the equation for Faraday's law and the emf can be calculated.

$$V = -\frac{Blv\Delta t}{\Delta t} = Blv$$

2. Changing flux density over time



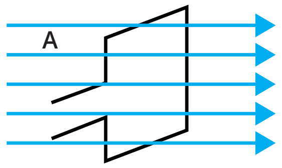
In this example, the B field is changing at a rate of 43mT s^{-1}. As the area and the number of turns on the coil are constant, this means the change of flux linkage is equal to $NA \times 43mT$ per second. This can be substituted into the equation for Faraday's law and divided by time, t = 1s.

Rotating coil:

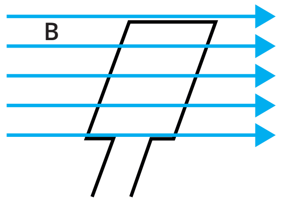
A generator uses a rotating coil in a magnetic field to induce an emf. The magnitude is given by Faraday's law. The average emf for a time t can be calculated as described, by subtracting the flux linkage at the end from the stars and dividing by the time. However, the instantaneous emf must be considered.

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.



A = area in m^2
N = number of turns
V = emf in V
t = time in s
ϕ = flux in Webber (Wb)
B = flux density in T
θ = angle between the field lines and the **normal to the surface** in °