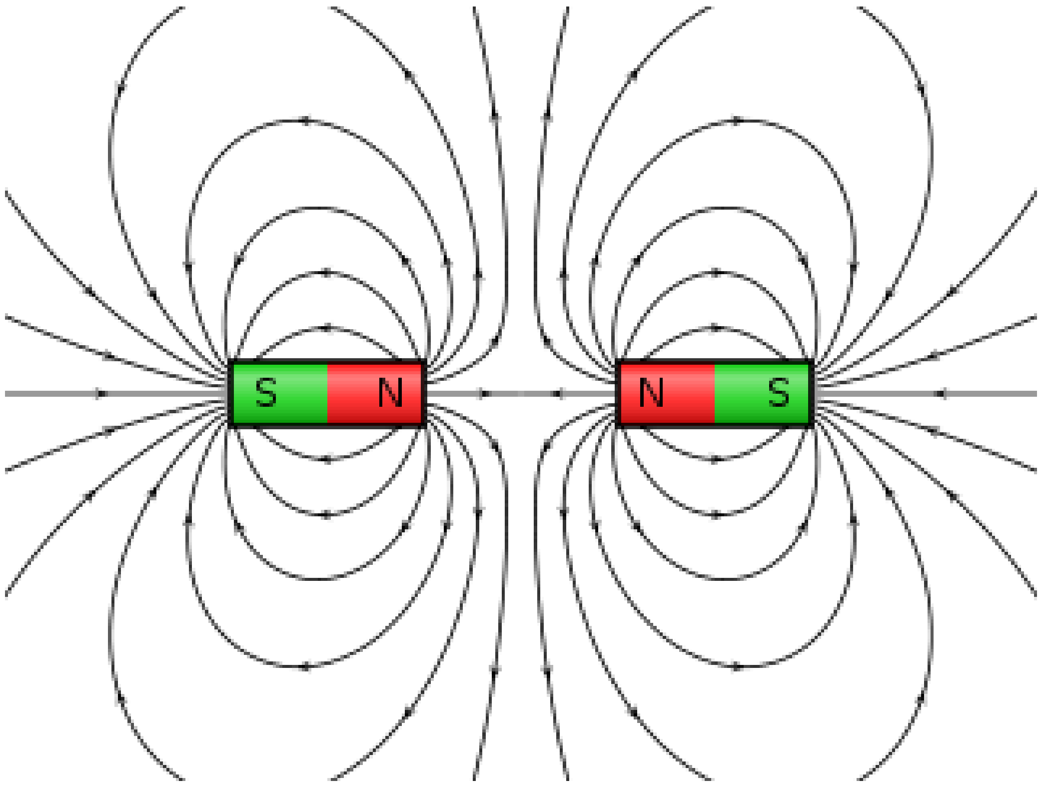
Electromagnetic Effect

YORK COLLEGE & UNIVERSITY CENTRE

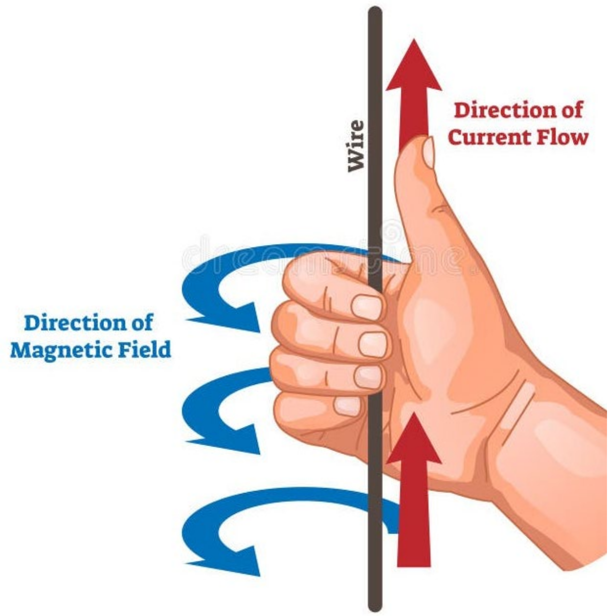
Refresher on magnetic fields

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



Refresher on magnetic fields

- A wire carrying current will generate a magnetic field, this is **electromagnetism**
- A wire moving through a magnetic field will have a current generated in it, this is **electromagnetic induction**
- The field generated from a flow of current will follow the right-hand curl rule



The Electromagnetic effect

- The electromagnetic effect is the term that encompasses all interactions between magnets and electronics

- It's split into two main fields:

1) Electromagnetism (electricity -> magnetic flux)
2) Electromagnetic induction (magnetic flux -> electricity)

- It follows 3 main rules:

1) **Faraday's Law of Electromagnetic Induction** (electromagnetic induction)
2) **Lenz's Law** (electromagnetic induction)
3) **Ampere-Maxwell Law** (electromagnetism)

The 3 laws

- **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 magnet moves through it, these will typically be in a loop setup

  - Motivational Induced EMF where the conductor moves through the magnetic field.

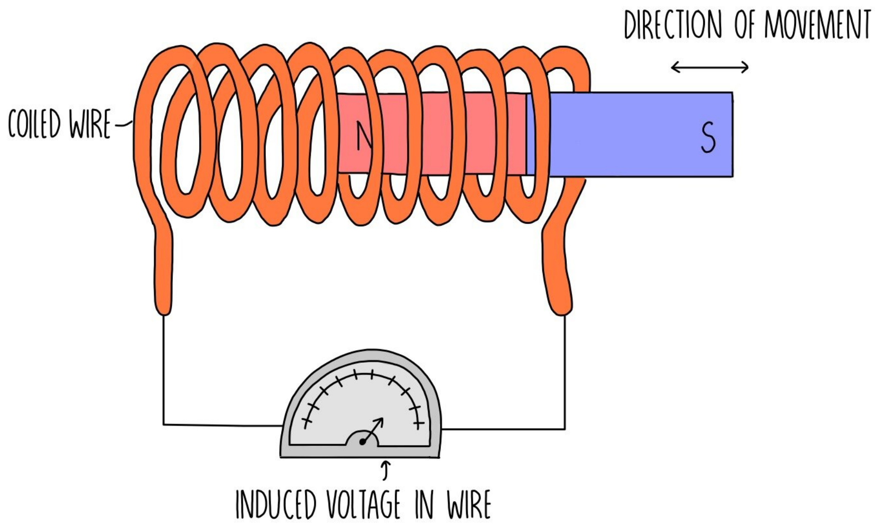
Statically Induced EMF

- 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:

- ε = induced voltage (emf)
- Φ_B = magnetic flux
- t = time
- N= number of loops
- - = Lenz’s component



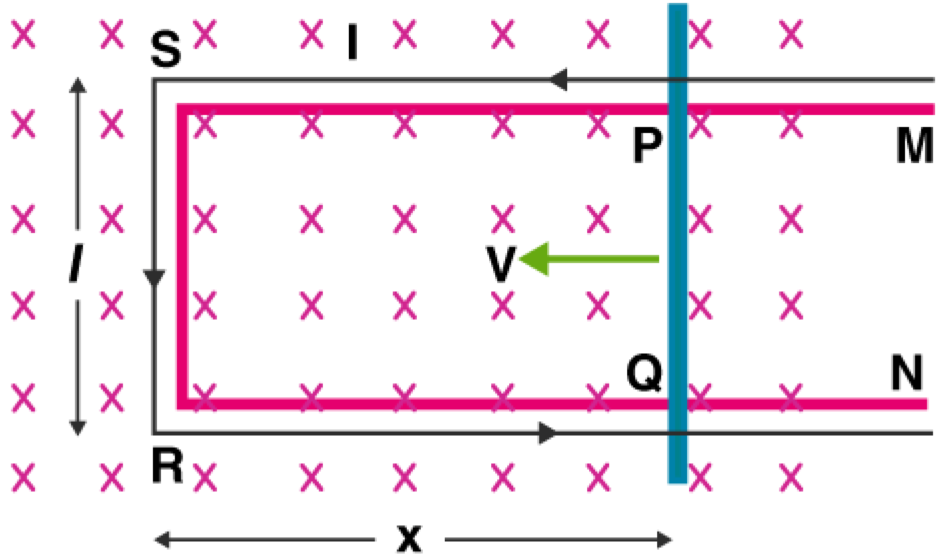
Motivational Induced EMF

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

$$\mathcal{E} = Blv$$

Where:

- ε = induced voltage (emf)
- B = Magnetic field
- l = Length of conductor
- v = velocity of the conductor

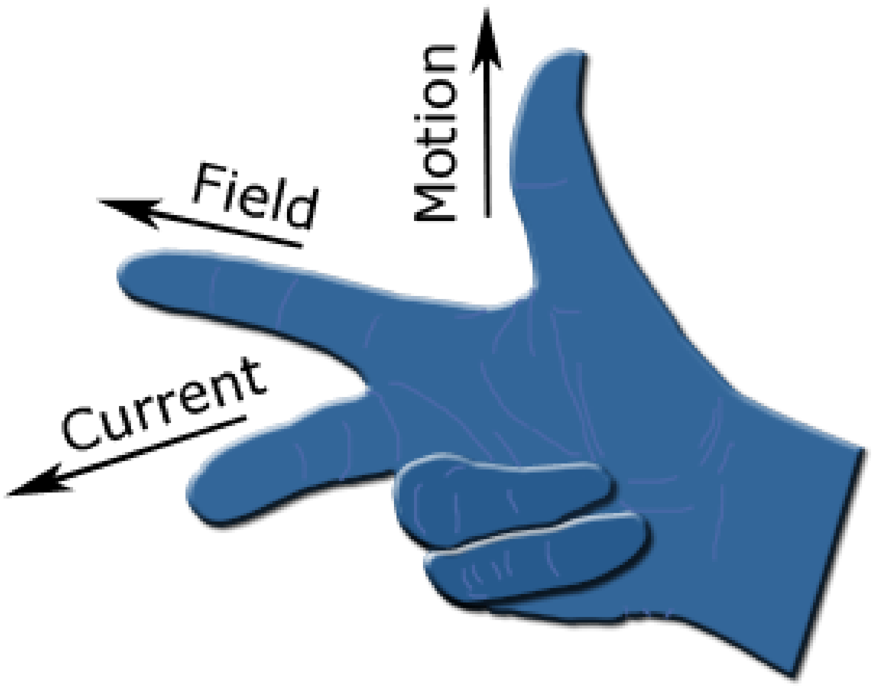


Motivational Induced EMF

- 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:

- <u>Th</u>umb = <u>Th</u>rust (velocity/motion)
- <u>Fi</u>rst finger = Magnetic <u>Fi</u>eld
- Second finger = Current



Your turn

- **Have a go at these questions deciding it they are static or motivational and then work out the answer**

1) A coil with 250 turns is placed in a magnetic field. The magnetic flux through each turn changes from 0.02 Wb to 0.005 Wb in 0.1 seconds. Find the induced EMF in the coil.

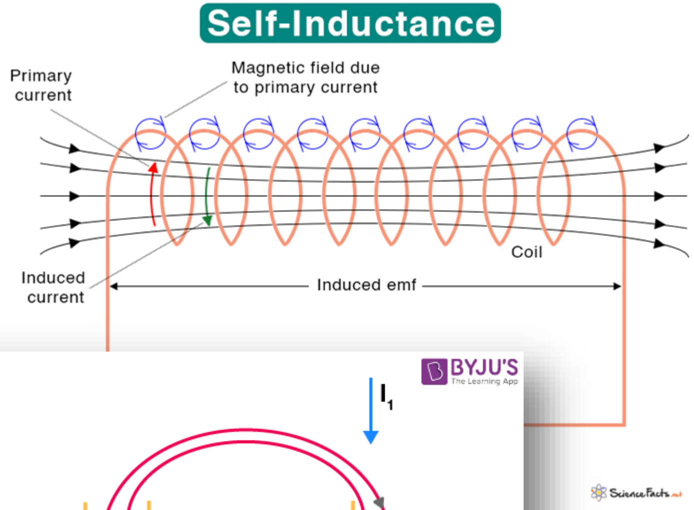
2) A 0.5 m long conductor moves at 10 m/s perpendicular to a 0.2 T magnetic field. Calculate the induced EMF across the conductor.

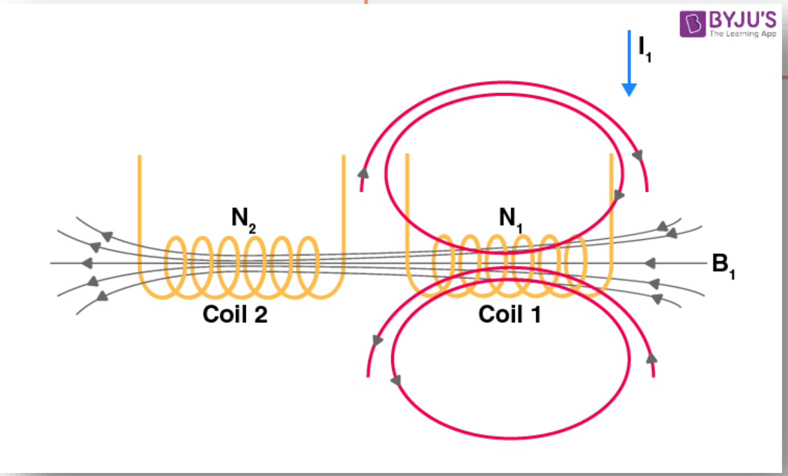
3) A coil with 400 turns experiences a change in magnetic flux from 0.03 Wb to 0.01 Wb in 0.2 seconds. Find the induced EMF in the coil.

4) A 0.6 m long conductor moves at 5 m/s perpendicular to a 0.15 T magnetic field. Determine the induced EMF across the conductor.

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.



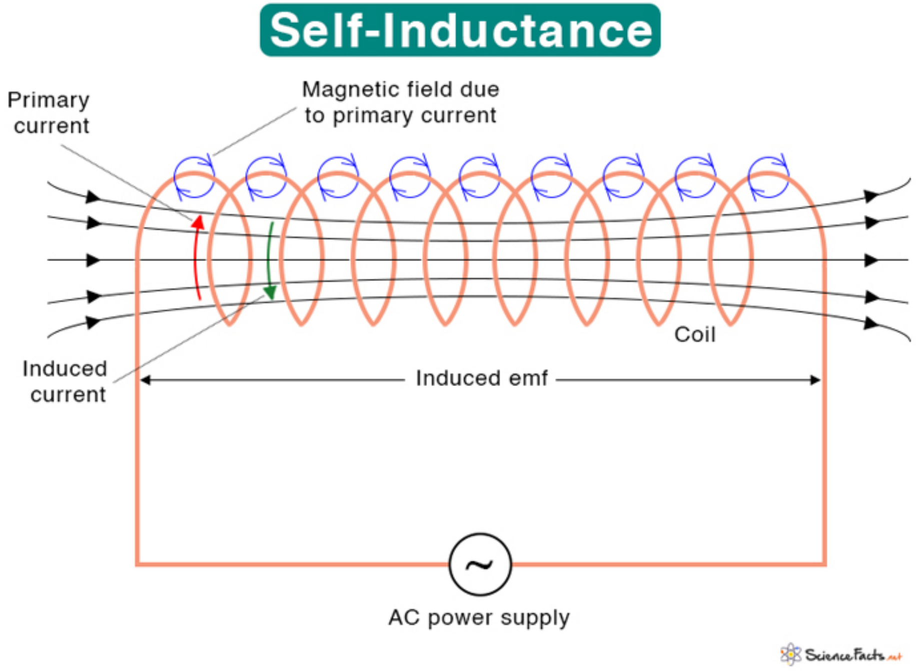


Self Induced EMF

- 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



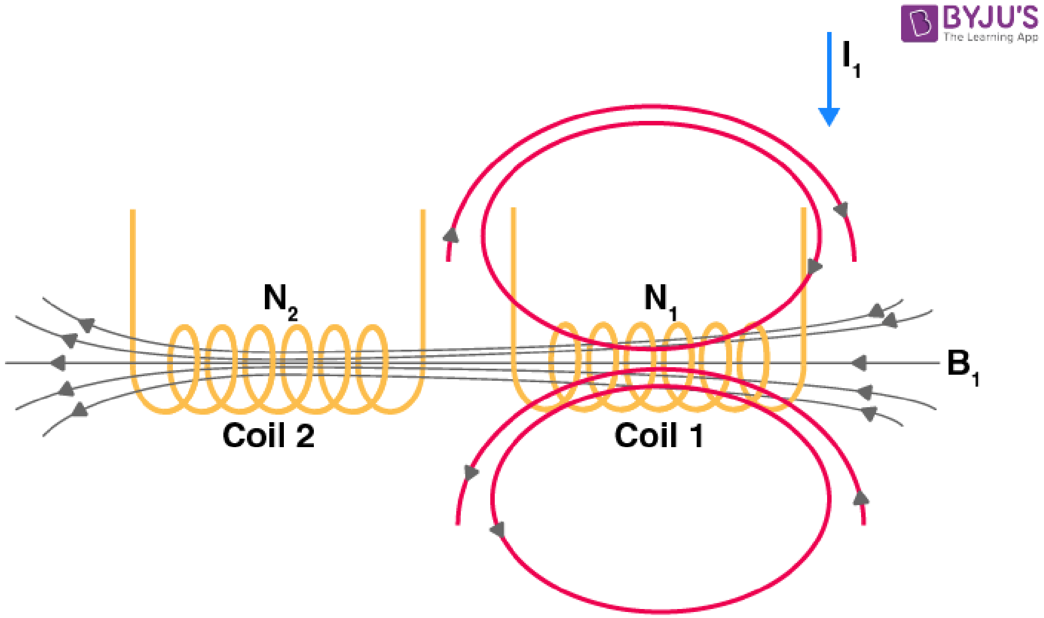
Mutually Induced EMF

- 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



Your turn

- **Have a go at these questions:**

1) A coil with an inductance of 0.3 H carries a current that changes at a rate of 5 A/s. Find the self-induced EMF in the coil.

2) Two coils have a mutual inductance of M = 2H. If the current in the first coil changes at a rate of 5A/s, what is the mutually induced EMF in the second coil.

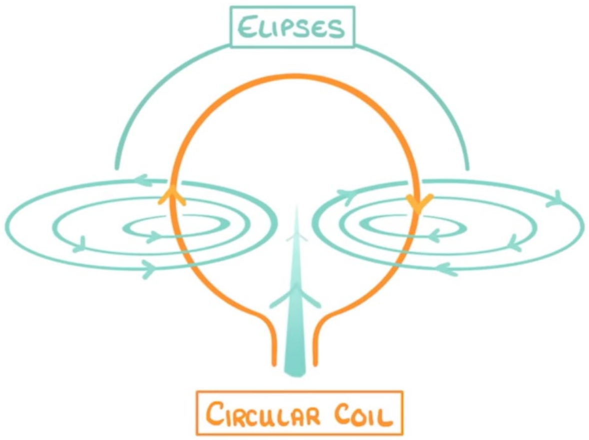
3) Two coils are placed close to each other, and the mutual inductance between them is 1.5H, if the current in the first coil is changing at a rate of 0.8A/s, calculate the induced EMF in the second coil.

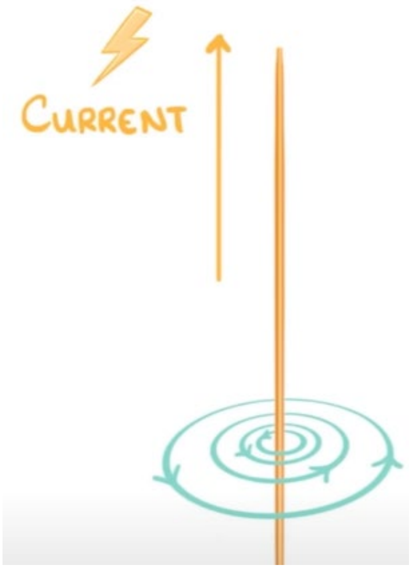
4) An inductor produces a self-induced EMF of 0.2v when the current through it changes at a rate of 4A/s. What is the inductance of the coil?

Electromagnetism

- We know that current going through a wire makes a magnetic field

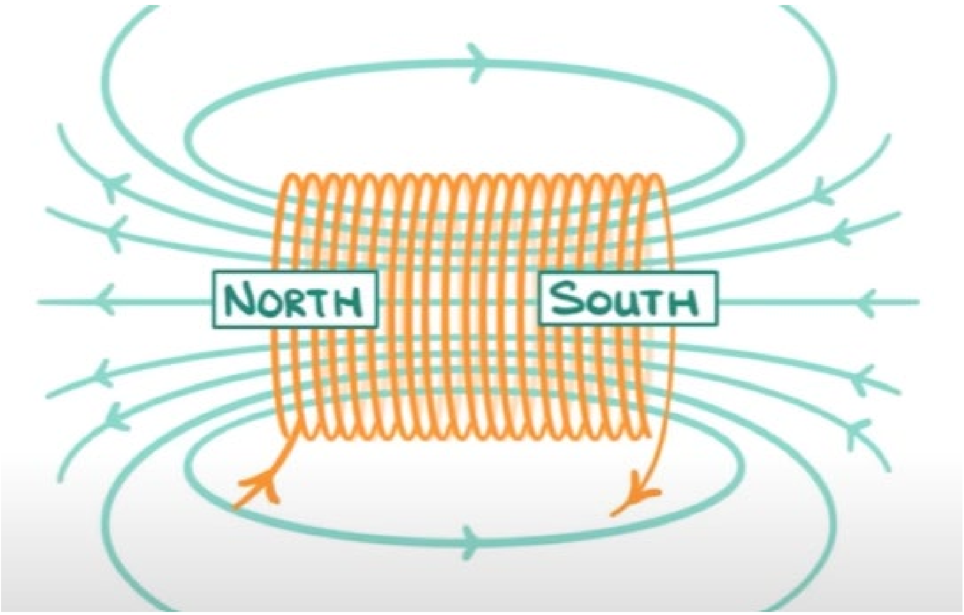
- However, if we make the wire into a loop it interacts with itself forming a different electric field





Electromagnetism

- 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



Electromagnetism

- 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

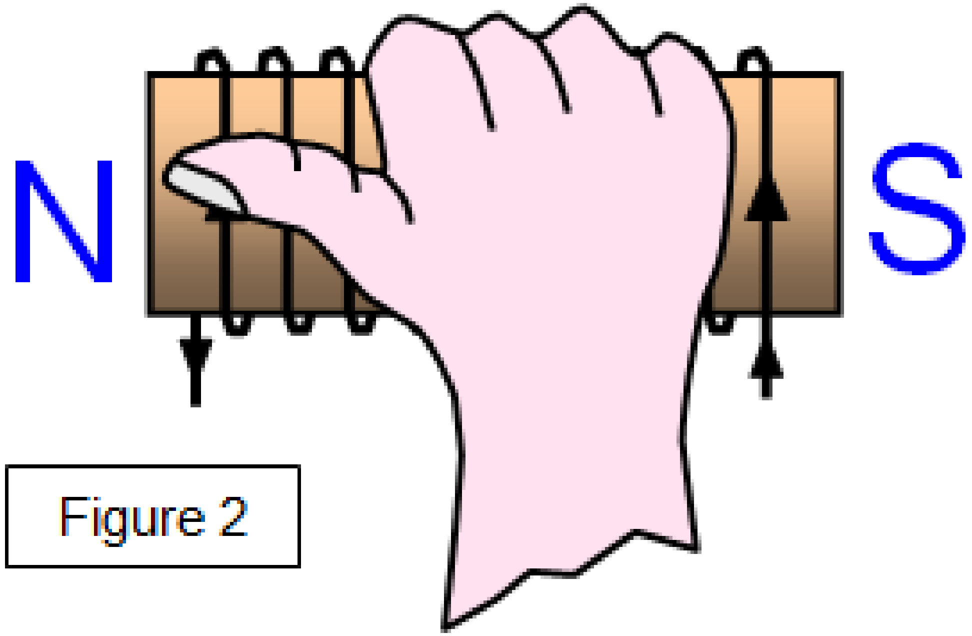


Figure 2

Ampere + Maxwell's Law

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

$$\int_c B * \Delta l = \mu_0 \left(I_{enc} * + \mathcal{E}_0 \frac{\Delta \Phi_E}{\Delta t} \right)$$

- 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 $(1.25663706 * 10^{-6})$
  - $\mathcal{E}_0$ is the permittivity of free space $(8.85418782 * 10^{-12})$