Topic 4 – Electricity and magnetism

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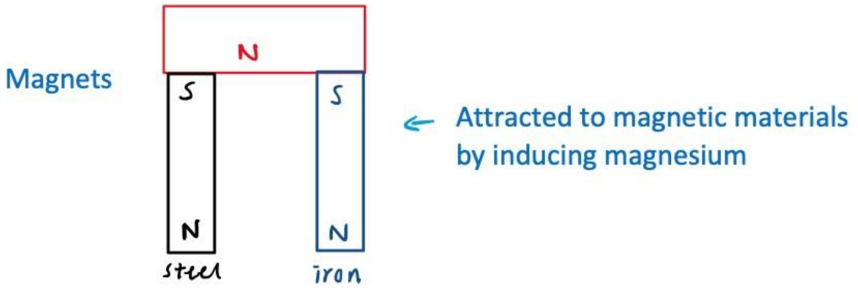
4.1 Simple phenomena of magnetism

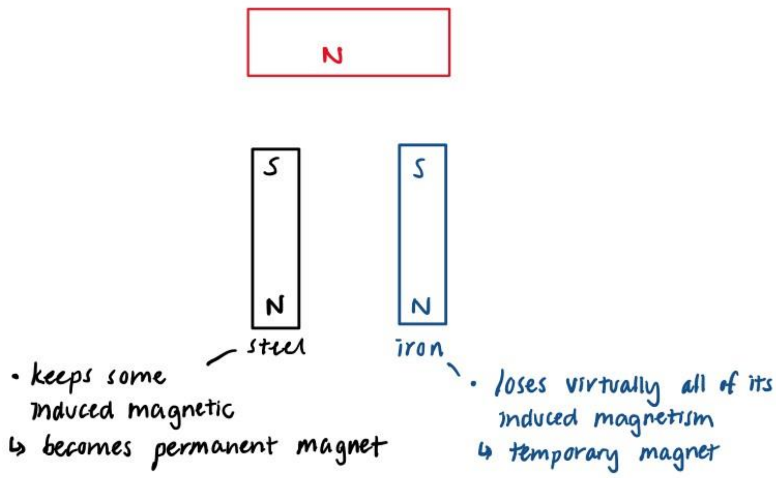
Magnets

- Magnets have a magnetic field around them
- Like poles repel, unlike poles attract – caused by interaction of magnetic fields
- Closer poles, greater force
- Attract magnetic materials by inducing (permanent or temporary) magnetism in them
- Will exert little / no force on non-magnetic material
- Direction of electric field at a point = direction of force on a +ve charge at that point

Induced magnesium

• Magnets attract materials by inducing magnetism in them - material becomes a magnet • Side of the material facing the magnet will become the opposite pole as the magnet





Magnetic and non-magnetic materials

Ferrous – magnetic materials

- Can be magnetized
- Attracted to magnets

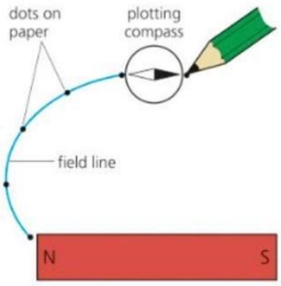
Hard	Soft
Eg steel, alloys	Eg irons
• Difficult to magnetise • X lose magnetism easily → permanent magnets	• Easy to magnetise • Lose magnetism easily → temporary magnets

	• Used in cores of electromagnets & transformers coz magnetic effect can be 'switched' on / off easily

Non-ferrous – non-magnetic materials
- X attracted to magnets
- Eg brass, copper, zine, tin, aluminium & other non-metals

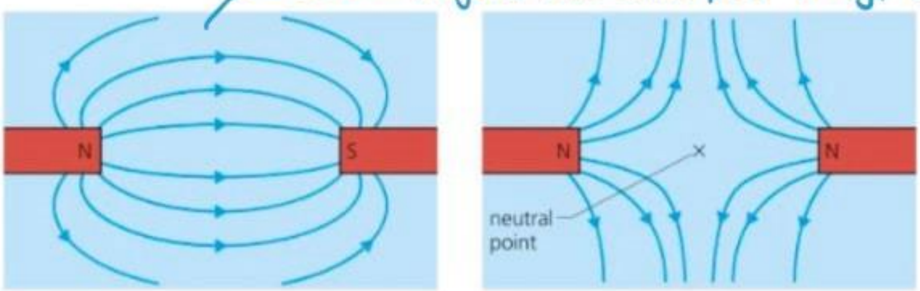
Magnetic fields

Magnetic fields patterns



1. Place compass near one end of magnet
2. Mark needle position using 2 dots
3. Line compass with previous dot.
4. Join the dots to show magnetic field.
5. Place compass at different directions and draw more lines.

between magnets with unlike poles facing, combined field is almost uniformed in strength.

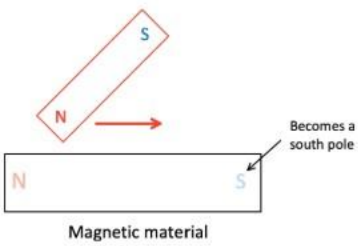


- Magnetic field lines always N → S
- Closer field lines = stronger field

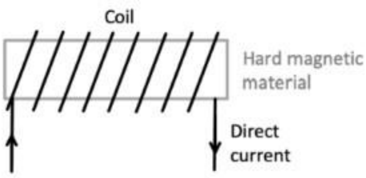
↳ neutral point
- field from 1 magnet cancels field from other
↳ magnetic force = 0

Making a magnet

1. Permanent magnet (steel) can be magnetised more stronger by bringing it close to a magnet and stroking it repeatedly with one end of magnet



2. Place steel into a solenoid, connect d.c supply to circuit & switch on. The current has a magnetic effect which magnetises steel.



3. If the material is placed in a magnetic field and then hit with a hammer, the material will also become magnetised

Demagnetise a magnet

- Hammer the magnet / heat it at high temp to throw atomic magnet out of line

(a) Describe how to demagnetise a bar magnet using alternating current (a.c.) in a coil.
Place magnet in coil. Then gradually withdraw magnet with a.c. in coil switched on. OR reduce current to zero.

4.2 Electrical quantities

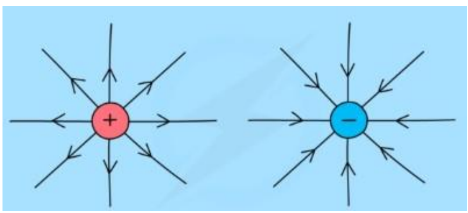
4.2.1 Electric charge

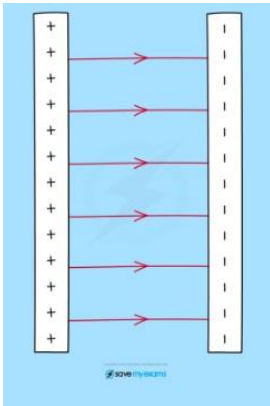
Like charges repel; opposite charges attract

A conducting sphere is mounted on an insulating stand. Explain how you would use a positively charged rod of insulating material to change the sphere by induction (3)

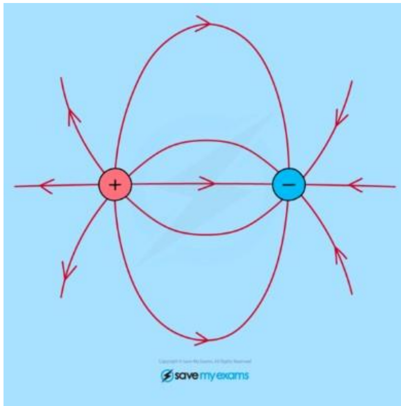
1. Bring +ve charged rod near sphere
2. Connect earth wire to sphere
3. Remove earth wire from sphere but keep rod close to sphere until earth removed

- Electric charges create electric fields in the regions surrounding them
- **Electric field:** region in which an electric charge experiences a force
- Fields lines always go away from +ve charges to -ve charges
- They have the same direction as the direction of the force on a +ve charged particle at a point in that field

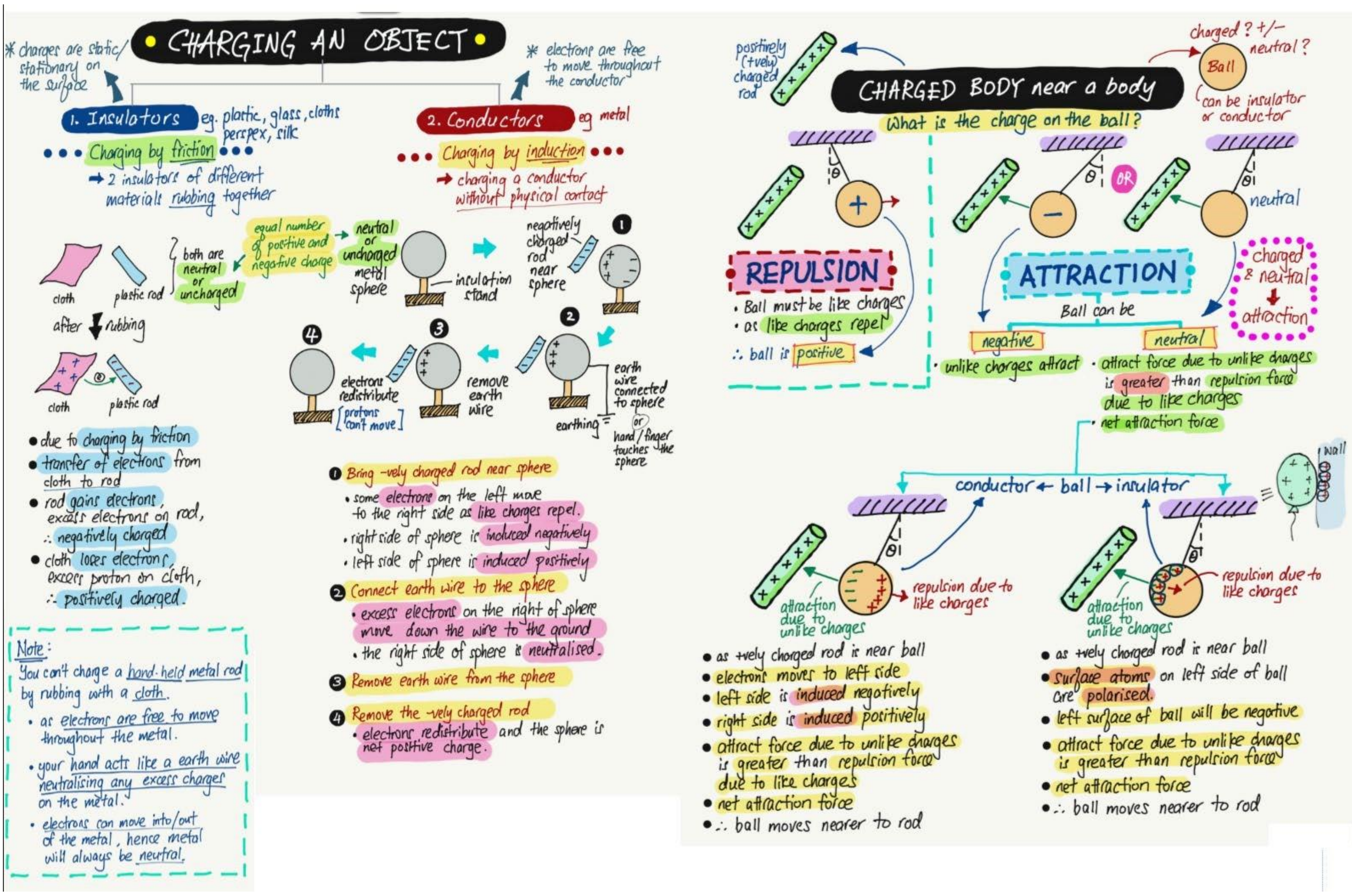




The electric field between two parallel plates



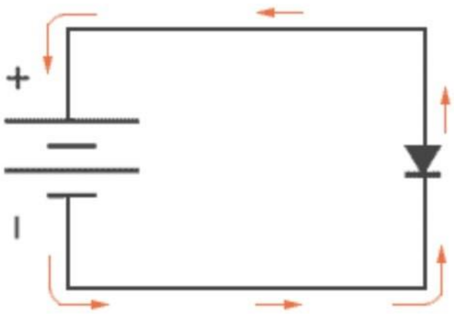
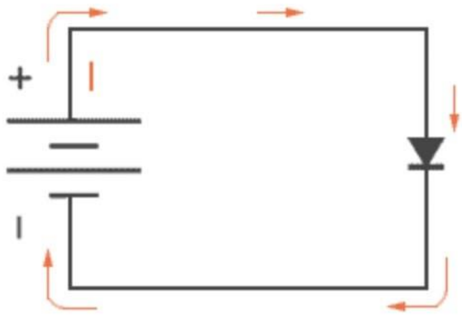
The electric field between two opposite charges



4.2.2 Current

Define current (1)

- Flow of charge / electrons around circuit

Explain how electron flows. (2) • e^- flows from -ve to +ve terminal • -ve charged e^- attracted to +ve & repelled by -ve terminal	**Describe conventional current. (1)** • From +ve to -ve terminal
 Electron Current	 Conventional Current

Why is electron flows & conventional current the same? (1)

- Transfer of +ve charge = transfer of -ve charge in opposite direction

Calculation

$$CChaaaaaaaa\ (CC) = ccccaaaaaacccc\ (AA) \times ccttttaa\ (ss)$$

$$QQ = IIcc$$

Define 1 coulomb. (1)

- Charge that passes when current of 1A flows for 1sec
- $1CC = 6.25 \times 10^{18} aae$
- $1aae = 1.6 \times 10^{-19} CC$

4.2.3 Electromotive force

Define electromotive force (e.m.f). (2)

- Work done per unit charge to drive charge around a complete circuit per coulomb • Max p.d

4.2.4 Potential difference

Define voltage (aka potiential difference / p.d)

- How much energy is transferred between 2 points in circuit
- A p.d. pf 1V = 1J of energy is transferred for each C of charge that's moving through circuit

$$1VV = 1JJ/CC$$

- ↑ p.d, ↑ energy given to e^- pushed out

Calculation

$$aaccaaaaaaee\ (JJ) = cchaaaaaaaa\ (CC) \times vvvvvvccaaaaaa(VV)$$

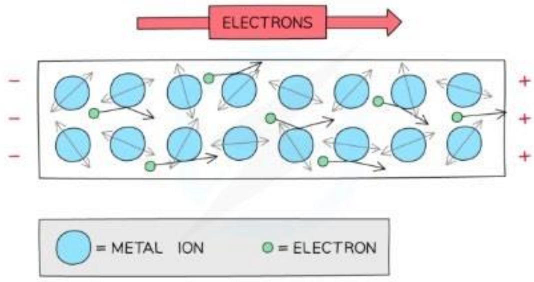
$$EE = QQVV$$

4.2.5 Resistance

$$RRaassttssccaaccccaa\ (\Omega\Omega) = \frac{vvvvvvccaaaaaa\ (VV)}{ccccaaaaaacccc\ (AA)}$$

$$RR = \frac{VV}{II}$$

- As electrons pass through a wire, they collide with the metal ions in the wire.
- The ions get in the way of the electrons, resisting their flow



If wire is longer → each electron will collide with more ions and so there will be more resistance so

- Longer a wire, *greater* its resistance.

If wire is thicker (greater diameter) → more space for the electrons and so more electrons can flow so

- Thicker a wire, *smaller* its resistance

What factors affect resistance of wire? (4)

- Length
- Cross-sectional area
- Material - nichrome wire has more resistance than copper
- Temp

Why is there a heating effect when current flows in resistance?

- e^- collide with atoms as they pass through conductor
- e^- loses energy
- Atoms gain energy, vibrate faster, ↑temp
- Electrical energy transferred into thermal energy

Effects of length & area on resistance

$$RRaassttssccaaccccaa \propto vvaaccaacch$$

$$RRaassttssccaaccccaa \propto \frac{1}{aaaaaaaa}$$

$$RRaassttssccaaccccaa \propto \frac{vvaaccaacch}{aaaaaaaa}$$

$$\frac{RRaassttssccaaccccaa\ AA \times aaaaaaaa\ AA}{vvaaccaacch\ AA} = \frac{RRaassttssccaaccccaa\ BB \times aaaaaaaa\ BB}{vvaaccaacch\ BB}$$

Series & parallel

	Series	Parallel
I	Same	Different
V	Different	Same

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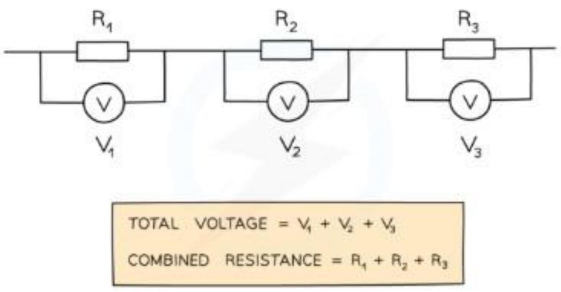

Series
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- ↑resistors ↑resistance

$RR = RR_1 + RR_2$
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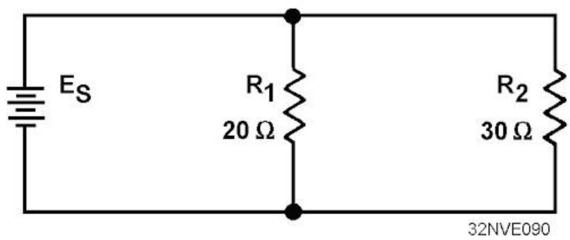

Parallel
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- ↑resistors ↓resistance

1 1 1
— = + RR RR1
RR2
</td>
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4.2.6 Electrical working

- Electrical energy is transferred from the battery or power source to the circuit components then into the surroundings
- 1 Watt = 1J/s

Power

$PPvvPPaaaa\ (WW) = ppvvccaaccccttaavv\ ddttddddaaaaaaccccaa\ (VV) \times ccccaaaaaacccc\ (AA)$

$$PP = VVII$$

Energy

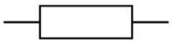
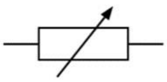
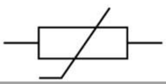
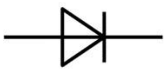
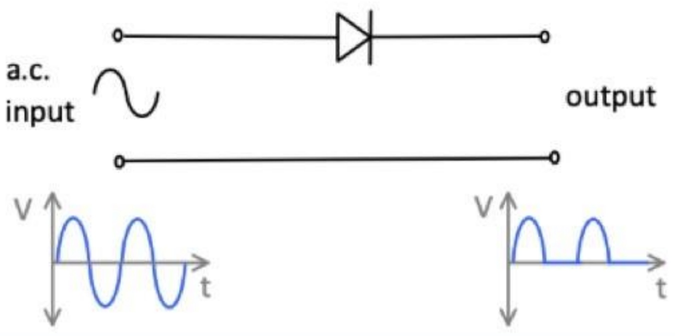
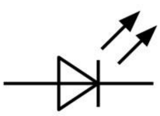
$EEccaaaaaaee\ (JJ) = vvvvvvccaaaaaa \times ccccaaaaaaacccc \times ccttttaa$

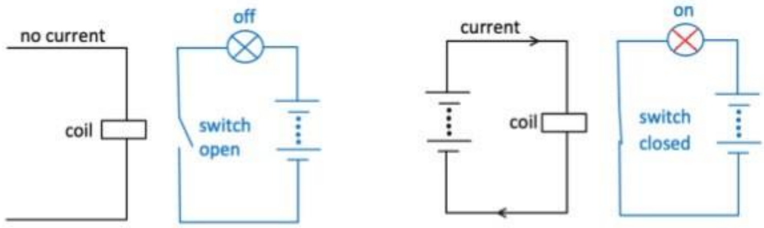
$EE = VVIIcc$
$EE = PPcc$
$EE = VVQQ$

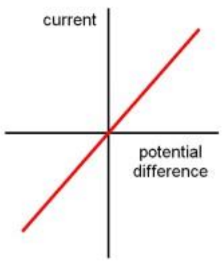
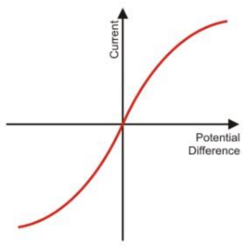
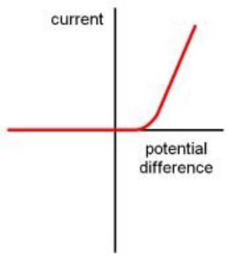
4.3 Electric circuits

4.3.1 Circuit diagrams

Resistance components

 **Fixed resistor**	• Keep currents & p.d at level needed for other components to work properly
 **Variable resistor (rheostat)**	• Varying current
Thermistor 	• Cold - high Ω • Hot - low Ω
Light-dependent resistor (LDR) 	• Changes its resistance when light is shone on it Dark • - high Ω • Light - low Ω • Detect light eg switch on/off light automatically
Diode 	• Extremely high Ω in one direction but low in other • So current flows in one direction • Useful for controlling flow of current in circuit • **Rectrification** – if a diode is connect to an a.c. power supply, it will only allow a current half of the time 
Light-emitting diodes (LEDs) 	• Glows when small current passes through them • Used as indicator (on/off) lights & alphanumeric displays eg digital clocks

Transistor	• Used for amplifying signals & for switching
	• Most are made from specially treated crystals of silicon
Relay	Consists of two parts: • A coil (an electromagnet)  • A magnetic switch • When there is a current in the coil, it creates a magnetic field which attracts the switch, closing the right-hand part of circuit • This can be used to control a switch in a separate circuit, as shown in the above diagram

 **Resistor at constant temp**	 **Filament**	 **Diode**

• Ohm's law: I∝ V • Resistance constant	**Why curve?** • ↑V, ↑energy transferred in lamp • ↑temp of filament • Atom vibrate more vigorously, ↑collision with e- of current • More energy needed to push current through filament • ↑resistance	• Current only flows in one direction

4.3.2 Series and parallel circuits

Series Circuits

- A series circuit consists of a string of two or more components, connected end to end:

Series:

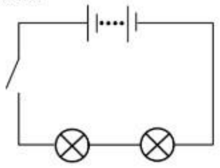
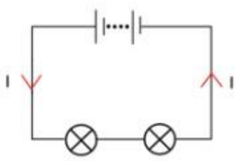


Diagram showing two bulbs connected in series

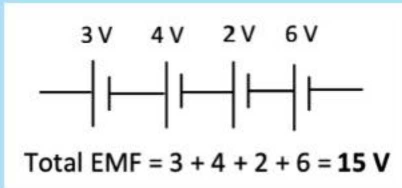
- In a series circuit the current is the same at all points.



The current is the same at all points in a series circuit

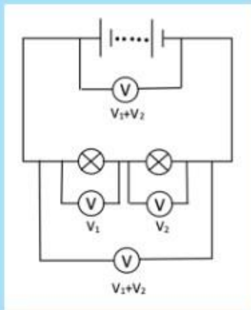
Potential Difference in Series

- When several cells are connected together in series, their combined EMF is equal to the sum of their individual EMFs.



The total EMF of these cells is equal to the sum of their individual EMFs

- In a series circuit, the sum of potential differences across the components is equal to the total EMF of the power supply.



In a series circuit the components share the EMF of the power supply

Parallel Circuits

- A parallel circuit consists of two or more components attached along separate branches of the circuit.

Parallel:

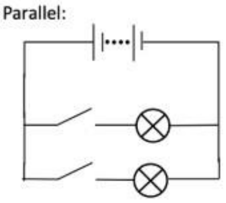
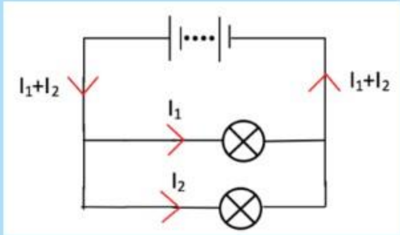


Diagram showing two bulbs connected in parallel

- The **advantages** of this kind of circuit are:
  - **The components can be individually controlled, using their own switches.**
  - If one component stops working the others will continue to function.
- **In a parallel circuit the current splits up** – some of it going one way and the rest going the other.
- This means that the current in each branch will be smaller than the current from the power supply.

Determining Current in Parallel

- Because the current splits up, the sum of currents in each branch will equal the current from the power supply.



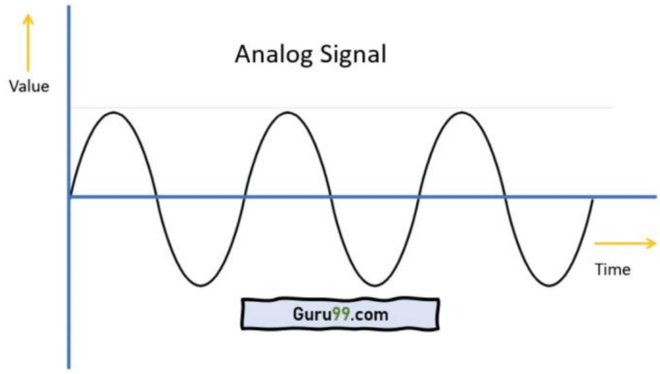
In a parallel circuit the current splits up, dividing between the various branches of the circuit

- Note that the current does not always split equally – often there will be more current in some branches than in others.
- The current in each branch will only be identical if the components along each branch are identical (or at least have the same resistance).

4.3.3 Action and use of circuit components

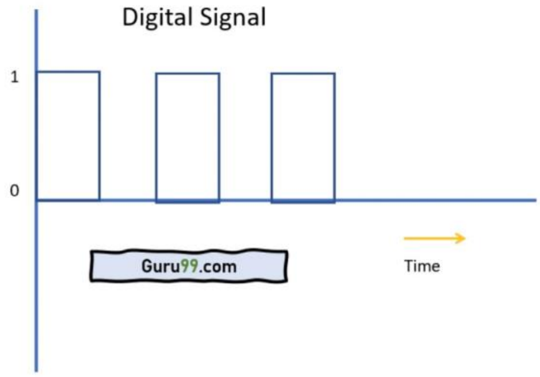
(See above)

4.4 Digital electronics



Analogue signals

- Current varies continuously
- Eg speaker



Digital signals

- Signals represent only 2 states – on & off
- Eg digital clock

Input | Output

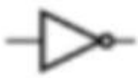
A	B	Lamp
0	0	0
1	0	0
0	1	0
1	1	1

AND

A	B	Lamp
0	0	0
1	0	1
0	1	1
1	1	1

OR

A		Lamp
1		0
0		1



NOT

A	B	Lamp
0	0	1
1	0	1
0	1	1
1	1	0

NAND

equivalent to AND gate with its output inverted by a NOT gate

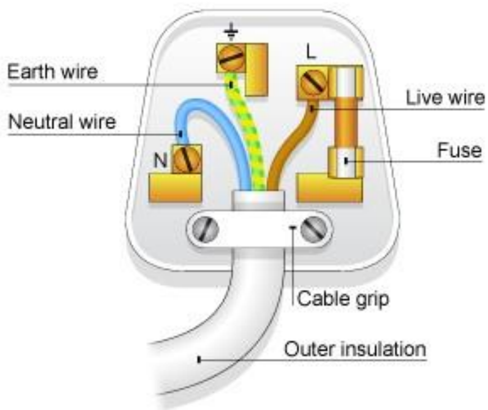
What logic gate behaves in the same way as NAND gate?

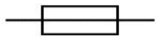
A	B	Lamp
0	0	1
1	0	0
0	1	0
1	1	0

NOR

equivalent to OR gate with its output inverted by a NOT gate

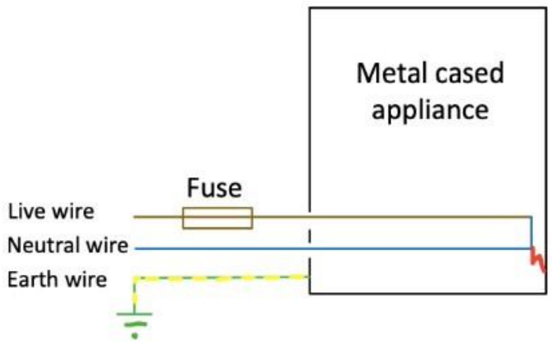
4.5 Dangers of electricity



Live wire	• Carries current to the appliance
Neutral wire	• Completes the circuit & carries current away • 0V
Earth wire	• Safety wire - connects metal body to earth & stops it becoming live
Fuse 	• Thin piece of wire - Current too high, overheats, melts, breaks circuit • Always choose the next size up
Double insulation	• Plastic around wires
Residual current device (RCD)	• Compares currents in live & earth • If not same, breaks current

Earthing

- Many electrical appliances have metal cases.
- This poses a potential safety hazard:
  - If a live wire (inside the appliance) came into contact with the case, the case would become electrified and anyone who touched in would risk electrocution.
- The earth wire is an additional safety wire that can reduce this risk



A diagram showing the three wires going to a mains powered appliance: live, neutral and earth

- If this happens:
  - The earth wire provides a **low resistance path to the earth**.
  - This causes a **surge of current in the earth wire** and hence also in the live wire. ○ The high current through the fuse causes it to **melt and break**.
  - **This cuts off the supply of electricity to the appliance**, making it safe.

What are the electrical hazards? (4)

Damaged insulation	• Higher resistance at a point • When current flows, heating effect high enough to melt insulation • Cause fire
Overheating of cables eg long extension leads	• Overheat when coiled up Current • warms wire • Heat has less area to escape
Damp conditions	• Water conduct current

(b) Fig. 7.2 shows an extension lead used to supply power to a 3kW electric heater on a cool evening.

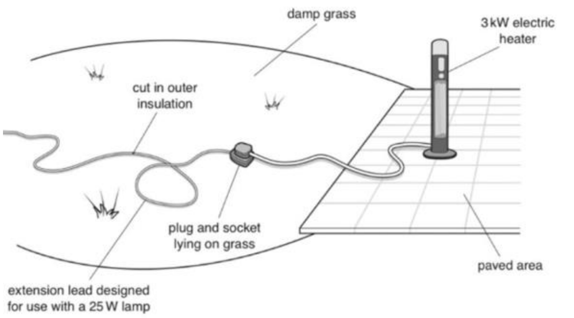


Fig. 7.2

State and explain three dangers with this arrangement.

danger 1 Damp grass is dangerous because water conducts electricity

danger 2 Trip hazard because extension lead too long and should be coiled up

danger 3 Risk of getting electric shock because plug and socket are lying on the grass

(b) A circuit breaker is recommended for use with an electric lawnmower.

State **two** reasons for this recommendation.

reason 1 Prevents electric shock & overheating

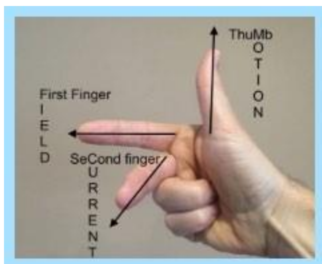
reason 2 Avoids lawnmower to become damaged

4.6 Electromagnetic effects

4.6.1 Electromagnetic induction

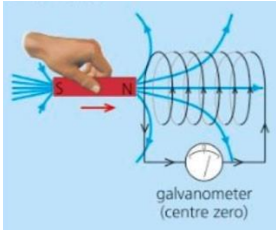
Right-Hand Rule

- When moving a wire through a magnetic field, the direction of the induced EMF can be worked out by using the Right-Hand Dynamo rule

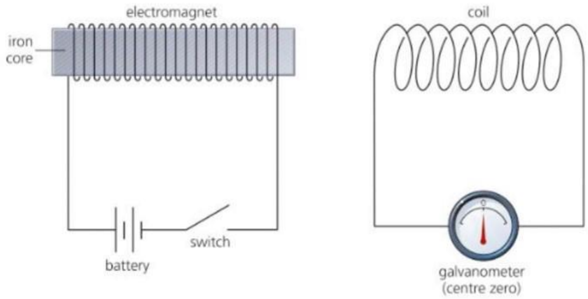


Electromagnetic induction

• Magnet push in/out of coil • Coil cuts through magnetic field lines	

• Emf induced • Current flow	

Mutual induction



- When coils are magnetically linked, change in current cause emf induction
- Electromagnet switched on
  - Change in current cause emf induction in the other coil but only for fraction of sec
  - Effect = push magnet into coil quickly
- Electromagnet switched off
  - Emf induced in opposite direction
  - Effect = pull magnet out of coil quickly
- Steady current in electromagnet → no emf induced coz no change in magnetic field

To increase emf induction at switch-on/off

- Core of electromagnet goes right through 2nd coil
- ↑ no of turns on 2nd coil

(a) Fig. 7.1 shows a coil of wire wound on a thin plastic cylinder. The plastic has no effect on any magnetic field. The galvanometer is extremely sensitive.

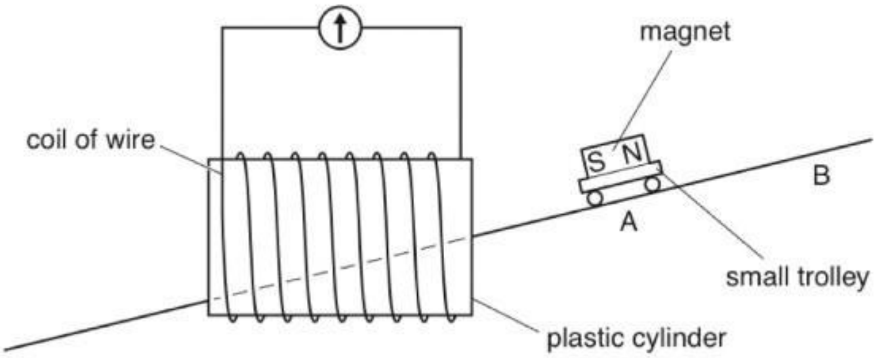


Fig. 7.1

A magnet is fixed to a small trolley that runs without friction on a track through the cylinder and coil.

(i) The trolley is released from point A so it runs through the coil from right to left.

State and explain what is observed on the galvanometer.

The needle of the galvanometer deflects because coil cuts through the magnetic field lines and emf is induced.

[2]

(ii) The trolley is now released from point B so it runs through the coil from right to left again.

State what is observed on the galvanometer and explain why it is different to your answer in **(a)(i)**.

The needle of the galvanometer will deflect more because the magnet gains more gravitational potential energy and moves faster so there will be an increase in emf induction.

[2]

10 (a) A magnet and a coil are attached separately to a door and a door frame as shown in Fig. 10.1.

The purpose of the arrangement is to activate a circuit connected to an LED indicator when the door is opening or closing. This will provide a visual indication that the door is being used.

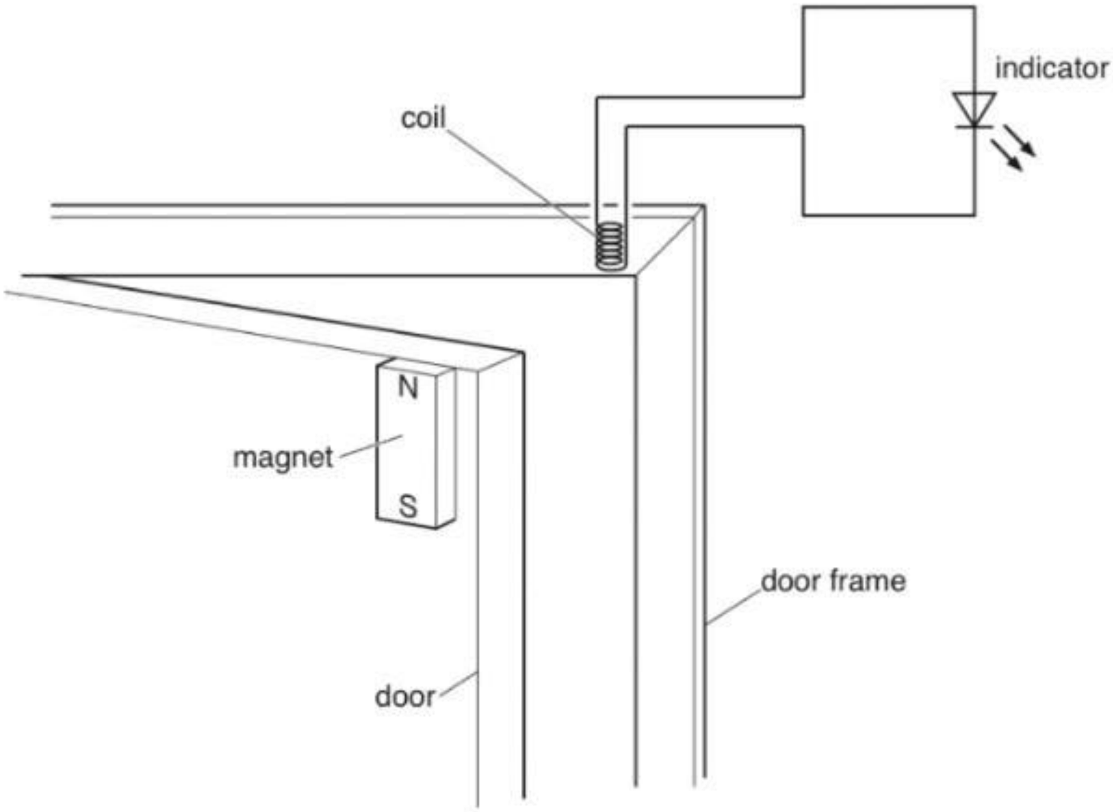


Fig. 10.1

Initially, the door is closed and then it is opened.

(i) Explain why the indicator comes on and then goes off when the door is opened.

When the door is opened, the magnet is not below the coil, no emf induction occurs so no current is flowed. Therefore, the inductor goes off.

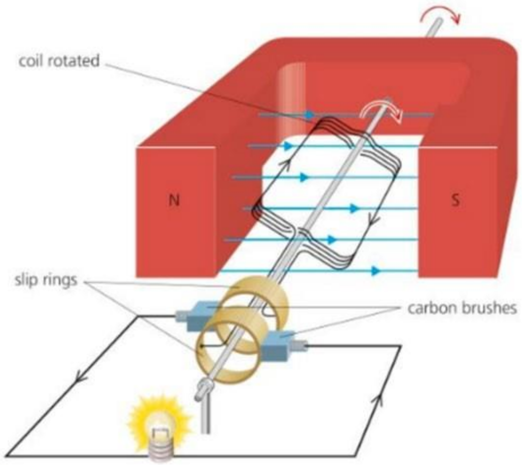
.... [2]

(ii) The door shuts. The indicator comes on more brightly but for a shorter time than it did in **(i)**. Suggest and explain why this happens.

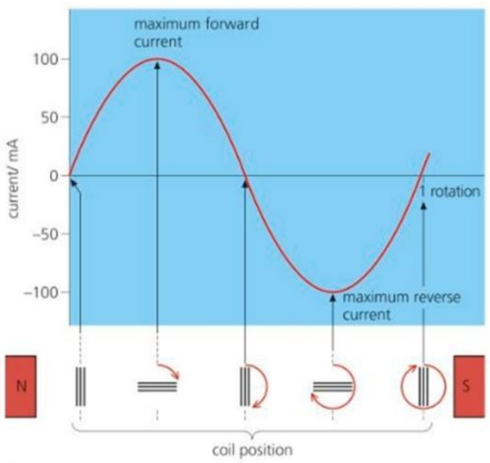
The door closes quicker, which makes the magnet to move faster. This increases emf induction and increases flow of current. Therefore, the indicator comes on more brightly.

.... [2]

4.6.2 a.c. generator



Coil	• Made of insulated copper wire • Rotated by tuning the shaft
Slip rings	• Provide continuous connection while coil rotating • Fixed to coil & rotate with it
Brushes	• Two contacts which rub against slip rings & keep coil connected to outside part of circuit • Made of carbon



When coil rotates → coil cut magnetic field → emf induced → current flows

Maximum - coil **horizontal** & cutting field lines at fastest rate

Zero - when coil **vertical** & no field line cut

How to ↑ maximum emf?

- ↑ no of turns on coil
- ↑ strength of magnetic field
- ↑ speed of rotation of coil

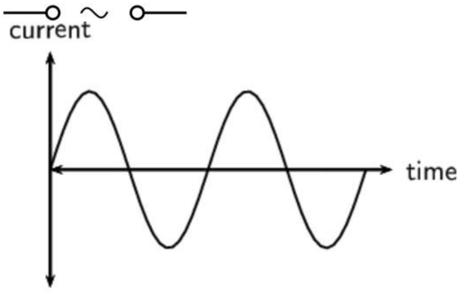
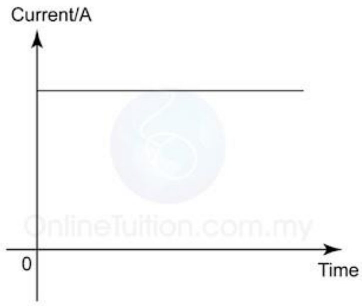
Mains generator must keep steady frequency - 50Hz cycles per sec in UK

(b) A lamp and an open switch are connected in series to the output terminals of the a.c. generator.

The switch is closed and the lamp lights up. The student has to apply a greater force on the handle.

Explain why a greater force is needed to keep the lamp lit.

Energy eg heat energy is lost from lamp so more energy is needed to keep the lamp lit. Therefore, greater force is needed.

Alternating current (a.c.)	Direct current (d.c.)
	 
• Main current • A rapid, oscillation of electrons that alternate back & forth	• Current flows in only one direction • Eg electric cells (batteries)

4.6.3 Transformer

A simple transformer

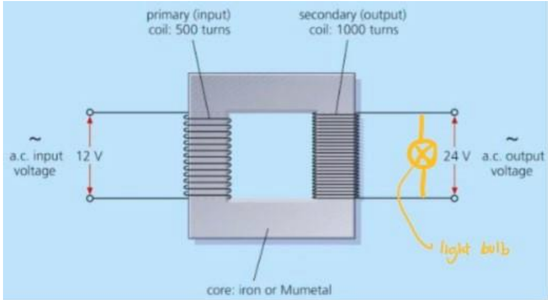
- A.c voltage can be increased/decreased using transformer
- Works by mutual induction
- Function: change voltage to a.c.

Calculations

vvccccppcccc vvvvvvccaaaaaa
ccccaaccss vvcc vvccccppcccc ccvvttvv
= ttccppcccc vvvvvvccaaaaaa
ccccaaccss vvcc ttccppcccc ccvvttvv

$$\frac{NN_{ss}}{NN_{pp}} = \frac{VV_{ss}}{VV_{pp}}$$

Explain why there's a current in the lamp



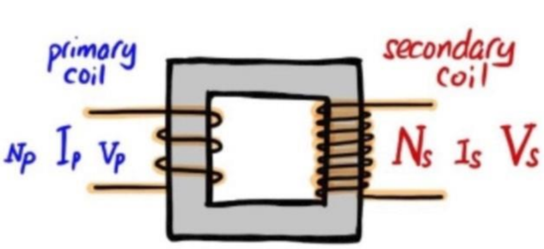
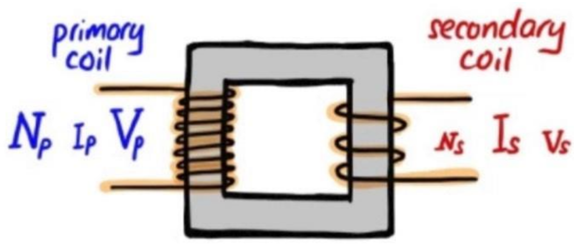
1. When an alternative emf is supplied to primary coil, a.c. flows in primary coil. This produces changing magnetic field within primary coil
2. Changing magnetic field is linked to secondary coil via core
3. Changing magnetic field cuts through coil → emf induced → bulb lights up **Why use a.c. not d.c.?**
    - a.c. flows alternately forwards & backwards → produce changing magnetic field → cut through coil → emf induced
    - d.c. flows one way only
    - X produce changing magnetic field
    - High current flows in input coil can overheat it

Why soft iron is used as core?

- Soft magnetic material
- Easy to magnetise & demagnetize
- Ability to concentrate magnetic field lines

Why copper is used as coil?

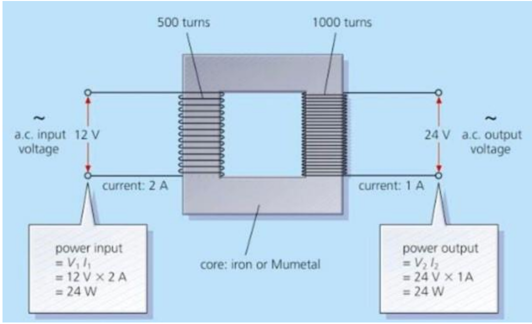
- Good conductor

Step-up transformers v → V	Step-down transformers V → v
 	
• More coils on output than input coil • ↑ voltage • Used in power stations to ↑ voltage to levels needed for overhead power lines	• More coils on input than output coil • ↓ voltage • Used in battery chargers/computers to ↓ voltage of a.c. mains to much lower levels needed for other circuits

Power through a transformer

IIccppcccc vvvvvvccaaaaaa × ttccppcccc ccccaaaaaacccc = vvccccppcccc vvvvvvccaaaaaa × vvccccppcccc ccccaaaaaacccc

$$VV_1II_1 = VV_2II_2$$



Power across the country

- Power for a.c. mains is generated in power stations → step-up transformer → transmitted through long-distance cables → step-down transformer → distributed to consumers

Why step-up at power station & step-down when distribute to consumers

- Transmission cables have resistance
- Power lost to resistive heating

$$ppvvPPaaaa\ vvvvsscc = (ccccaaaaaacccc)^2 \times aaaassttssccaaccccaa$$

$$PP = II^2RR$$

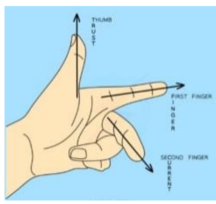
- Use high-voltage low-current transmission
- Tinner, lighter & cheaper cables used
- Reduces heat energy losses

State & explain 1 advantage of transmitting electrical power at a high voltage

- Use high-voltage low-current transmission
- Tinner, lighter & cheaper cables used
- Reduces heat energy losses

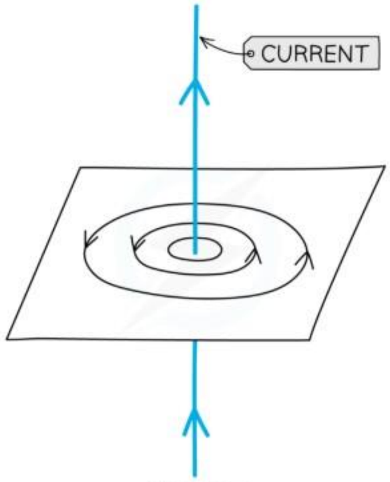
4.6.4 The magnetic effect of a current
4.6.5 Force on a current-carrying conductor

Left-Hand rule



- The force is always directed at 90 degrees to both the field and the current.
- The direction of the force on a current-carrying wire can be worked out by using the left-hand rule

When there is a current in a wire, a magnetic field is created around the wire



Magnetic Field Strength & Direction

- **Direction of a magnetic field** - direction of the force on the north pole of a magnet placed at that point.
- **Strength & direction of the field** depend on the size and direction of the current:
  - If the current is increased, the field will get stronger.
  - If the direction of the current is changed, the direction of the field will change.
- The **strength of the magnetic field** is related to the distance between the field lines: As the field lines spread out, the field gets weaker.
- The field lines around a wire get further apart the further they are from the wire

The Field around a Coil

- When a wire is looped into a coil, the magnetic field lines circle around each part of the coil, passing through the centre of it

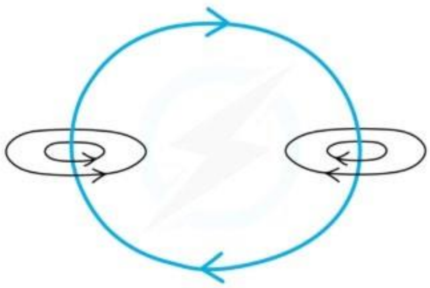
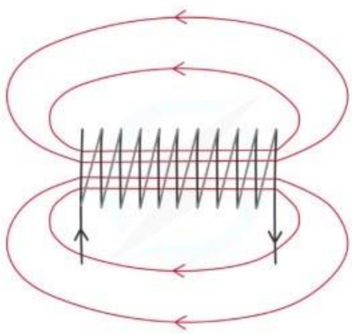


Diagram showing the magnetic field around a flat circular coil

A solenoid is a long coil.

The magnetic field around a solenoid looks the same as the magnetic field around a bar magnet:

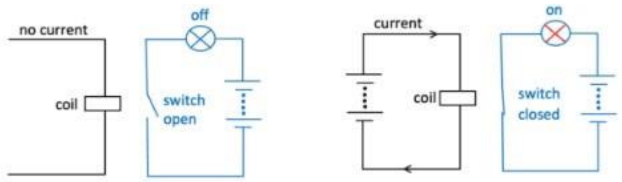


The magnetic field around a solenoid (a long coil) is identical to the magnetic field of a bar magnet

- One end of the solenoid behaves like the north pole of a magnet; the other side behaves like the south pole.
- Inside the solenoid the field lines straighten up and are very close together – they form a strong uniform field.

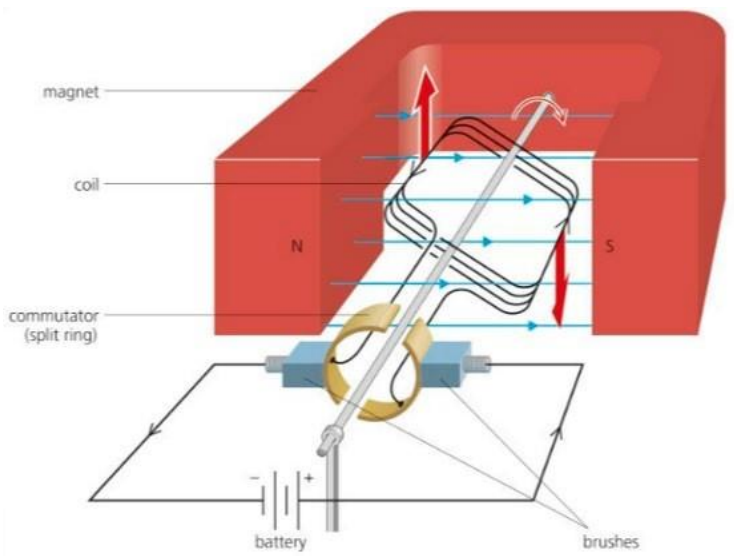
Solenoid Applications

- A solenoid can be used as an electromagnet by adding a soft iron core.
  (This increases the strength of the magnetic field significantly).
- Electromagnets are used in a wide variety of applications eg doorbells, electronic door locks • An electromagnet is also used in a relay:



When a current passes through the coil, it attracts the switch, closing it, which allows a current in the right-hand part of the circuit

4.6.6 d.c. motor



Coil	• Made of insulated copper wire • It's free to rotate between poles of magnet
Split-ring commutator	• Fixed to coil & rotates with it • When coil is nearly vertical, forces cannot turn it much further • When coil overshoots vertical, commutator changes direction of current in it, so forces change direction & keep coil turning • (i) Explain the purpose of the split-ring commutator. Keeps coil rotating in the same direction by changing direction of current in the coil every 180 degrees

Brushes	• Two contacts which rub against commutator • Keep coil connected to battery • Made of carbon

- When coil horizontal, forces are furthest apart & have max turning effect **(leverage)** on coil
- With no change to forces, coil eventually come to rest in vertical position
- When coil overshoots vertical, commutator changes direction of current in it, so forces change direction & keep coil turning until it's vertical again
- Coil keeps rotating clockwise, half a turn at a time
- If battery / poles of magnet were the other way round, coil rotate anticlockwise

How to ↑ turning effect on coil?

- ↑ current
- ↑ no of turns on coil
- ↑ strength of magnet
- ↑ area of coil