WJEC (Wales) Physics A-level

Topic 4.5: Electromagnetic Induction

Notes

Magnetic Flux and Flux Linkage

Magnetic flux, ϕ, is a measure of the amount of magnetic field passing through an area, A. It is given by:

$$\phi = ABcos(\theta)$$

where B is the magnetic field strength/magnetic flux density, and θ is the angle between the field and the area.

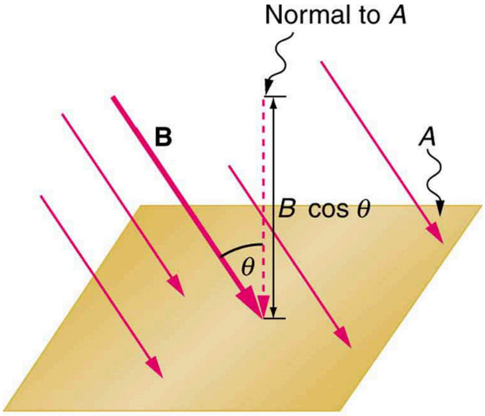


Image source: https://www.pathwayz.org/Tree/Plain/MAGNETIC+FLUX

The magnetic flux is **greatest when the magnetic field is normal (perpendicular) to the area** and the **unit of magnetic flux is the Weber**, Wb which is equivalent to Tesla Metre squared Tm^2.

To describe the amount of magnetic field going through a coil with area A we use **flux linkage** which is defined as:

$$Flux\ Linkage\ =\ N\phi\ = NABcos(\theta)$$

Where N is the number of turns in the coil and A is the area of the circle that the coil turns encompass. Flux linkage is measured in Webers or Weber turns (since N is dimensionless).

Electromagnetic Induction

Whenever the **magnetic flux through a coil changes, an EMF is generated** and if this coil is part of a circuit a current will flow through it.

There are a few ways to change the magnetic flux, since from the equation in the first section we know that the magnetic flux depends on the area, the magnetic flux density and the angle between the field and the coil.

To generate an EMF in a coil we can:

- **Change the magnetic flux density** of the field
- **Increase the area of the coil** in the field or rotate the coil
- **Move the coil** relative to the field and vice versa

The laws of Faraday and Lenz govern the induced EMF and are as follows:

Faraday's Law of Induction: The magnitude of the induced EMF is equal to the rate of change of flux linkage

Lenz's Law: The direction of any current resulting from an induced EMF is such as to oppose the change in flux linkage that is causing the current.

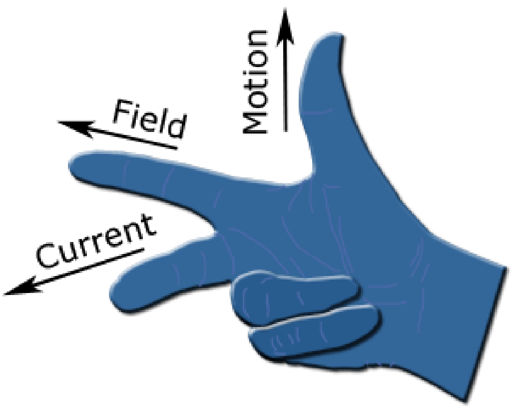
Combining these two laws and putting Faraday's law into mathematical terms gives:

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

Where ε is the induced EMF. The **minus sign comes from Lenz's law**.

Fleming's Right Hand Rule

Much like the left hand rule for forces on a wire in a B-field, we have a right hand rule to predict the direction of current when a conductor moves in a magnetic field.



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The thumb points in the direction the conductor is travelling, the index finger points in the direction of the B-field and the middle finger points in the direction the current will travel.

EMF induced in a linear conductor moving at right angles to a magnetic field

When a conducting rod moves through a magnetic field on contact rails a current flows since the magnetic flux linkage is changing. The direction of this current can be worked out using Fleming's right hand rule.

The reason the magnetic flux linkage changes is that as the rod moves to the right, the 'coil' made by the rod and the contact rails increases in area - encompassing more magnetic flux

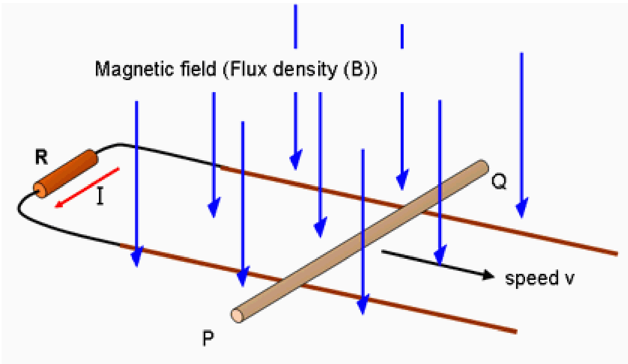
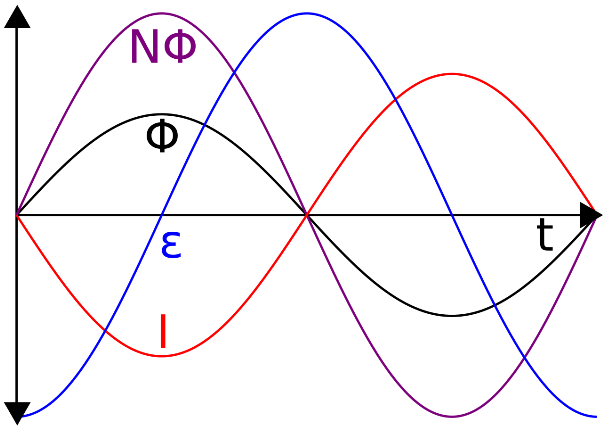
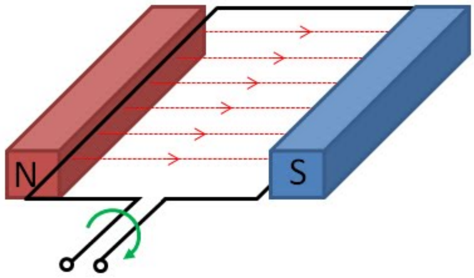


Image source: https://spark.iop.org/collections/electromagnetism#gref

Instantaneous EMF in a coil rotating at right angles to a magnetic field





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https://sites.google.com/site/fradleyphysics/fields/alternating-current

When a coil rotates in a uniform magnetic field, the above graph shows how various quantities change with time.

When the **coil is flat** as in the picture the rate of change of flux linkage is greatest and as a result the **EMF is greatest**. When the **coil is vertical** the rate of change of flux linkage is zero and as a result the **induced EMF is zero**.

Increasing the coil area increases the EMF and they are directly proportional since:

$$\varepsilon = \frac{-\Delta N\phi}{\Delta t} = \frac{-\Delta NAB}{\Delta t}.$$

Increasing the angular velocity of the coil increases the EMF since it means a rotation is completed in a smaller period of time, giving the same change in magnetic flux in a smaller period.