

Electromagnetic Effect

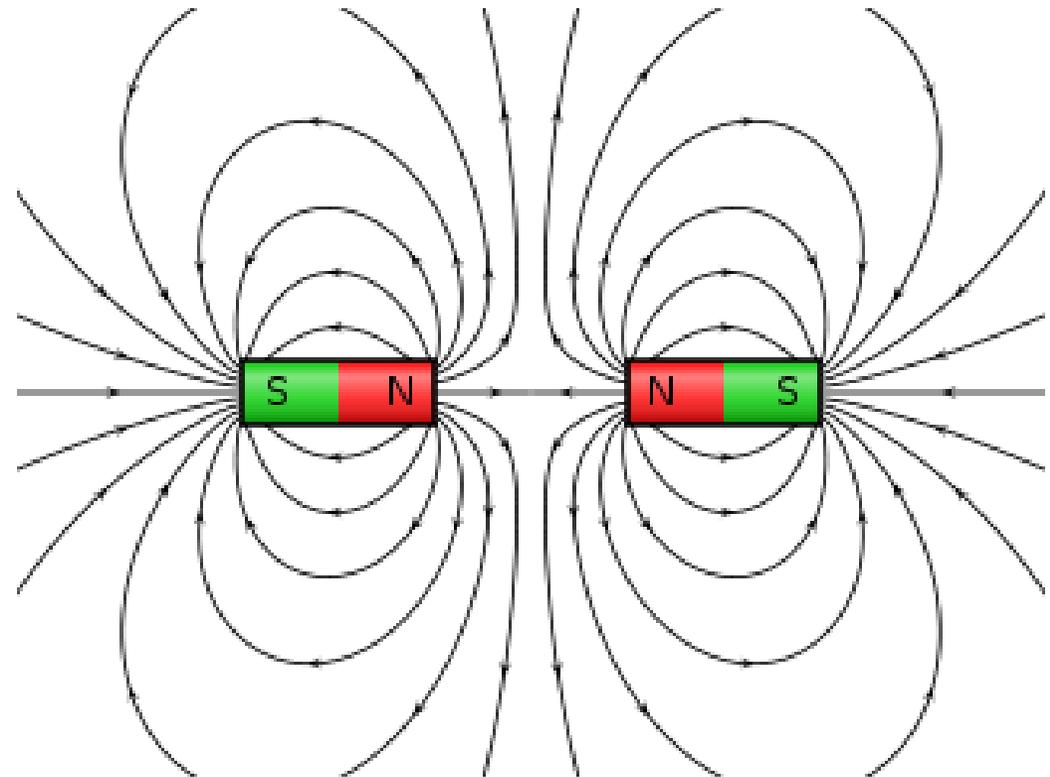


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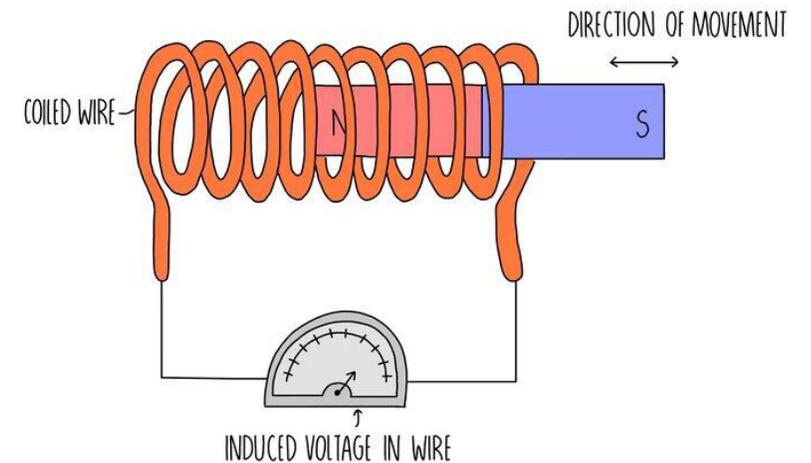
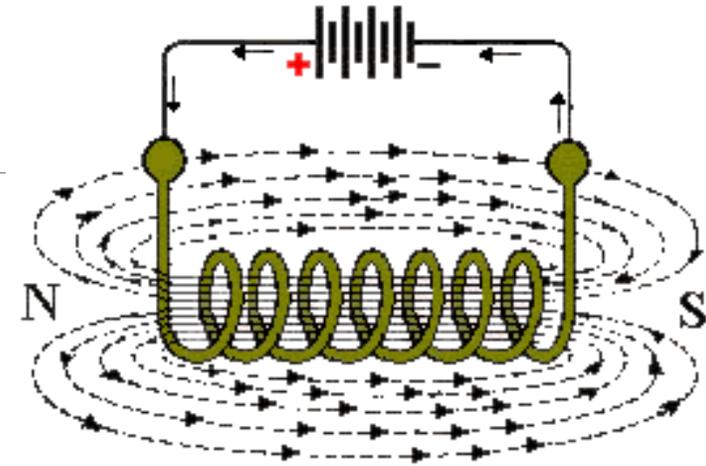
Refresher on magnetic fields

- Magnetic Fields always follow these 5 rules (properties):
 - Opposites attract
 - Like Repel
 - Flow North -> South
 - Field lines never cross
 - Field lines never break



Electromagnetic Effects

- The electromagnetic effect (electromagnetism) is the term that encompasses all interactions between magnets and electronics
- A wire carrying current will generate a magnetic field, this is an **electromagnet**
- A wire moving through a magnetic field will have a current generated in it, this is **electromagnetic induction**



The 3 laws

All electromagnetic effects are governed by 3 rules:

- **Faradays law:**

- The magnitude of the induced emf is directly proportional to the rate of change in magnetic flux. (a greater change in magnetic flux = a greater change in current)

- **Lenz's law:**

- The induced emf acts in such a direction to produce effects that oppose the change causing it. (the current acts in the opposite direction to the movement of the magnet)

- **Ampere-Maxwell law:**

- Magnetic fields are created by electric currents and changing electric fields, meaning that both steady and changing electric currents can produce magnetic fields.

Electromagnetic Induction

- Electromagnetic induction is the effect where a magnetic field generates a current flow in a circuit.
- There are two main types of electromagnetic induction
 - Statically Induced EMF where the conductor stays still and a magnetic field moves through it, these will typically be in a loop setup
 - Motivational Induced EMF where the conductor moves through the magnetic field.

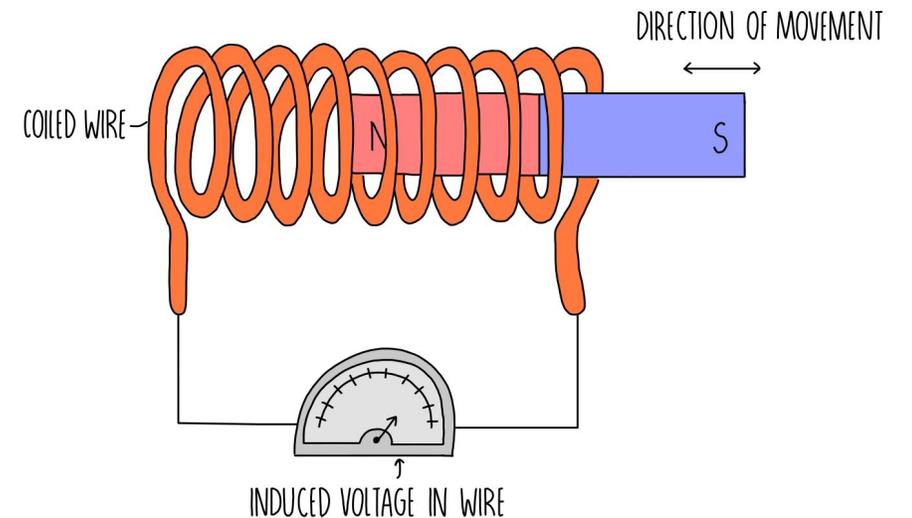
Statically Induced EMF

- Statically induced EMF follows faraday's law as well as Lenz's law which combine into:

$$\mathcal{E} = -N \frac{\Delta\Phi_B}{\Delta t}$$

Where:

- \mathcal{E} = induced voltage (emf)
- Φ_B = magnetic flux
- t = time
- N = number of loops
- - = Lenz's component



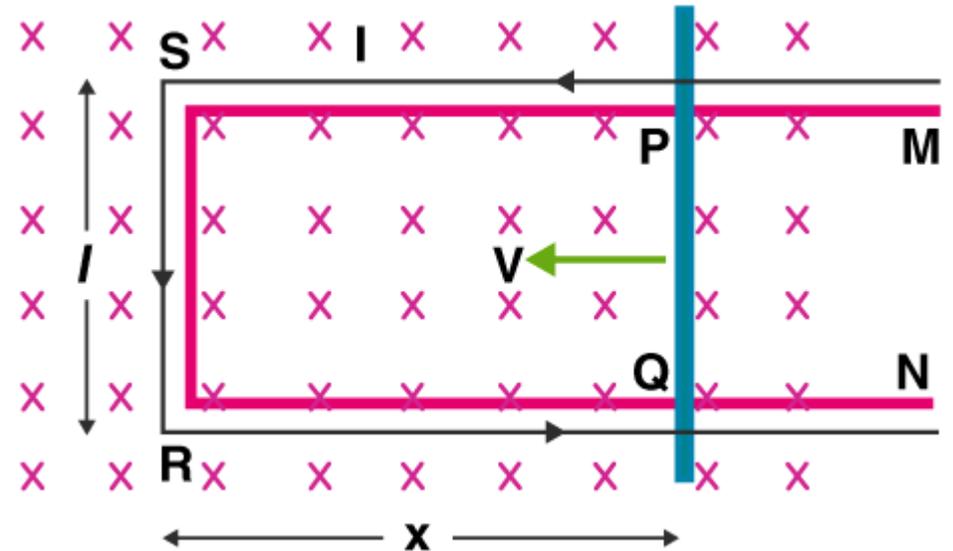
Motivational Induced EMF

- Motivational Induced EMF also follows faraday's law having the equation:

$$\mathcal{E} = Blv$$

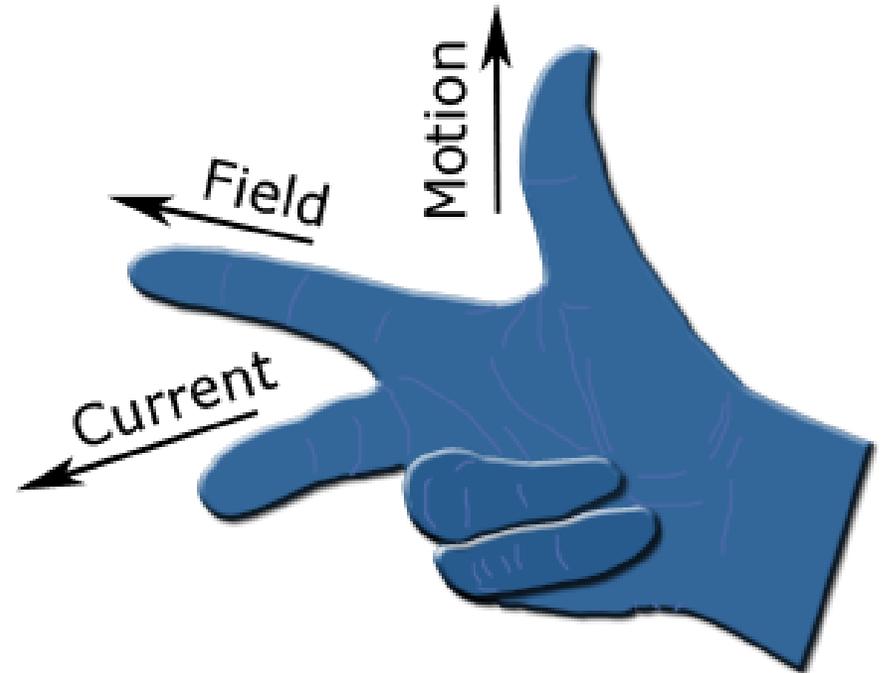
Where:

- \mathcal{E} = induced voltage (emf)
- B = Magnetic field
- l = Length of conductor
- v = velocity of the conductor



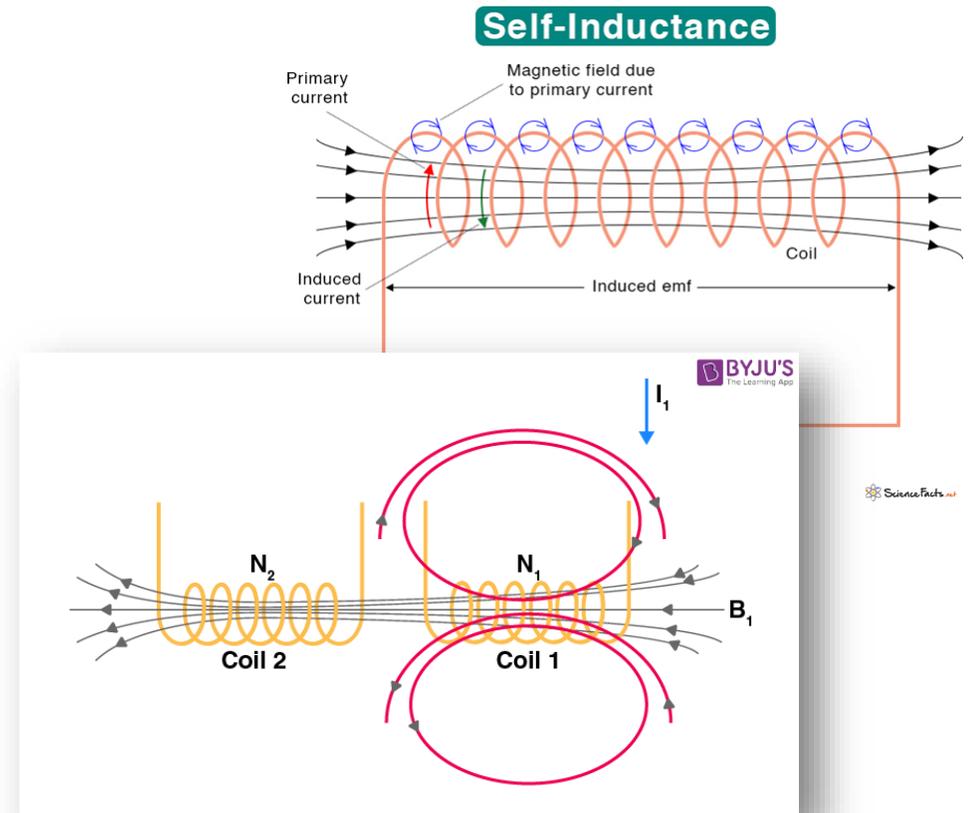
Motivational Induced EMF

- For motivational induced current we know the direction of the current based on the right-hand rule
- You line up your fingers with the following:
 - Thumb = Thrust (velocity/motion)
 - First finger = Magnetic Field
 - Second finger = Current



Other laws around EMF

- Self-Induced EMF (Back EMF):
 - Occurs when a coil opposes the change in current flowing through it.
- Mutually Induced EMF:
 - Induced in a secondary coil due to the changing current in a nearby primary coil.

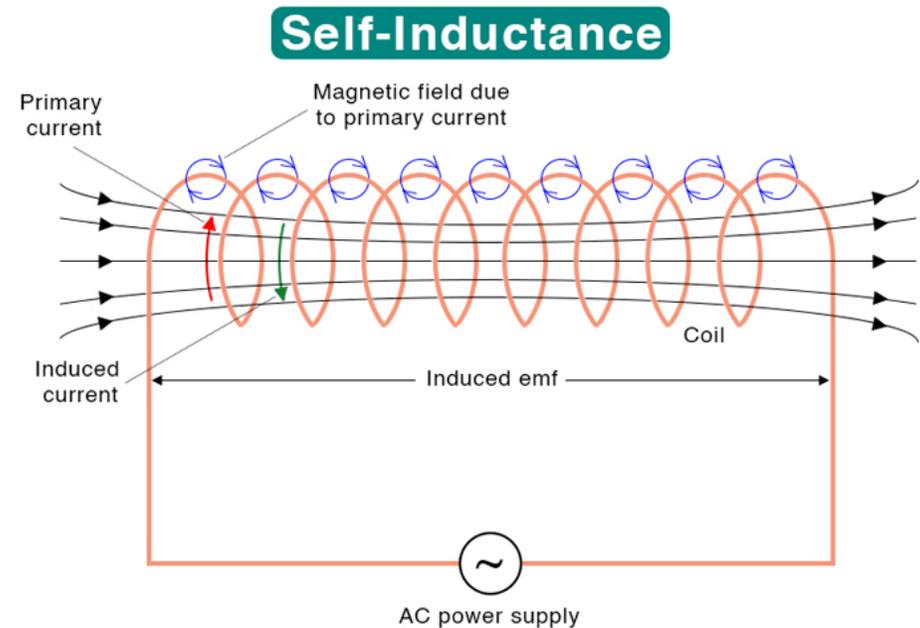


Self Induced EMF

- Occurs when the change in current in a coil induces a voltage (EMF) in the same coil
- Follows the equation

- $\mathcal{E}_{self} = -L \frac{\Delta I}{\Delta t}$

- Where:
 - \mathcal{E}_{self} = induced voltage (emf)
 - L = inductance of the coil
 - ΔI = change in current
 - Δt = change in time
 - - = Lenz's component



Mutually Induced EMF

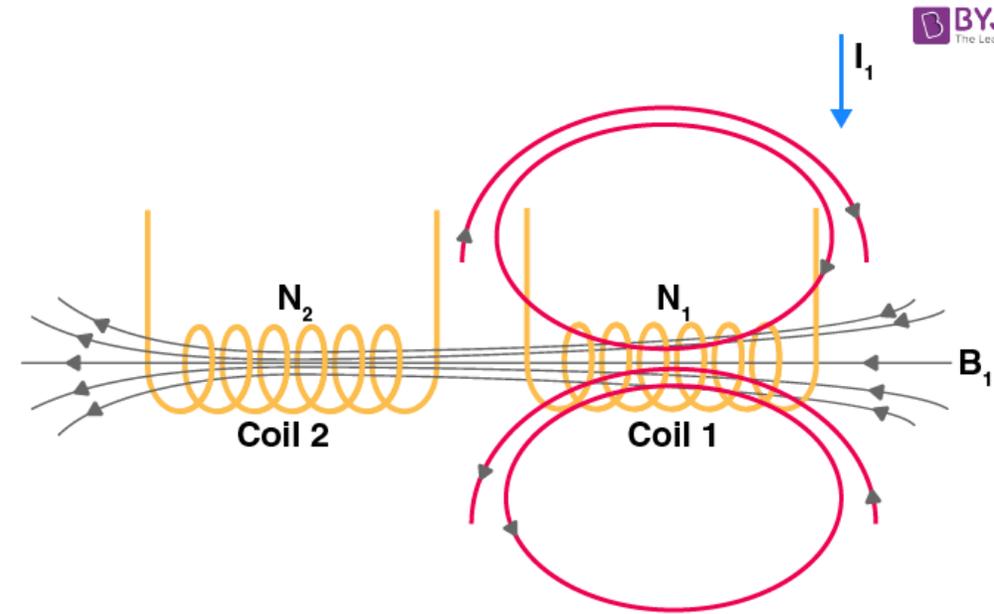
- Mutually induced EMF occurs when a changing current in one coil induces a voltage (EMF) in a nearby coil.

- It has the equation:

$$\mathcal{E}_{mutual} = -M \frac{\Delta I}{\Delta t}$$

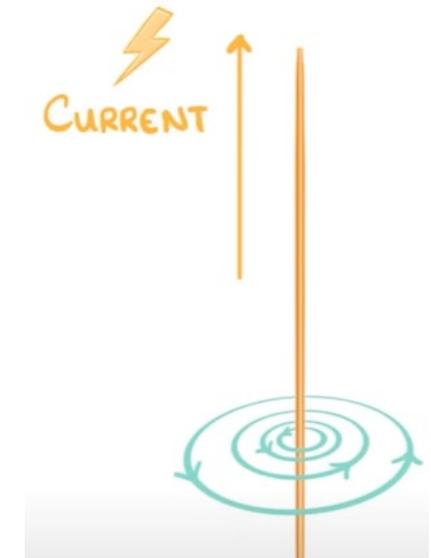
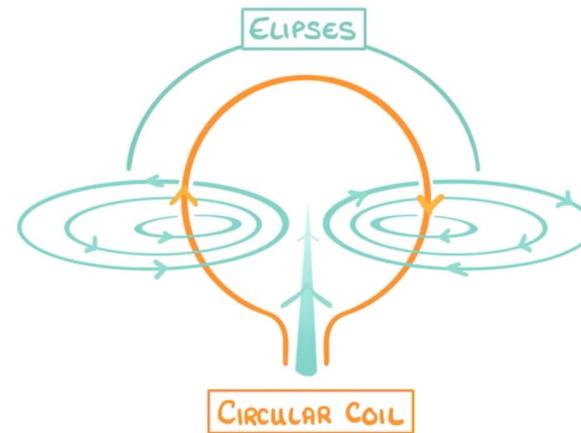
- Where:

- \mathcal{E}_{mutual} = induced voltage (emf)
- M = mutual inductance of the two coils
- ΔI = change in current
- Δt = change in time
- - = Lenz's component



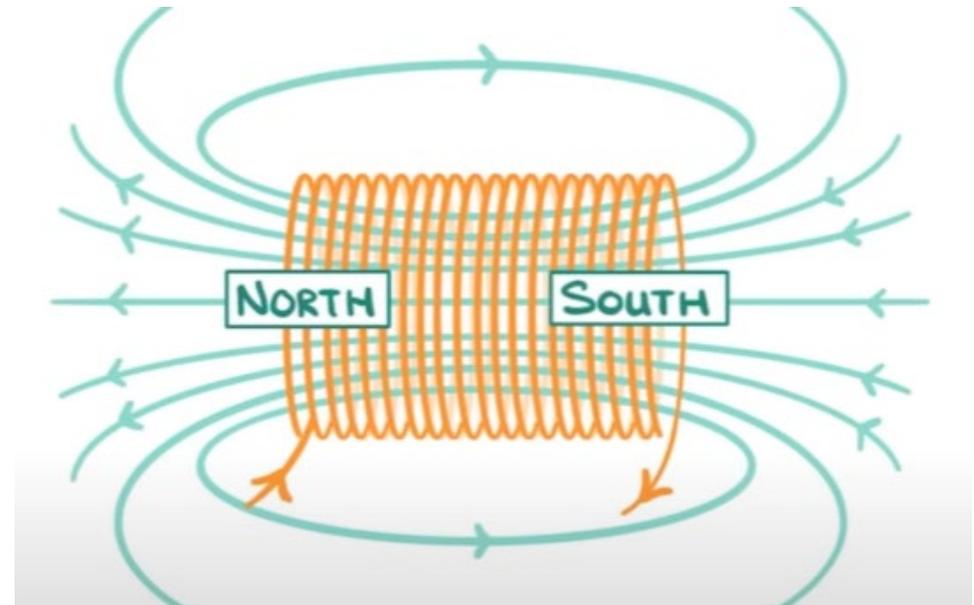
Electromagnets

- We know that current going through a wire makes a magnetic field
- However, if we make the wire into a loop it interacts with itself forming a different electric field



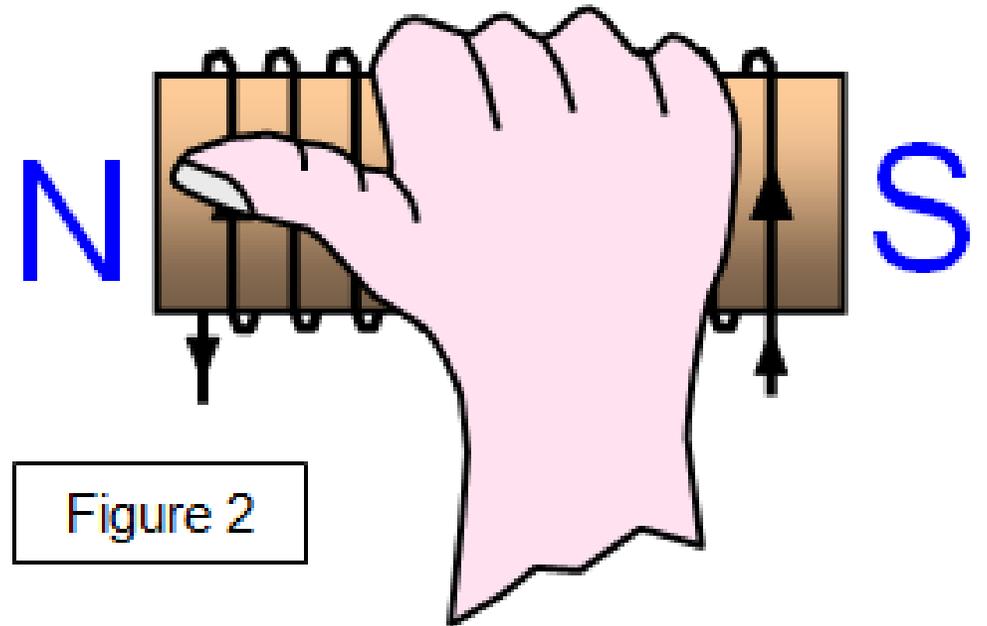
Electromagnets

- We can combine multiple loops to make a solenoid (electromagnet)
- The field inside of the solenoid is strong and uniform
- The field outside the solenoid is like that of a bar magnet



Electromagnets

- We can find out what direction the field is flowing using the right-hand curl rule
- The thumb will point towards the north pole, or the direction the field flows through the solenoid



Ampere + Maxwell's Law

- The strength of the magnetic field can be worked out using the ampere-maxwell equation:

$$\int_c B * \Delta l = \mu_0 \left(I_{enc} * + \epsilon_0 \frac{\Delta \Phi_E}{\Delta t} \right)$$

- Where:
 - B = the magnetic field
 - Δl = the infinitesimal vector along the closed loop c
 - I_{enc} is the enclosed current within the loop
 - $\frac{\Delta \Phi_E}{\Delta t}$ is the rate of change of electric flux through the loop
 - μ_0 is the permeability of free space ($1.25663706 * 10^{-6}$)
 - ϵ_0 is the permittivity of free space ($8.85418782 * 10^{-12}$)