Electromagnetic induction

Stage 2 physics

NOTE

This lecture goes back over a number of the key points of Motion of a charged particle in a magnetic field, since the key concepts underpin electromagnetic induction.

An introduction

- Watch Matt Anderson's radio video

https://www.youtube.com/watch?v=KPp9qsZcZUo

A bit of history

- Michael Faraday is generally credited with the discovery of induction in 1831, and James Clerk Maxwell mathematically described it as Faraday's law of induction. Lenz's law describes the direction of the induced field. Faraday's law was later generalized to become the Maxwell–Faraday equation, one of the four Maxwell equations in his theory of electromagnetism. (Wikipedia)
- Though credited with the discovery, he used the works of Hans Christian Oersted. Faraday started using different combinations of wires and magnetic strengths and currents, but it wasn't until he tried moving the wires that he got any success.

What causes what

- A **moving** electric charge creates a magnetic field
  - Which ‘circles’ around the charge according to the right hand rule
- A **changing** magnetic field creates a force that will push charged particles
  - So, if you have a copper wire in a **changing** magnetic field, then the ‘free’ electrons will feel a force
    - Connect each end to a voltmeter and you will be able to measure a voltage (or electrical potential)
  - If the wire is in a circuit, then a current will flow

Michael Faraday

- Michael Faraday was key to our understanding of electromagnetism. Watch this;
  - How Michael Faraday Changed the World with a Magnet

    https://www.youtube.com/watch?v=32_3Um3a65s

- A further development of electromagnetism is here. This includes the equations YOU need to know

  Induction - An Introduction: Crash Course Physics

  https://www.youtube.com/watch?v=pQp6bmJPU_o

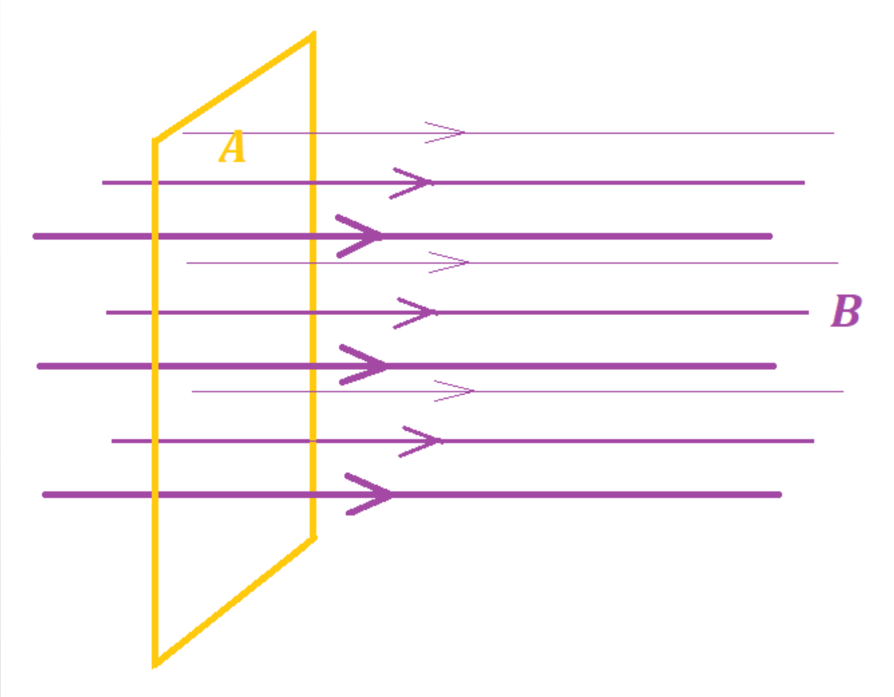
Remember the term ‘flux’

- Magnetic flux is a measure of the quantity of magnetic field in an area (2 dimensional space)
- Flux is denoted by the symbol Φ

$$\Phi = BA$$

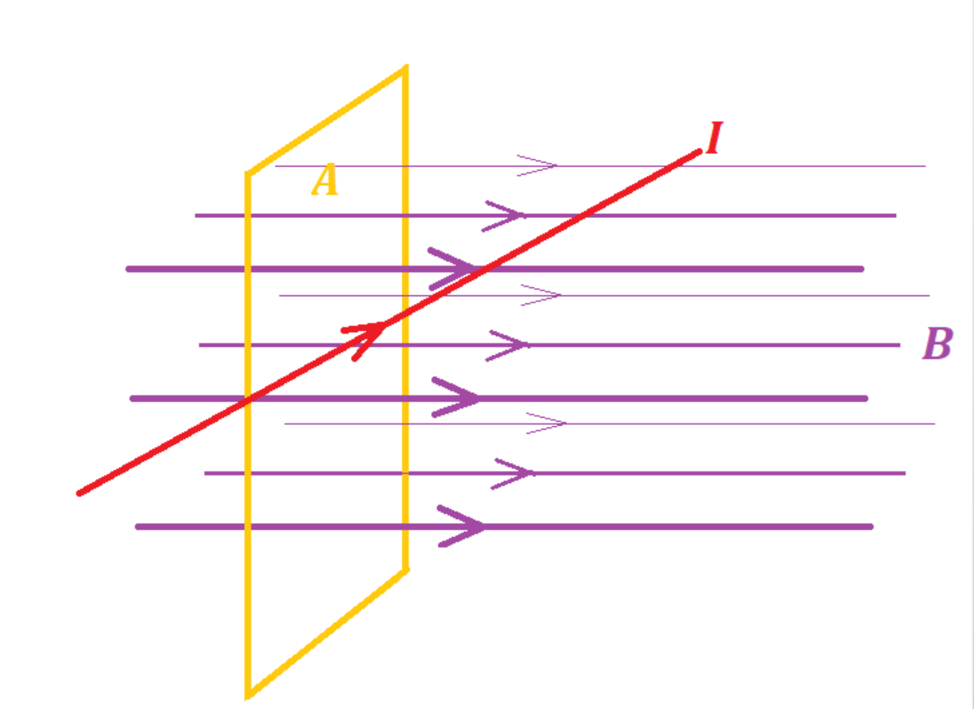
NOTE: the area is the area at 90^o to the field

$$\Phi = BA\cos\theta$$



Time to take a step back

- Remember
- A changing magnetic field will induce an electric current
- Consider a wire going through our magnetic field;
- If the flux Φ changes, a current I will be induced



This brings us to Faraday's Law

$$emf = \frac{\Delta\Phi}{\Delta t}$$

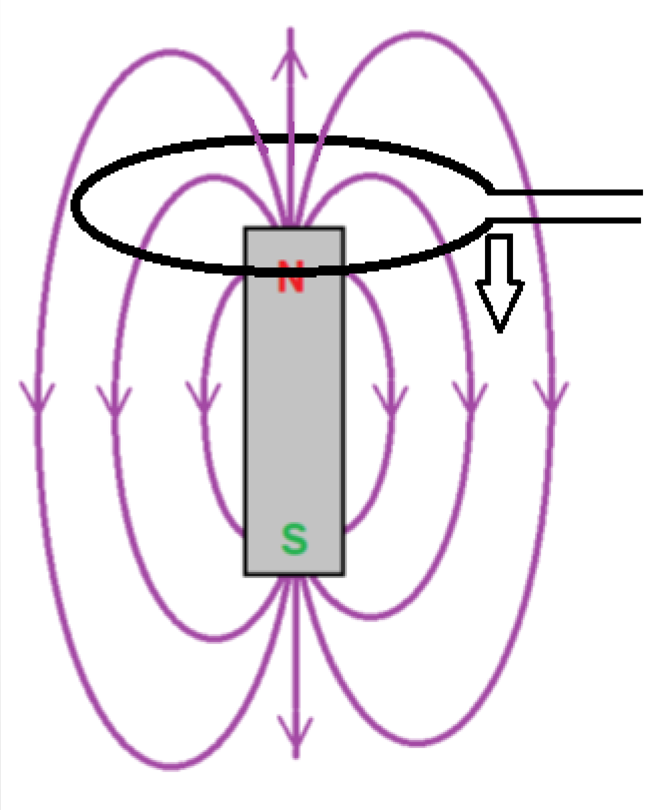
What is this emf thing?

- Electromotive Force – a force 'pushing' the electrons
- It is also known as voltage

So what the equation tells you is that a change in flux across a wire produces a voltage across that length of the wire.

An experiment

- The field around a magnet varies with position
- If we move a ring down over a magnet, it will experience a changing magnetic field
- .... therefore, the free electrons would feel a force, which we could measure as a voltage, or we could connect the wire to a circuit and measure a current



Video time

Understanding Electromagnetic induction (EMI) and electromagnetic force (EMF) - Physics

https://www.youtube.com/watch?v=tC6E9J925pY

Turning Magnetism Into Electricity – Science asylum

https://www.youtube.com/watch?v=tC6E9J925pY

Magnetic Induction – Matt Anderson (long but really good)

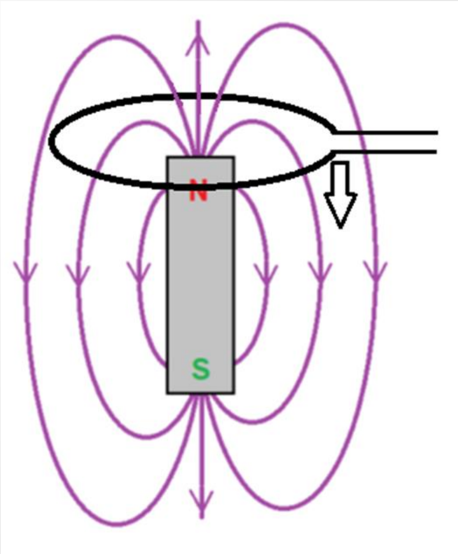
https://www.youtube.com/watch?v=mqZR3F4QA1s

Back to maths

- Remember Faraday's Law

$$emf = \frac{\Delta\Phi}{\Delta t}$$

$$emf = \frac{\Delta BA}{\Delta t} \ (since\ \Phi = BA)$$

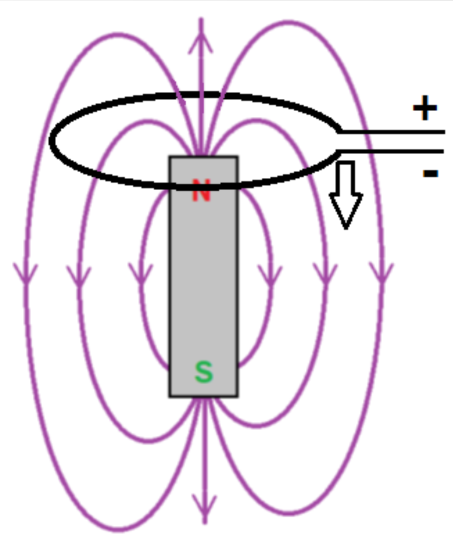


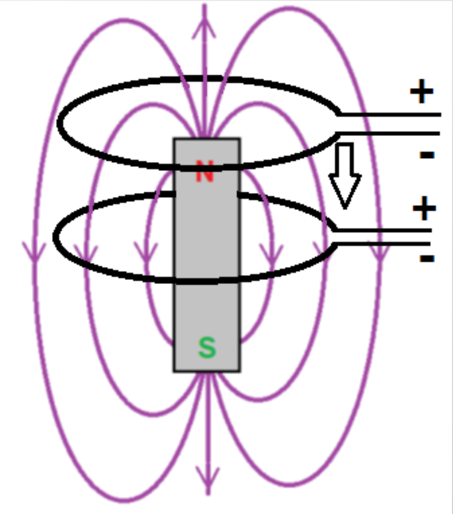
So, if we know the area of the loop A, how much the magnetic field changes ΔB, and how long it takes to move the loop Δt, we can calculate the voltage 'induced'

Consider the loop

- Whilst it is ‘producing’ an emf/voltage, it is just like a battery.
- Two loops would be like two batteries
- Four like four batteries
- So if the are connected in a coil, each new loop adds directly to the emf/voltage
- Therefore, if N is the number of loops

$$emf = \frac{N\Delta\Phi}{\Delta t}$$



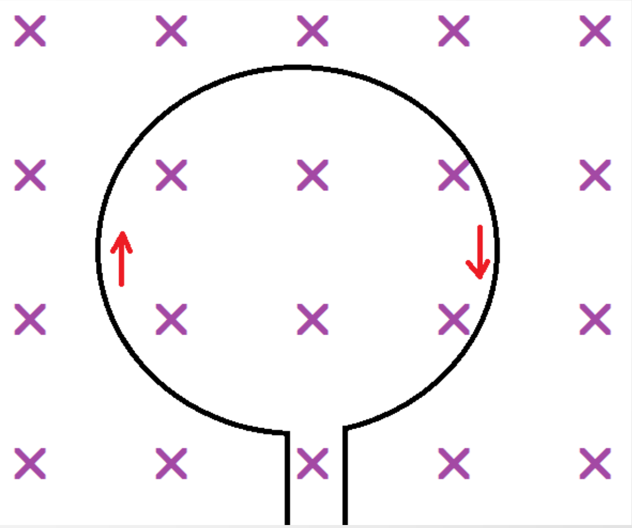


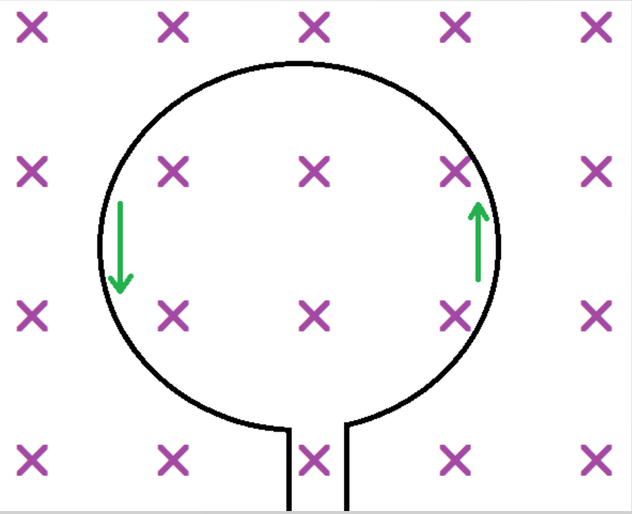
Direction of induced current

- To induce the field shown (going into the page) using a current in the wire, the current would be travelling clockwise, as shown by the arrows and as per the Right Hand Rule.

BUT

- The induced current will always be opposite that which would have produced the field in the first place





Direction of induced current

- The direction of a current induced in a wire by a changing magnetic field will always be opposite to the direction of a current that would induce the field in the first place.

- This makes perfect sense; after all if the field induced a current which then induced a field in the same direction and hence induced a further current in the same direction again increasing the field, etc, there would be a never ending spiral of increasing energy – Ah … no way.

This brings us to Eddy Currents

- If we induce a current, it produces a magnetic field opposite to that which originally produced it.
- If we are using a wire, we don’t get an opposing current, because there is no where for that current to run.
- However, if we have a flat metal sheet in a changing magnetic field, it will form a flow of charge in the opposite direction of the main charge. This is called an eddy current.

Eddy current videos

eddy currents and electromagnetic braking explained – physics highschool

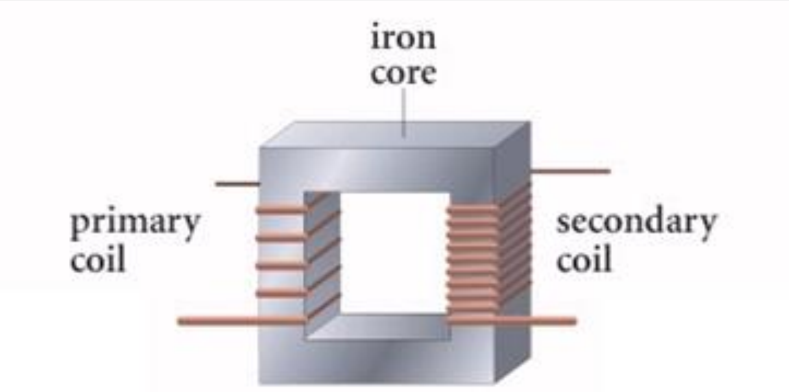
https://www.youtube.com/watch?v=BIsKthqeKSo

back emf and eddy currents – UNSW

https://www.youtube.com/watch?v=Q_4R4d1rnzE

Transformers

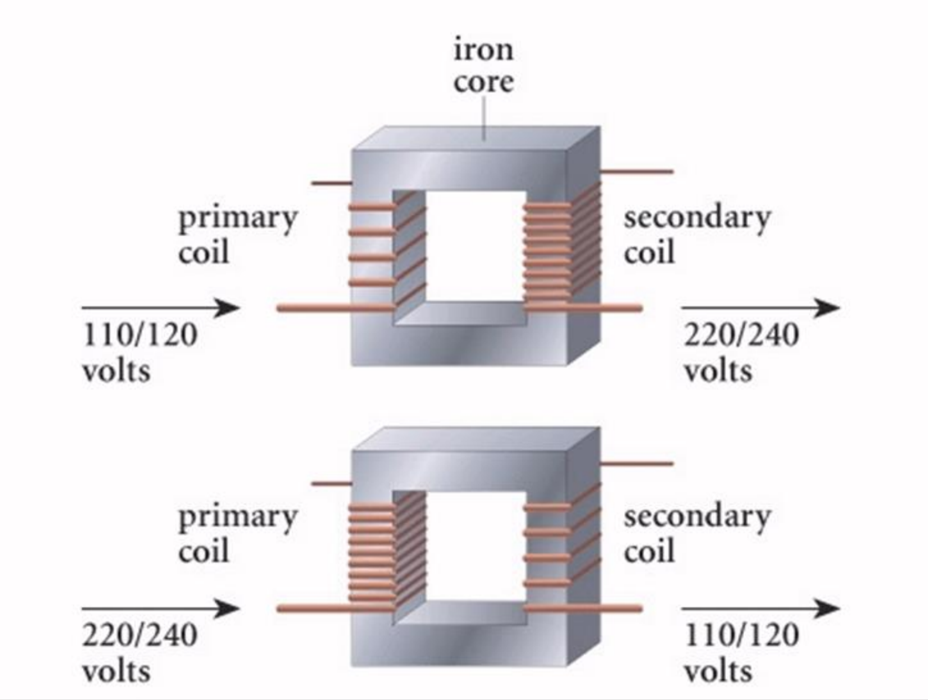
- Transformers increase or decrease voltage using electromagnetic induction.
- AC current in a wire that is wrapped in a coil around one side of the transformer core induces a changing magnetic field in the core.
- This changing magnetic field then induces an emf in the coils of a ‘secondary’ coil.



Transformers … continued

- If the secondary coil has **more** turns than the primary you can step up the voltage. This a **step up** transformer.

- If the secondary coil has **less** loops than the primary coil then this is a **step down** transformer.



Some maths

The relationship between input (primary voltage and number of loops) and output (secondary voltage and loops) is quite simple.

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$

Note; energy must be conserved

- Energy is equivalent to Power
- Power, $P = VI$
- So if V is increased, I must be decreased

$$V_p I_p = V_s I_s$$

So, an increase in voltage goes hand in hand with a decrease in current and vice versa.