Magnetic Fields Basics

6th Feb

Magnetic field: a region in space where a magnet or magnetic material experiences a non-contact force

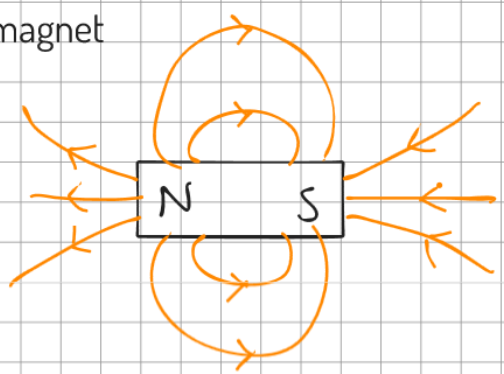
Four examples of magnetic materials: iron, steel, cobalt, nickel

The force between two PERMANENT MAGNETS (a material that is 'magnetically hard' and holds its field for a long time) can be both ATTRACTIVE (unlike poles) and REPULSIVE (like poles).

The force between an INDUCED MAGNET (a magnetic material that has become temporarily magnetic) and permanent magnet is ALWAYS ATTRACTIVE.

Common fields

Bar magnet

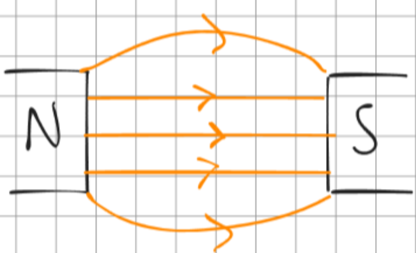


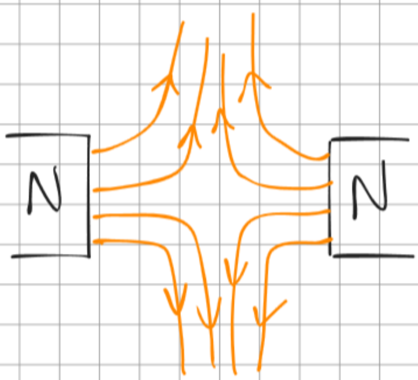
Shape: shown with continuous field lines

Strength: shown by field line density

Direction: arrows show the direction of the force a NORTH POLE would experience in that position in the field

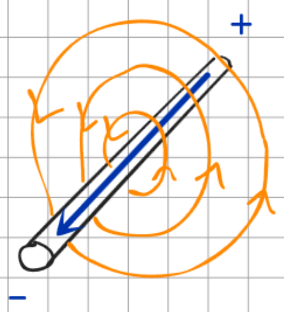
Magnetic fields are vectors so they follow the usual rules of vector addition.





Electromagnets

The flow of charge creates observable and measurable magnetic fields.



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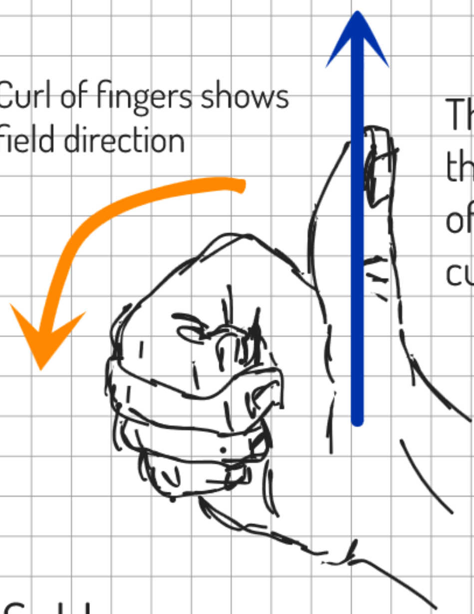
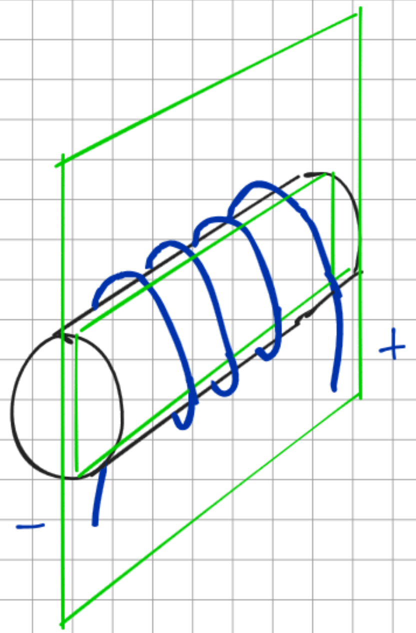
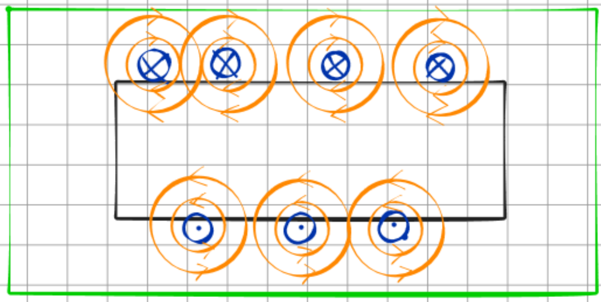
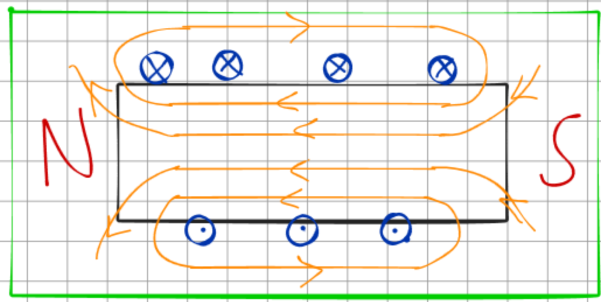
The field lines around a straight wire are circular. We can use the RIGHT HAND THUMB RULE to determine their direction.



We can increase the strength of the field by increasing the size of the current. We can also create a stronger field by wrapping the wire into a coil called a SOLENOID.

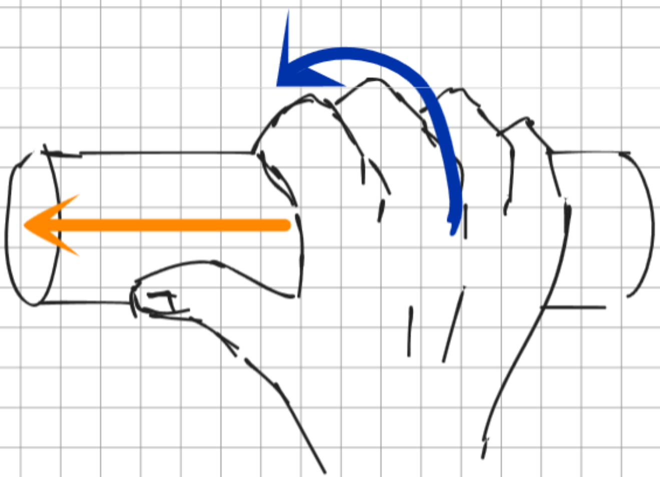






The resultant field is much stronger than the individual fields around each loop (or turn) of the wire.

The resultant field is STRONG and UNIFORM inside the solenoid. We can predict the direction of the field inside the solenoid (and hence assign a pole label to each end) by using the RIGHT HAND GRIP RULE.



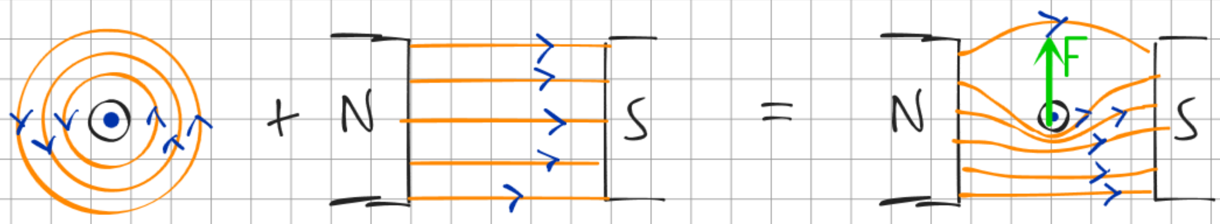
The curl of the fingers represents the direction of the current around the solenoid.

The thumb shows the field direction THROUGH the solenoid.

If the wire is wrapped around a core of magnetic material, then core becomes magnetised. The field of the core combines with the field of the solenoid and makes the resultant field even stronger.

The Motor Effect

13th Feb



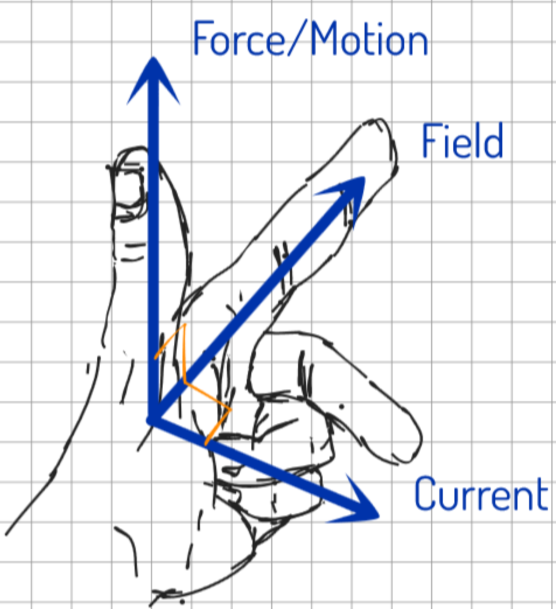
Passing a current through a wire creates a magnetic field around the wire.

If this wire is then placed in another magnetic field, the two fields interact and combine.

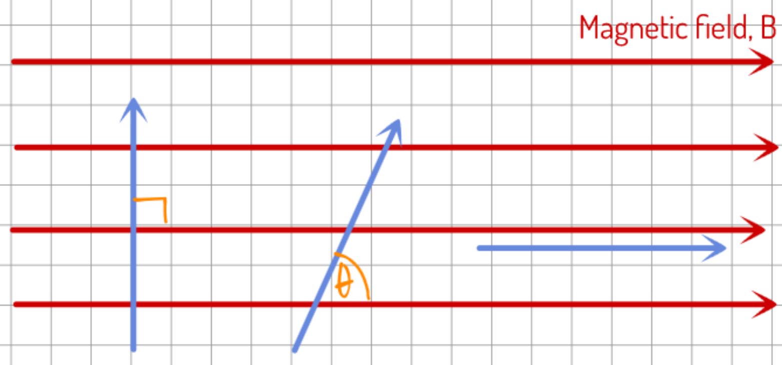
The wire then experiences a FORCE, which acts to move it from where the field is stronger to where it is weaker.

The magnets experience a force of the SAME MAGNITUDE but in the OPPOSITE DIRECTION according to N3L.

We can determine the direction of the force on the wire using FLEMING'S LEFT HAND RULE.



- Point index finger in the direction of the external magnetic field (north to south).
- Rotate hand until the middle finger points in the direction of current (or motion of positive charge)
- Thumb then points in the direction of the force on the conductor



The force experienced by the wire is at a MAXIMUM when the current flows perpendicularly to the magnetic field.

The conductor experiences NO force when the current flows parallel to the magnetic field.

The magnitude of the force can be found using:

$$F = BIL \sin\theta$$

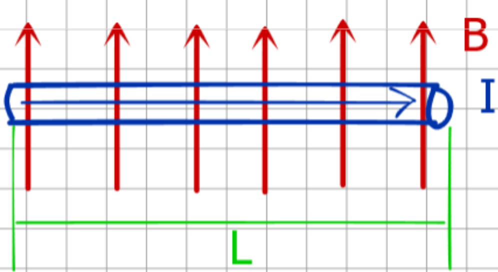
Where B is the magnetic flux density and has the unit of tesla, T.

$$B = \frac{F}{IL}$$

1 T is the flux density that produces a force of 1 N on 1 m of wire carrying a current of 1 A perpendicularly to the field.

Force on a Charged Particle

25th Feb



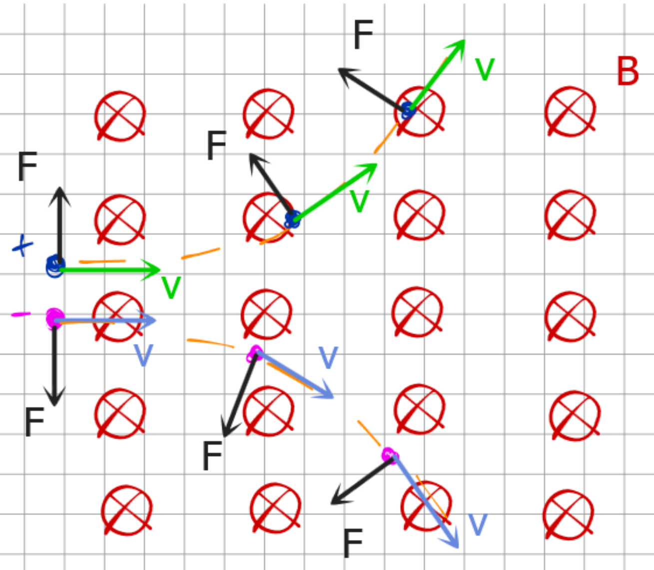
$$\boxed{F = BIL}$$ Wire

Where $I = Q/t$

$$F = \frac{BQL}{t}$$

Where $v = \frac{L}{t}$ hence $\boxed{F = BQv}$ Moving charge

When considering electrons or protons we often use: $F = Bev$



Both particles experience a force which is perpendicular to their velocity.

There is no component of this force acting in the same direction as the velocity.

The result is CIRCULAR MOTION.

The force acts as a CENTRIPETAL FORCE in this circular motion. The particles experience forces in OPPOSITE DIRECTIONS as they have OPPOSITE POLARITY.

Note: we can use FLHR to find the direction of the force on a POSITIVE CHARGE. When dealing with negatively charged particles we either use our RIGHT HAND or use the left but pointing the current finger in the opposite direction to the motion of the particle.

Centripetal force = BQv

$$\frac{mv^2}{r} = BQv$$

$$\boxed{r = \frac{mv}{BQ}}$$

We know that $v = \frac{2\pi r}{T}$ hence $r = \frac{2\pi r m}{BQT}$

$$\boxed{T = \frac{2\pi m}{BQ}}$$

Note: deriving these is a very common question

Cyclotrons

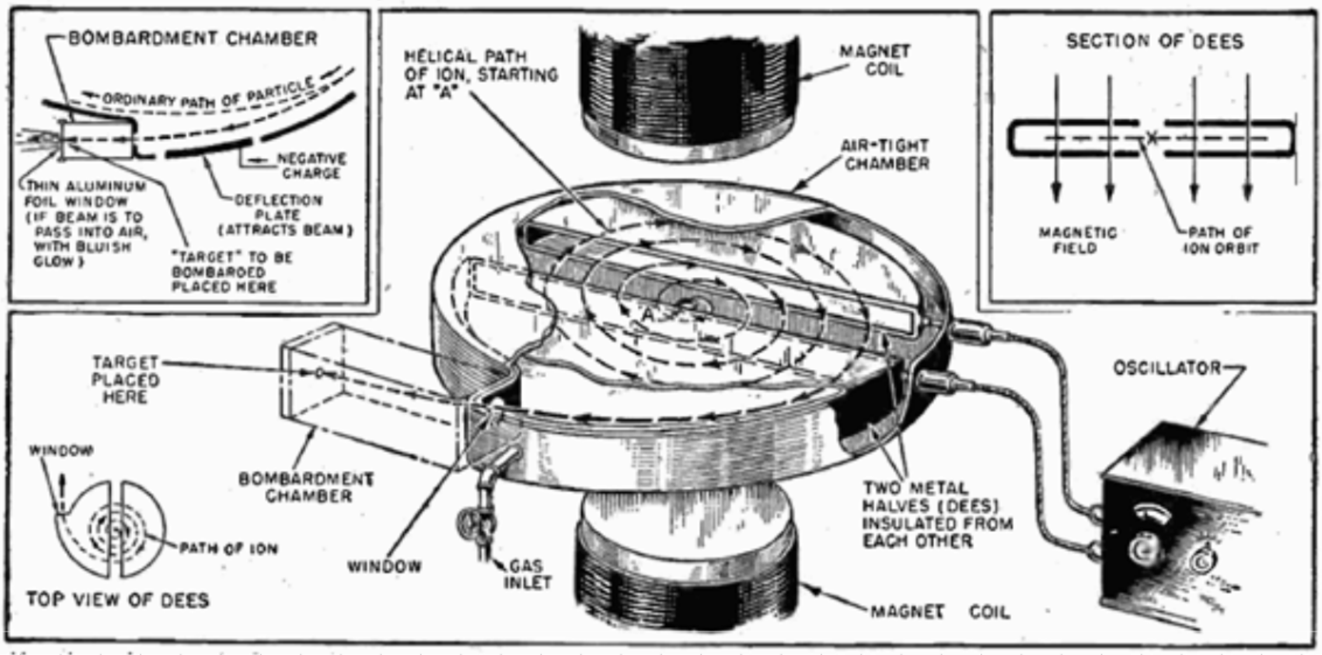
27th Feb

Cyclotrons use ELECTRIC FIELDS to DO WORK on charged particles and INCREASE THEIR KINETIC ENERGY.

$$W = Q\Delta V = \Delta E_k$$

work done by a p.d.

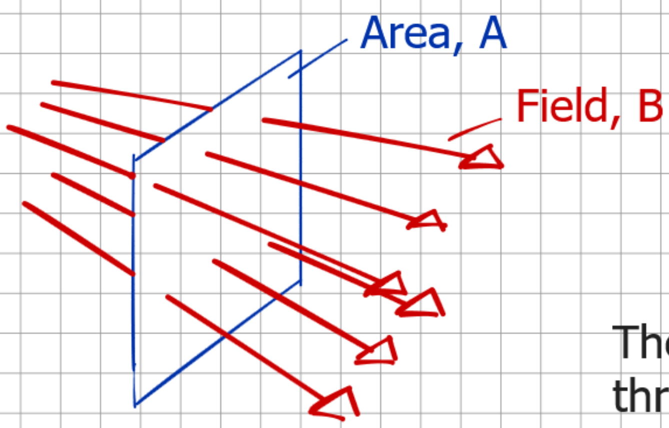
the work done by the p.d. tells us the change in kinetic energy of the particle



- Charged particle injected into the centre of the electrodes
- p.d between electrodes creates an electric field that accelerates the particle
- magnetic field through the electrodes (perp. to motion & E field) causes the particles to follow a curved path
- polarity of the electrodes is reversed, once again accelerating the particle across the gap between them
- particle spirals outwards, as the radius of curvature is proportional to the particle's velocity

Flux, Flux Density and Flux Linkage

6th March



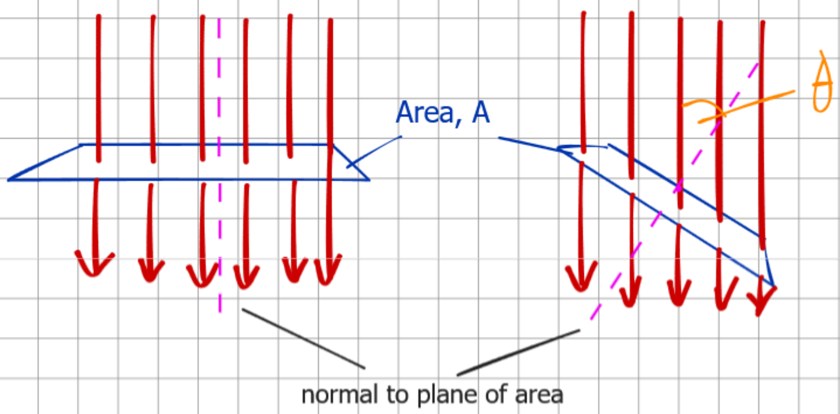
Magnetic flux is a measure of how much magnetic field passes through an area.

ϕ — in webers, Wb

The magnetic flux density is the flux through each square metre, or the flux per unit area.

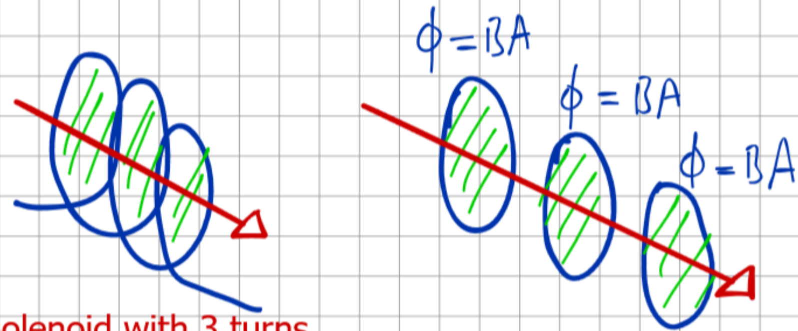
$$B = \frac{\phi}{A} \qquad \text{hence} \qquad \phi = BA$$

in weber per square metre, Wb/m^2 or Tesla, T



The angle between the normal to the plane of the area and the magnetic field can affect the flux through any area, A.

$$\phi = BA\cos\theta$$



Solenoid with 3 turns, each with area A in a field of flux density B,

Total flux linked with the solenoid:

$$BA + BA + BA = 3BA.$$

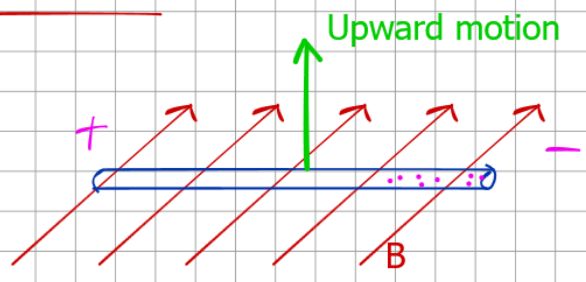
The FLUX LINKAGE of a solenoid with a field is the PRODUCT OF THE FLUX AND THE NUMBER OF TURNS.

$$\text{'}N\phi\text{'} = BAN\cos\theta$$

in weber turns or webers

Induction

11th March



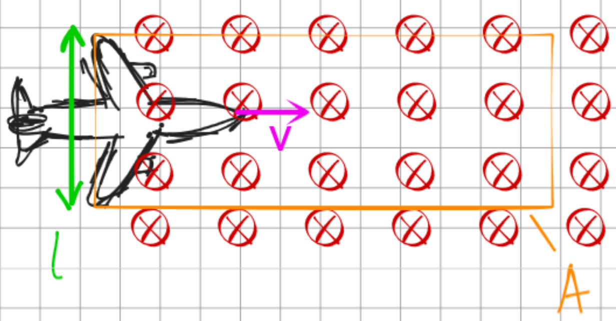
Moving this conductor through the magnetic field exerts a force on the charged particles in the conductor.

This INDUCES a potential difference between the ends of the conductor. If it was part of a complete circuit then a CURRENT would also be induced.

This potential difference can DO WORK on charged particles so is referred to as an INDUCED EMF.

So a CHANGING FLUX LINKAGE leads to an INDUCED EMF.

Examples of changing flux linkage



$$N\phi = BAN$$

This conducting rod (plane wings) sweeps out area A in time t.

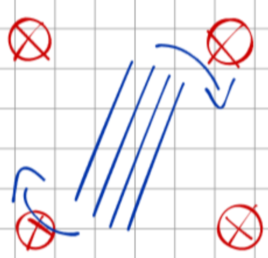
$$A = vt \times l$$

$$N = 1$$

Hence, in time t, $N\Delta\phi = Blvt$

change in flux linkage

Consider a solenoid of N turns, rotating in a field of flux density B with an angular velocity of ω;



At any instant: $N\phi = BAN\cos\theta$

And $\omega = \dfrac{\theta}{t}$ so $\theta = \omega t$

Hence; $N\Delta\phi = BAN\cos\omega t.$

Faraday's Law: the MAGNITUDE of the INDUCED EMF is DIRECTLY PROPORTIONAL to the RATE OF CHANGE of FLUX LINKAGE.

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

Applied to moving rod: $\varepsilon = \frac{Blvt}{t} = Blv$ (differential of Blvt wrt t)

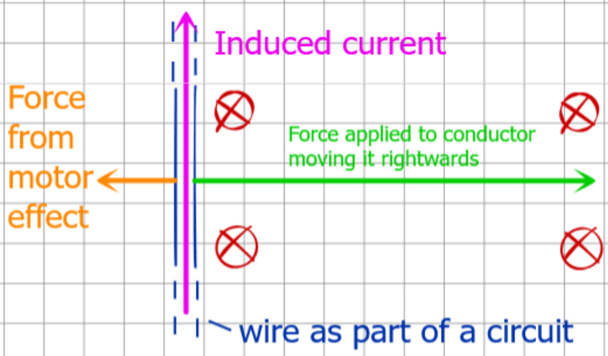
Applied to rotating solenoid: $\varepsilon = -\omega BAN \sin \omega t$

given in data sheet without '-' so we can calculate magnitude

Lenz's Law

13th March

Lenz's law states that: any induced emf is induced in such a way as to oppose the change that induces it



This wire is being moved by an external force to the right.

It is experiencing a change in flux linkage.

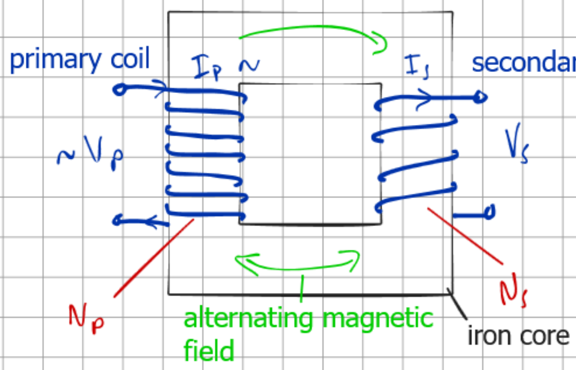
An emf is induced, equal to the rate of change of flux linkage, according to Faraday's law.

The wire is part of a circuit so a current is induced. This creates a field around the wire, which produces a force as per the motor effect.

The induced current acts upwards creating a force that OPPOSES the motion of the wire. The extra work we do against this resistive force provides the energy that creates the current.

Transformers 17th March

A STEP UP transformer INCREASES potential difference. A STEP DOWN transformer DECREASES potential difference.



- Alternating p.d. across the primary coil, produces an alternating current in primary coil.
- This creates a magnetic field through the primary coil and the iron core that changes direction continually.
- This means there is a continously changing flux linkage through the secondary coil.
- This induces an alternating potential difference across the secondary coil, (and hence an alternating current if the coil is part of a complete circuit).

Primary

$$V_p = \frac{N_p \Delta\phi}{\Delta t}$$

Secondary

$$V_s = \frac{N_s \Delta\phi}{\Delta t}$$

Both coils are in the same field changing at the same rate..

$$\frac{V_p}{N_p} = \frac{\Delta\phi}{\Delta t} = \frac{V_s}{N_s}$$

Hence

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

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

An ideal transformer is 100% efficient so:

$$P_{IN} = P_{OUT}$$

$$I_p V_p = I_s V_s$$

In reality some energy is dissipated due to heating in the wires as they have resistance, 'flux leakage' as the flux through the primary may not equal the flux in the secondary and by eddy currents in the iron.

We reduce this loss by using a 'laminated' iron core (has many layers), and by using low resistance wires.

$$\text{Efficiency} = \frac{P_{OUT}}{P_{IN}} = \frac{I_s V_s}{I_p V_p}$$

Alternating Current and p.d.

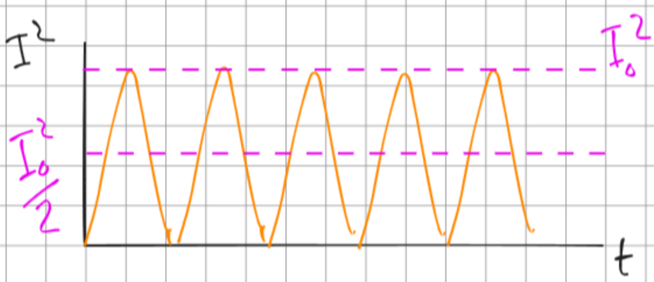
20th March

This is ac with a peak value of I_0

If we wish to use standard equations as we do with dc we need to find a value for this ac that would have the same effect/dissipate the same power in a component as an equivalent dc.

To find an appropriate value we square all of our values of current, find the mean of these squared values and then square root it.

This is then the ROOT MEAN SQUARE current.



mean of the squared values = $\frac{I_0^2}{2}$

root mean square values = $\frac{I_0}{\sqrt{2}} = I_{rms}$

For an ac with peak current I_0 the same energy would be dissipated in a resistor as a dc with value equal to I_{rms}.

$\frac{V_0}{\sqrt{2}} = V_{rms}$

Oscilloscopes

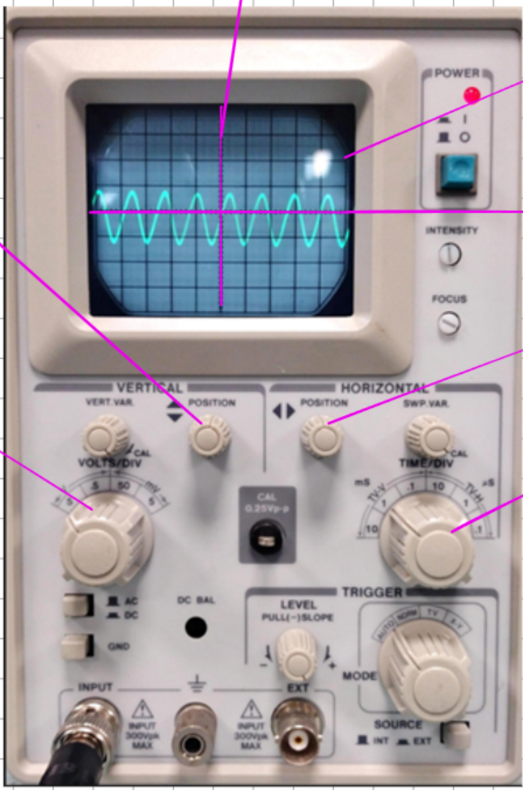
3rd April

p.d. on y-axis

y shift moves the trace vertically

1 sq is 1 div

time on the x



x shift moves the trace horizontally

y gain adjusts the scale on the y-axis (the number of volts each division represents)

x gain adjusts the scale on the x-axis (the number of seconds each division represents).