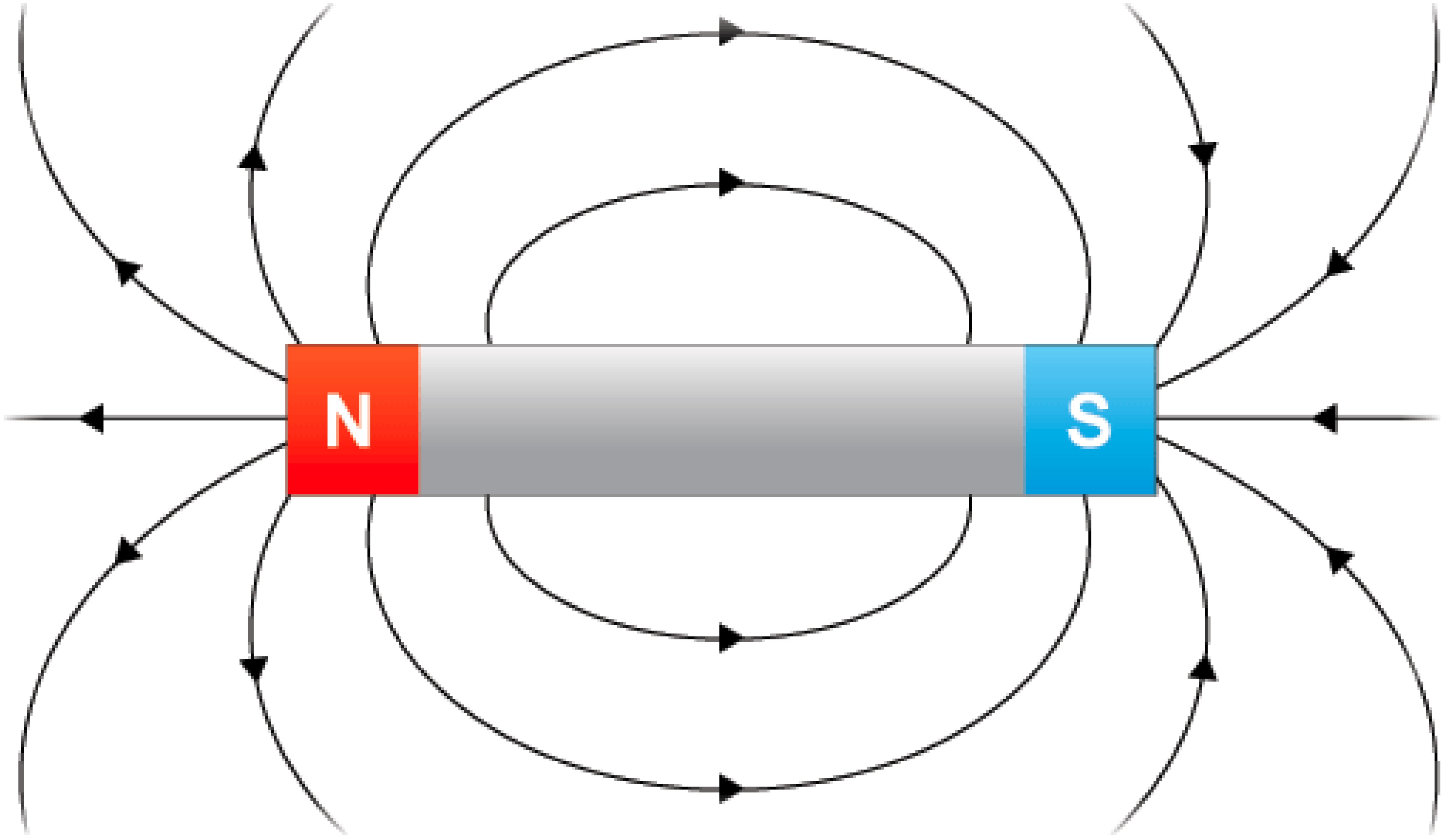
9702 C20 Magnetic fields (Part 1)

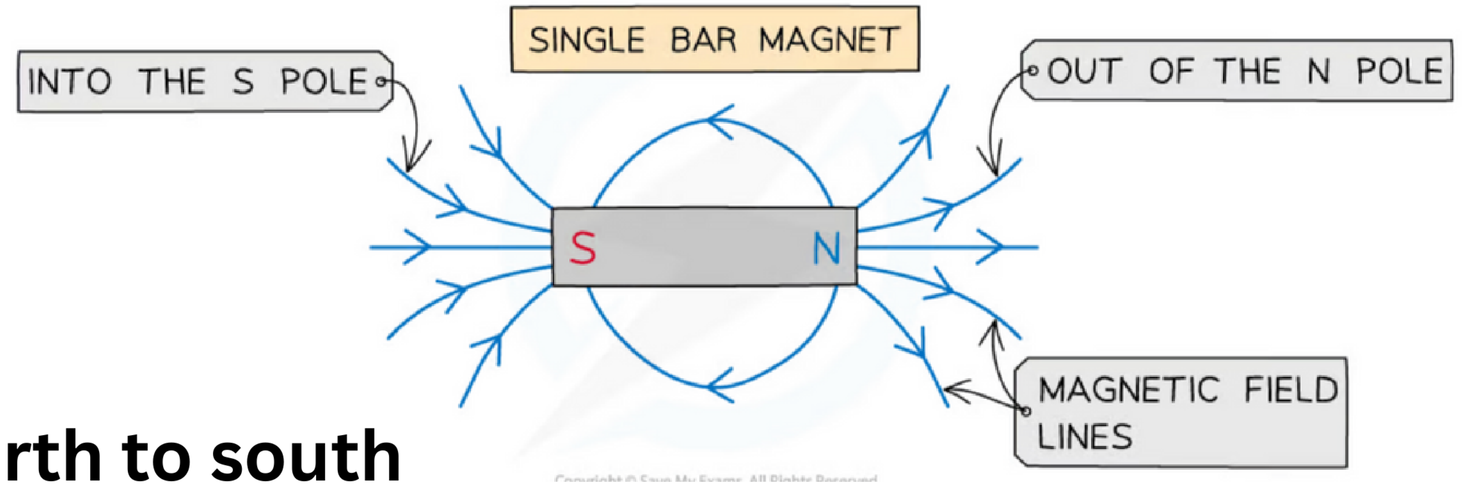


Representing Magnetic Fields(aka B-field)

A magnetic field is a field of force created either by:

-moving electric charge

-permanent magnets



The direction of a magnetic field on a bar magnet is always from **north to south**

Two like poles(north and north//south and south) repel each other
Two opposite poles(north and south) attract each other

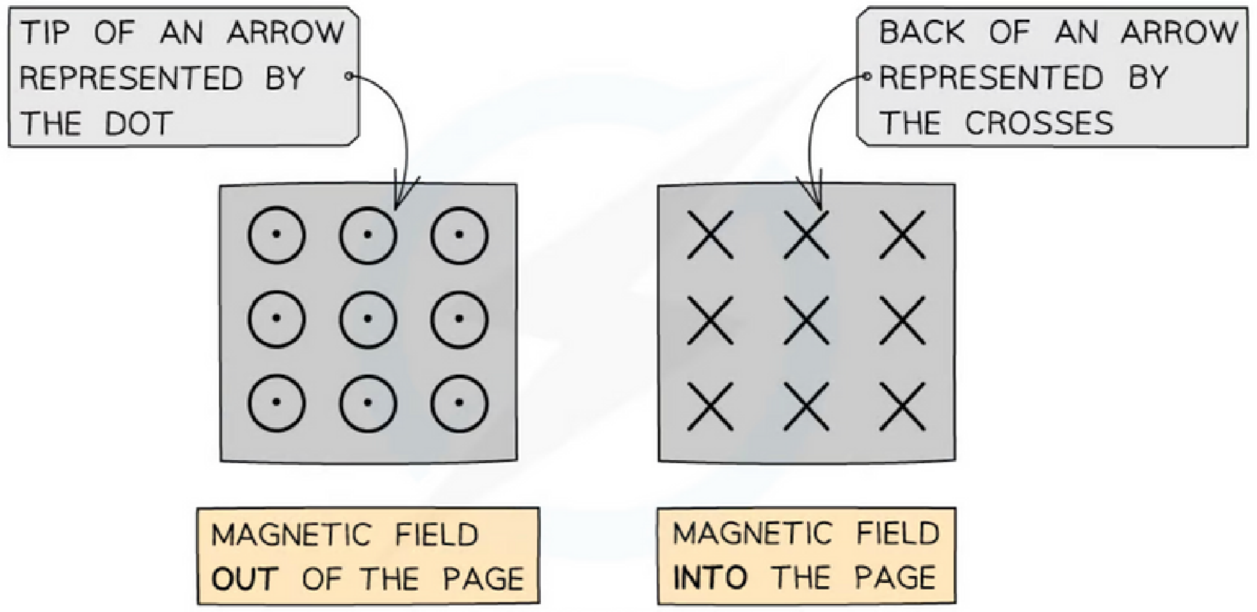
The field lines are stronger the closer the lines are together

-->a <u>uniform magnetic field</u> is where the magnetic field strength is the same at all points (this is represented by **equally spaced parallel lines**)

The direction of a magnetic field into/out of the page in 3D is represented by:

1.Dots = out of the page

2.Crosses = into the page



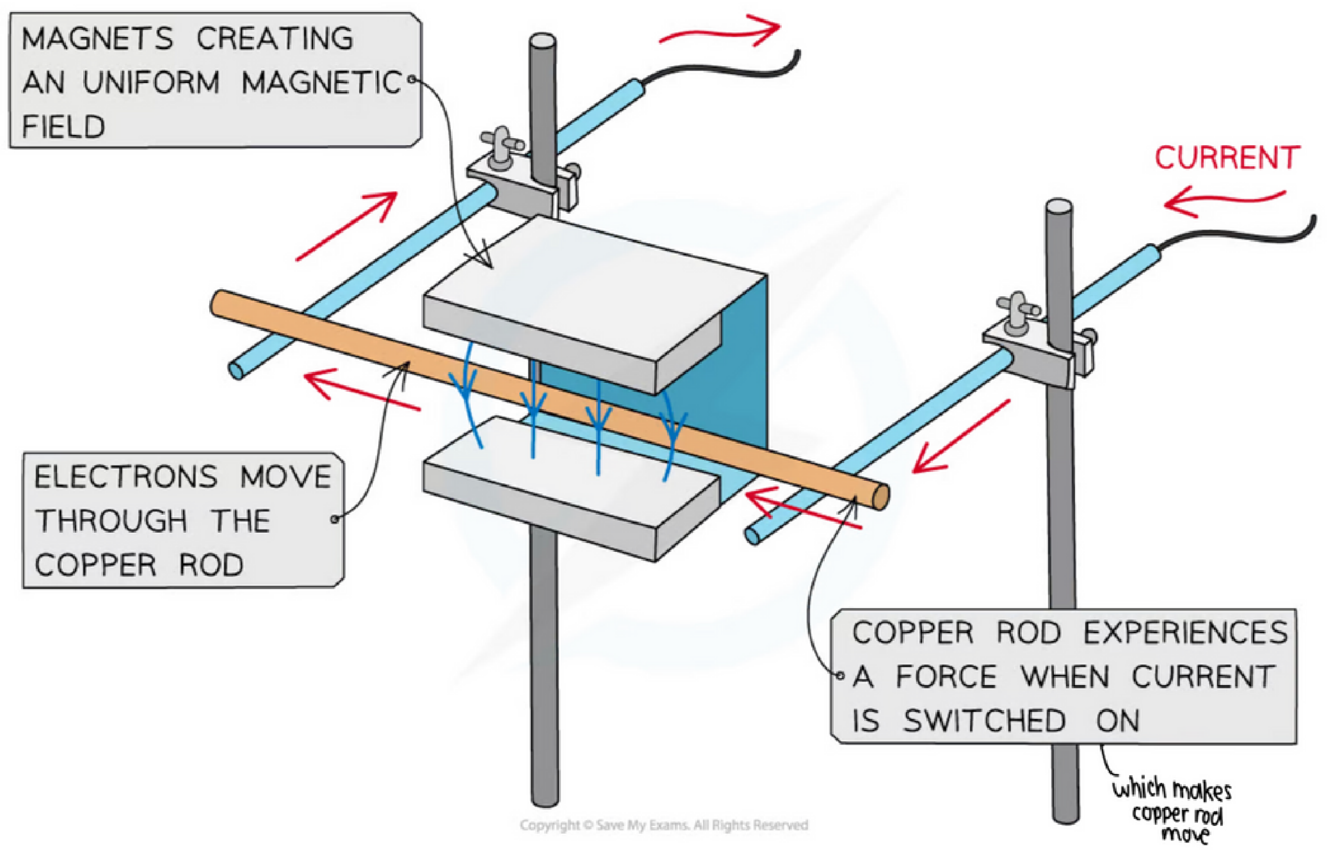
Force on a Current-Carrying Conductor (CCC)

e.g. wire

A current-carrying conductor(CCC) produces its own magnetic field
-->When interacting with an external magnetic field, it will experience a force

A CCC will ONLY experience a force if the current through it is **perpendicular** to the direction of the magnetic field lines + **must be current in the CCC(wire)**

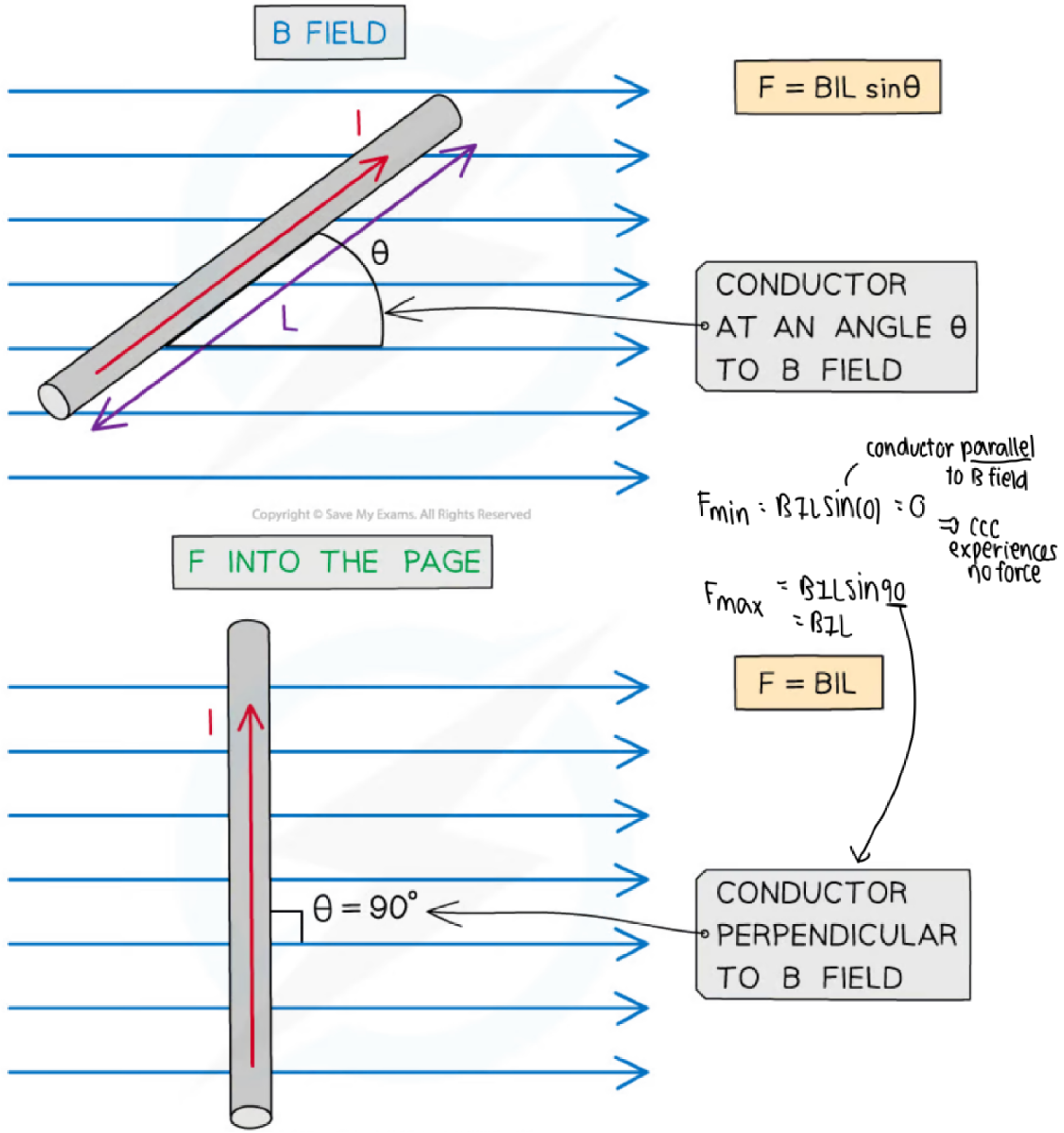
Magnetic flux density = force acting per unit current per unit length on a wire placed at right-angles to the magnetic field



$$F = BIL\sin\theta$$

Where:

- F = force on a current carrying conductor in a B field (N)
- B = magnetic flux density of external B field (T)
- I = current in the conductor (A)
- L = length of the conductor (m)
- θ = angle between the conductor and external B field (degrees)

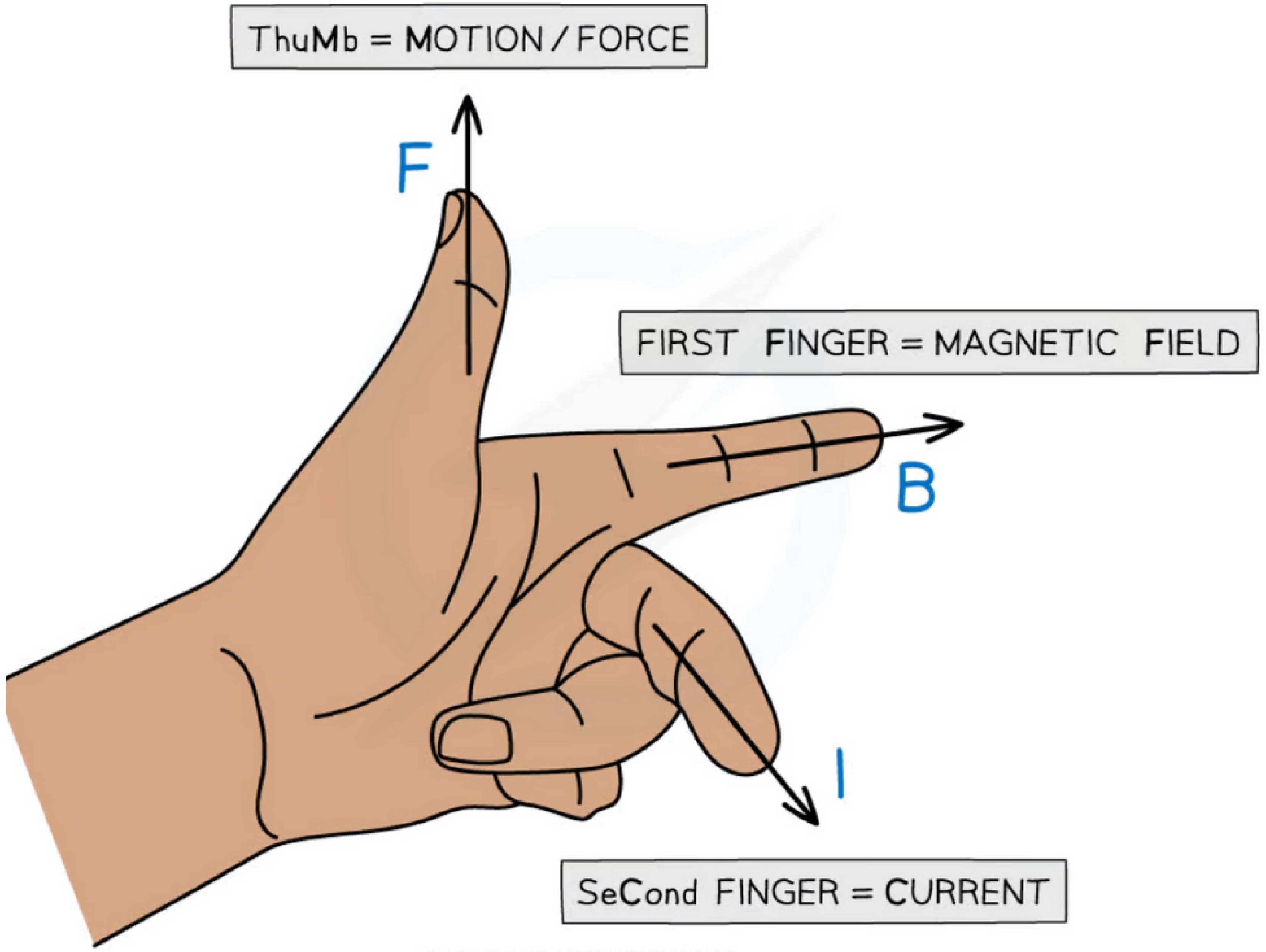


B FIELD
I
θ
L
F = BIL sinθ
CONDUCTOR AT AN ANGLE θ TO B FIELD
conductor parallel to B field
Fmin = BIL sin(0) = 0
⇒ ccc experiences no force
F INTO THE PAGE
Fmax = BIL sin 90 = BIL
F = BIL
I
θ = 90°
CONDUCTOR PERPENDICULAR TO B FIELD

Fleming's Left-Hand Rule

To find the direction of the force on a charge moving in a B-field, we can use Fleming's Left-Hand Rule

Recall that the direction of the current is the **direction of conventional current flow(positive to negative)**



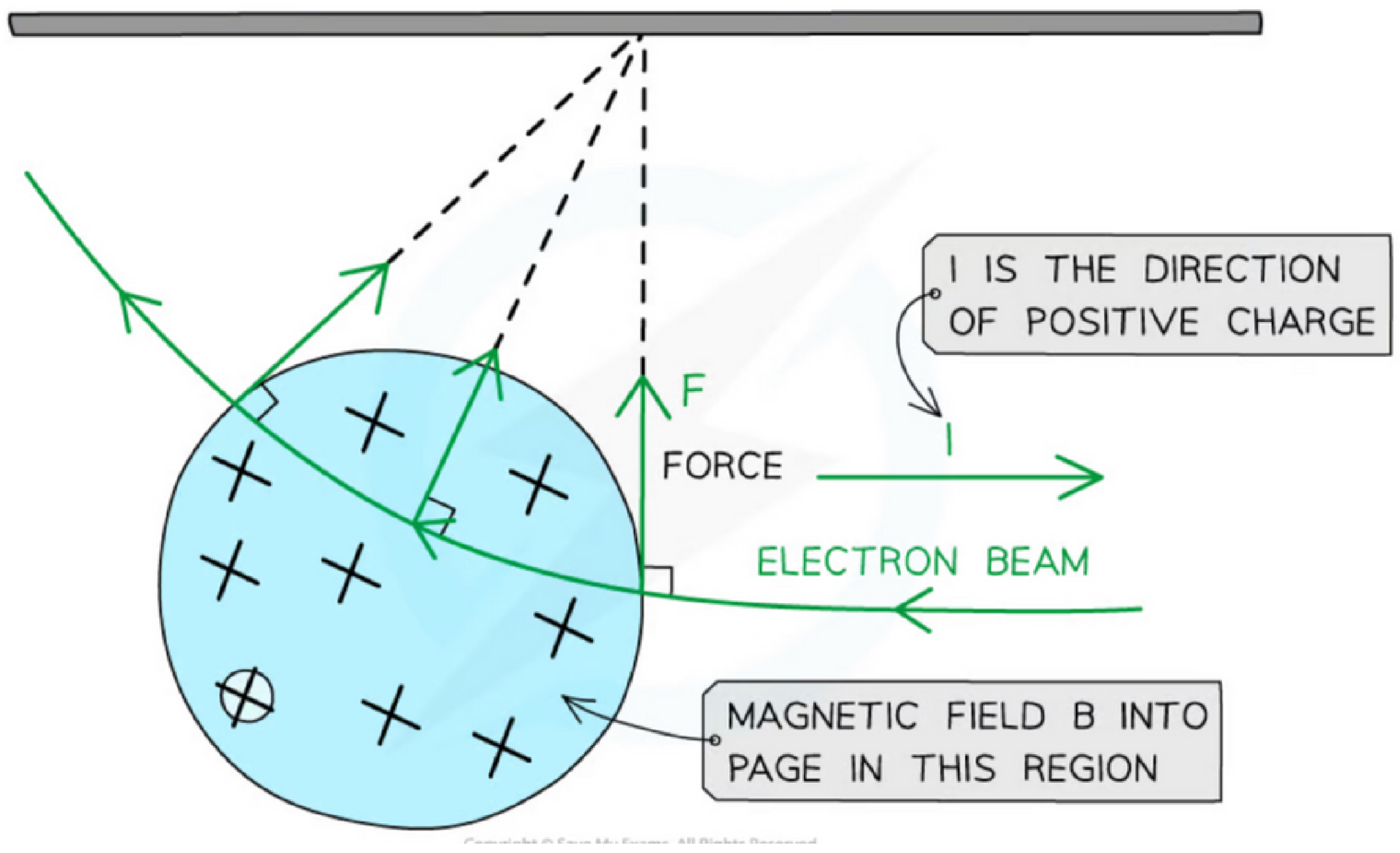
Fleming's left hand rule

Force on a Moving Charge

$$F = BQv \sin\theta$$

Where:

- F = force on the charge (N)
- B = magnetic flux density (T)
- Q = charge of the particle (C)
- v = speed of the charge ($m\,s^{-1}$)
- θ = angle between charge's velocity and magnetic field (degrees)



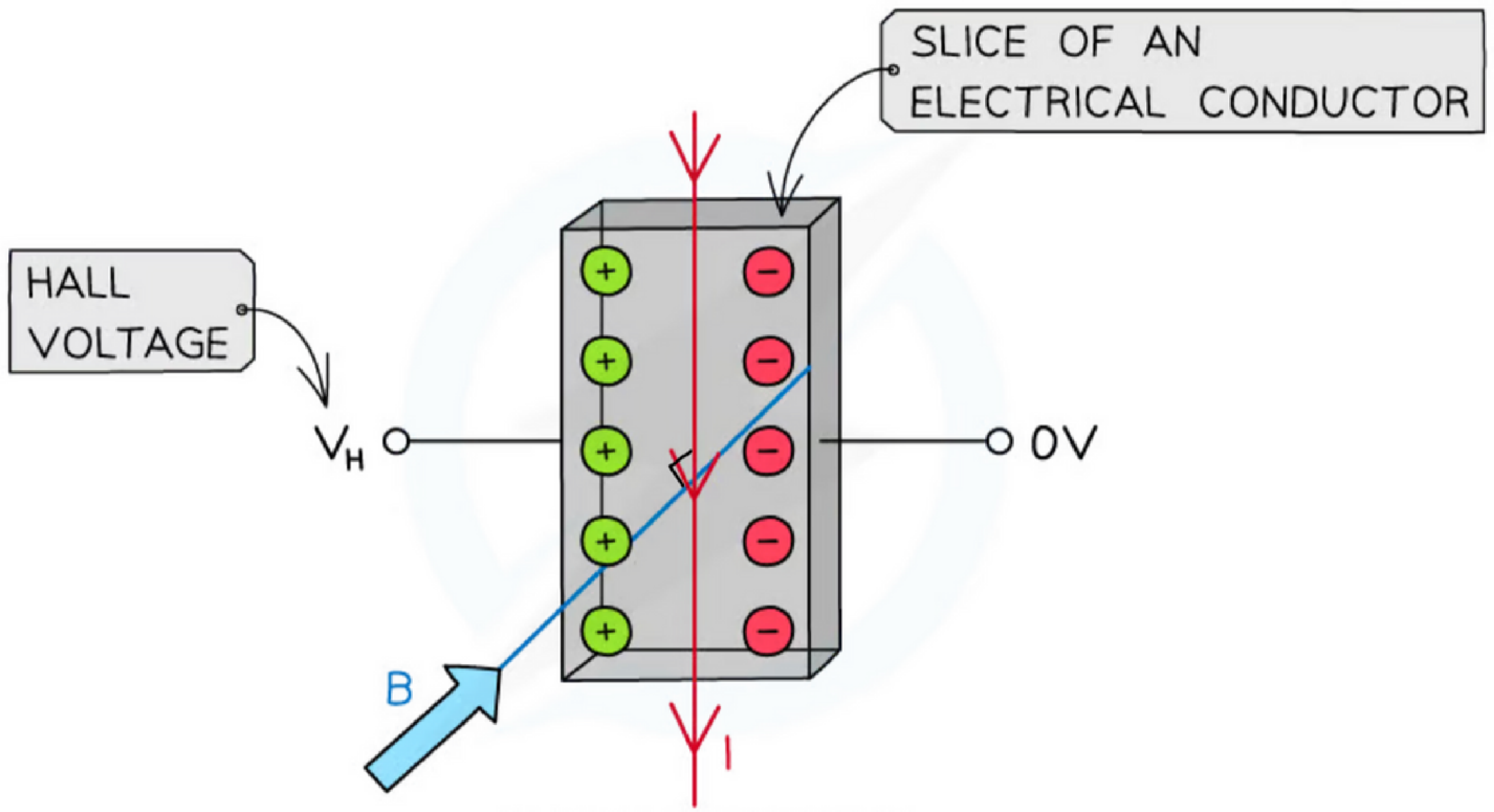
The force due to the B-field is always perpendicular to the velocity of the electron (This is equivalent to circular motion)

Fleming's left-hand rule can be used to find the force direction, b-field and velocity BUT second finger representing current is now the direction of velocity of the positive charge.

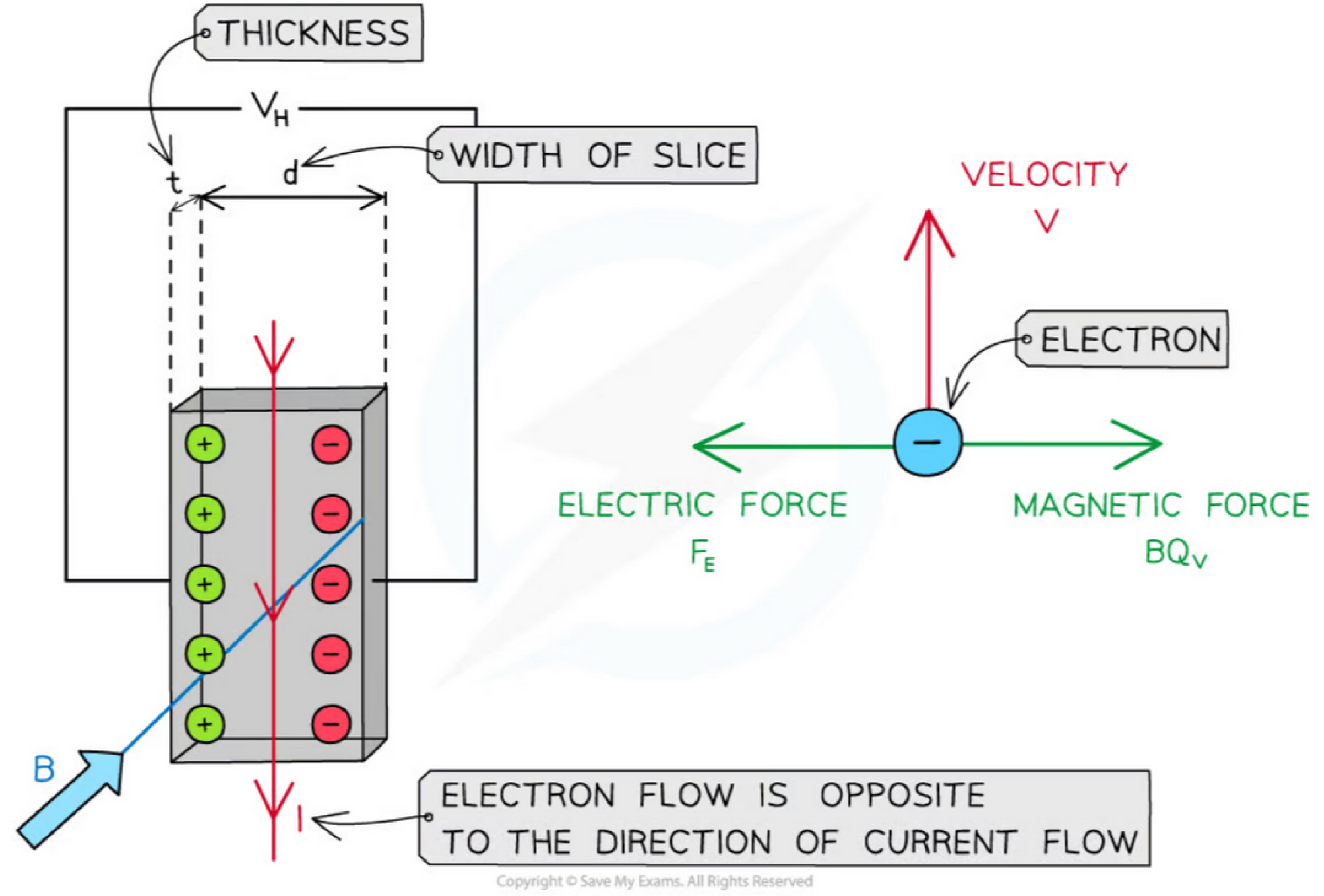
Hall Voltage

Hall voltage = p.d. produced across an electrical conductor when an external B-field is applied perpendicular to the current through the conductor

1. When an external B-field is applied perpendicular to the direction of current through a conductor, the electrons experience a magnetic force
2. This makes electron drift to one side of the conductor, where they all gather and becomes more negatively charged
3. This leaves the opposite side deficient of electrons, or positively charged
4. There is now a p.d. across the conductor. This is called the Hall Voltage (VH)



Hall voltage equation and derivation



The electric and magnetic forces on the electrons are equal and opposite

(n=number density of charge carriers)

Where:

- B = magnetic flux density (T)
- q = charge of the electron (C)
- I = current (A)
- n = number density of electrons (m^{-3})
- t = thickness of the conductor (m)

① $E = \frac{V_H}{d}$

② $F_B = Bqv$ $\quad F_E = qE$

$Bqv = qE$

$Bv = E$

$Bv = \frac{V_H}{d}$

③ $I = nAvq \Rightarrow v = \frac{I}{nAq}$

④ $B\frac{I}{nAq} = \frac{V_H}{d}$

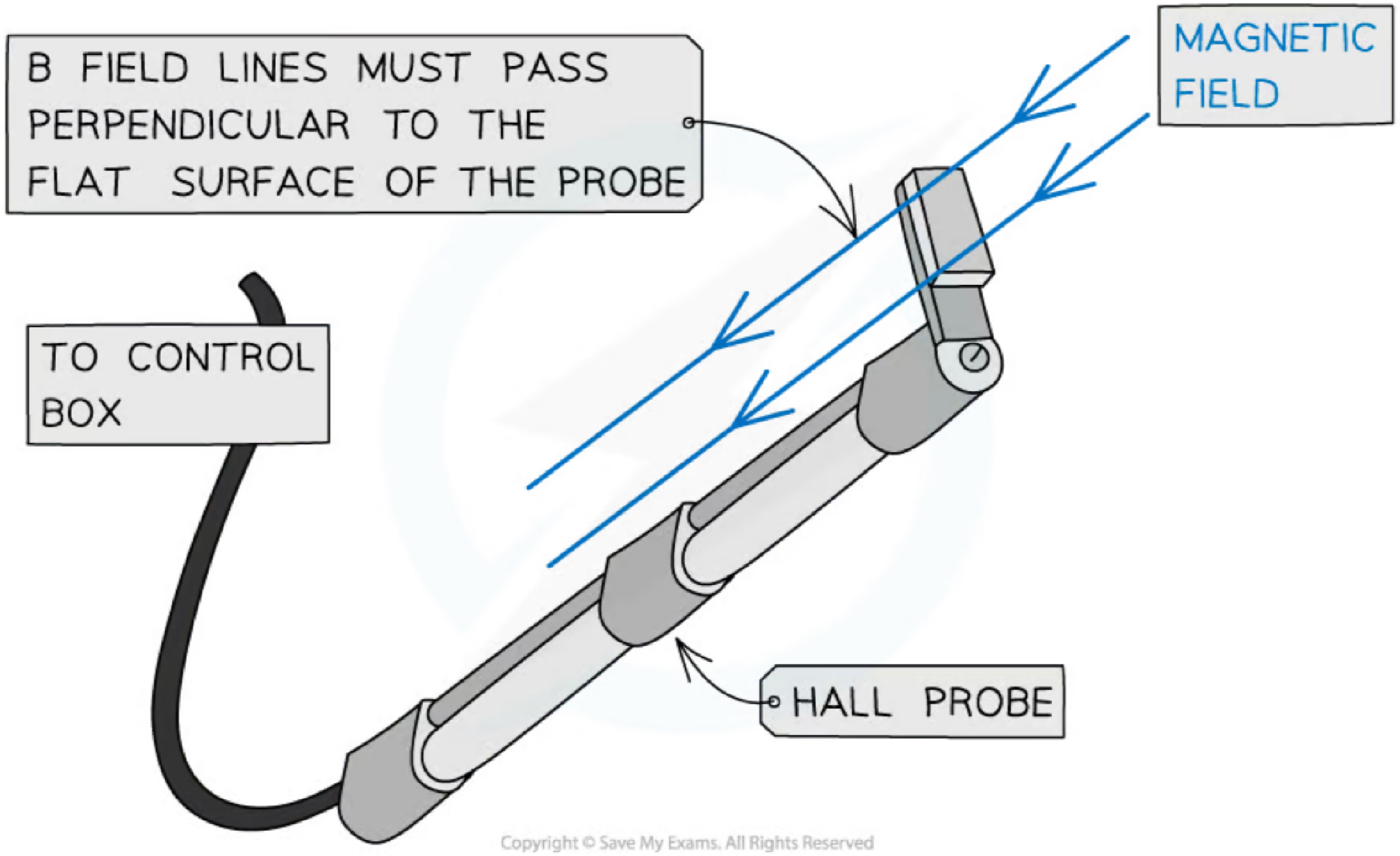
⑤ $A = dt$

⑥ $B\frac{I}{ndtq} = \frac{V_H}{d}$

$\therefore V_H = B\frac{I}{ntq}$

Hall Probe

Hall probe is an instrument to measure magnetic flux density(B) between two magnets based on the Hall effect



It is important that Hall probe is held in the correct orientation (Hall voltage is directly proportional to the magnetic flux density)

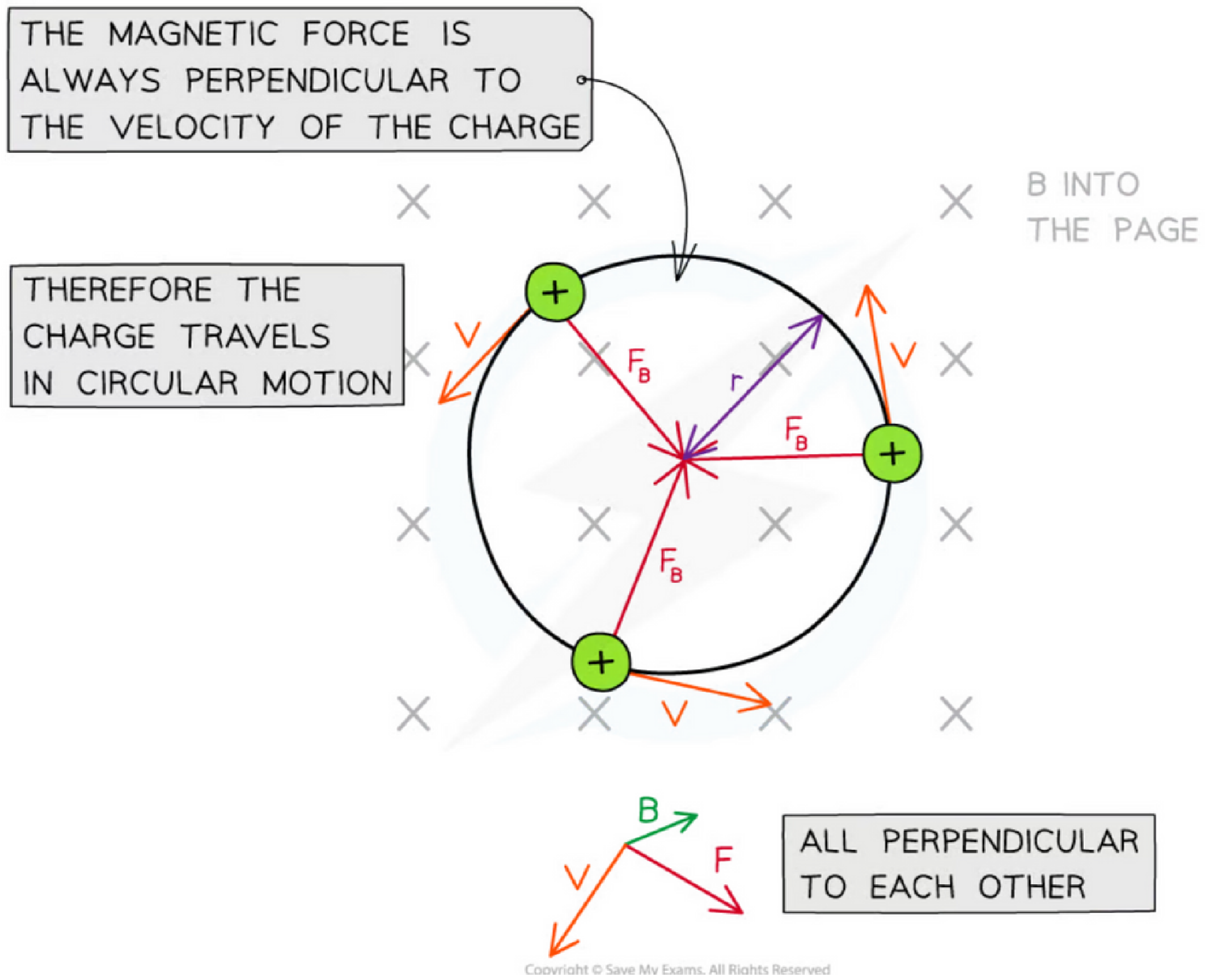
Hall voltage reaches a maximum when the field is perpendicular to the probe

Hall voltage is zero when the field is parallel to the probe

Motion of a Charged Particle in a Magnetic Field

A **charged particle** in **<u>uniform magnetic field</u> which is <u>perpendicular</u> to its direction of motion(velocity)** travels in a **circular** path

This is because **magnetic force will always be perpendicular to its velocity v** (due to Fleming's left-hand rule)



The magnetic force provides the centripetal force on the particle so we can equate equations together

$$F = \frac{mv^2}{r} \qquad F = Bqv$$

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

$$r = \frac{mv}{Bq}$$

Where:

- m = mass of the particle (kg)
- v = linear velocity of the particle ($m\,s^{-1}$)
- r = radius of the orbit (m)

Velocity Selection

Velocity selector is a device consisting of perpendicular e-field and b-field where charged particles with a specific velocity can be filtered

The construction of a velocity selector consists of:

-two horrizontal oppositely charged plates

-in a vacuum chamber

-->the plates provide a uniform E-field

There is also a uniform B-field with magnetic flux density B applied perpendicular to the E-field

When a beam of charged particles enter between the plates, they may all have the same charge but travel at different speeds v

Electric force does not depend on the velocity: F=EQ

Magnetic force does depend on the velocity: F=BQv

To select particles travelling at exactly the desired speed, the electric and magnetic force must be equal but in opposite directions.

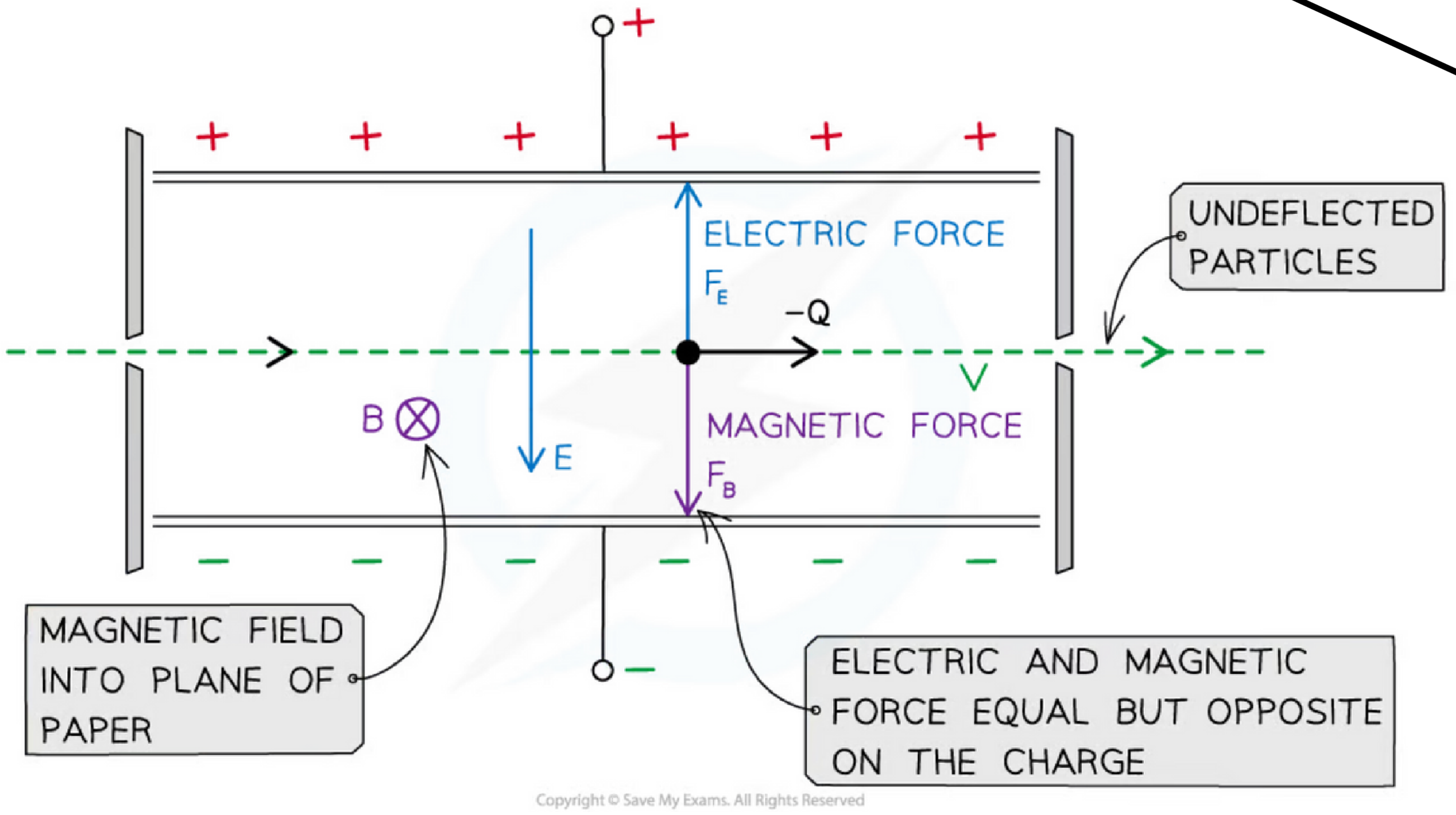
$$F_E = F_B$$
$$EQ = BQv$$

The charge Q will cancel out on both sides to give the selected velocity v equation:

$$v = \frac{E}{B}$$

Resultant force on the particle at v = 0 , so they will pass striaght throught between the plates without deflection

$F_E = F_B$



If a particle has a speed greater or less than v, the magnetic force will deflect it and collide with one of the charged plates. This would remove the particles in the beam that are not EXACTLY at speed v.

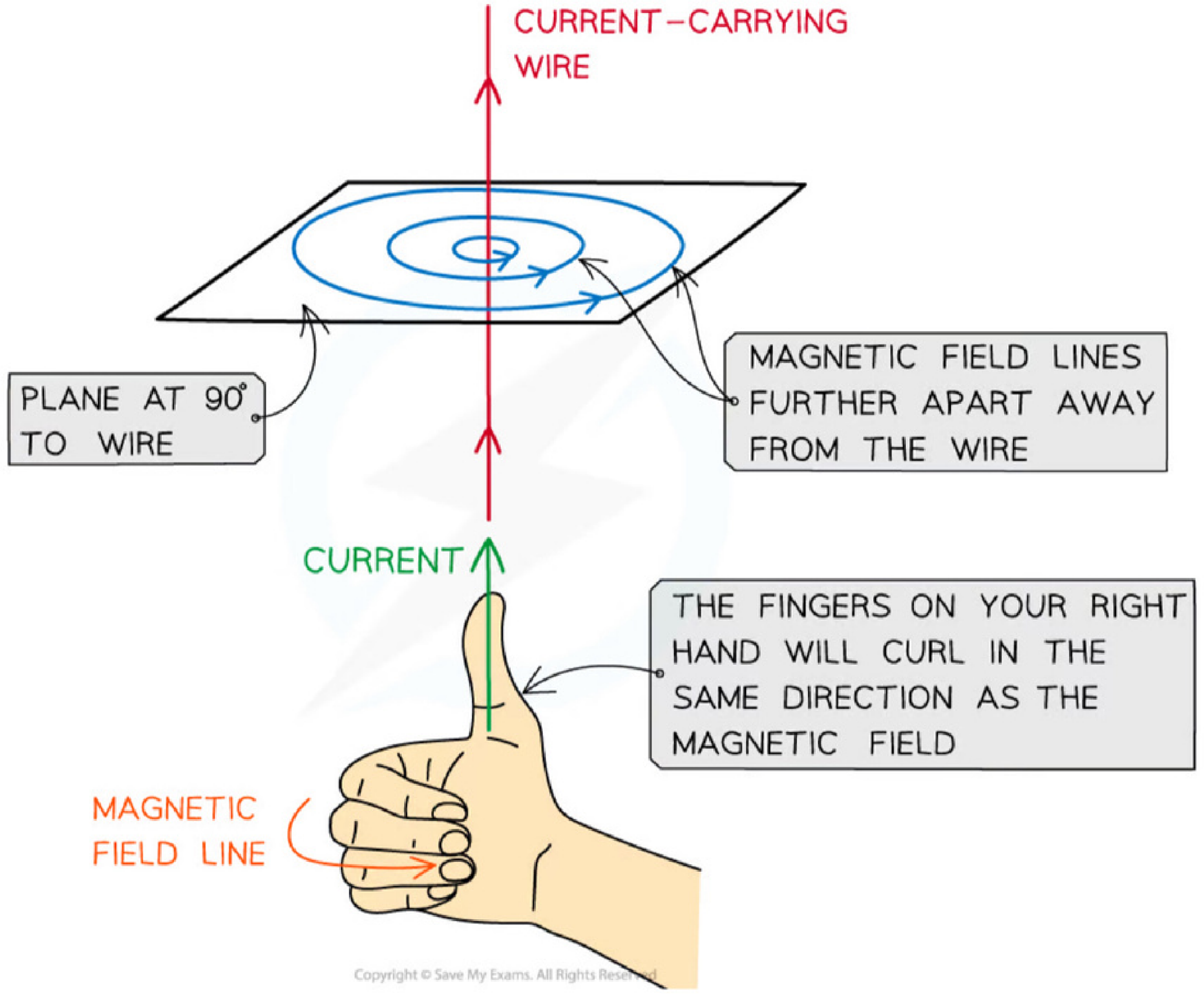
a flat circular coil = one of the coils of a solenoid

Field Lines

Field Lines in a Current-Carrying Wire

electric current produces B-field

Maxwell's right hand scew rule

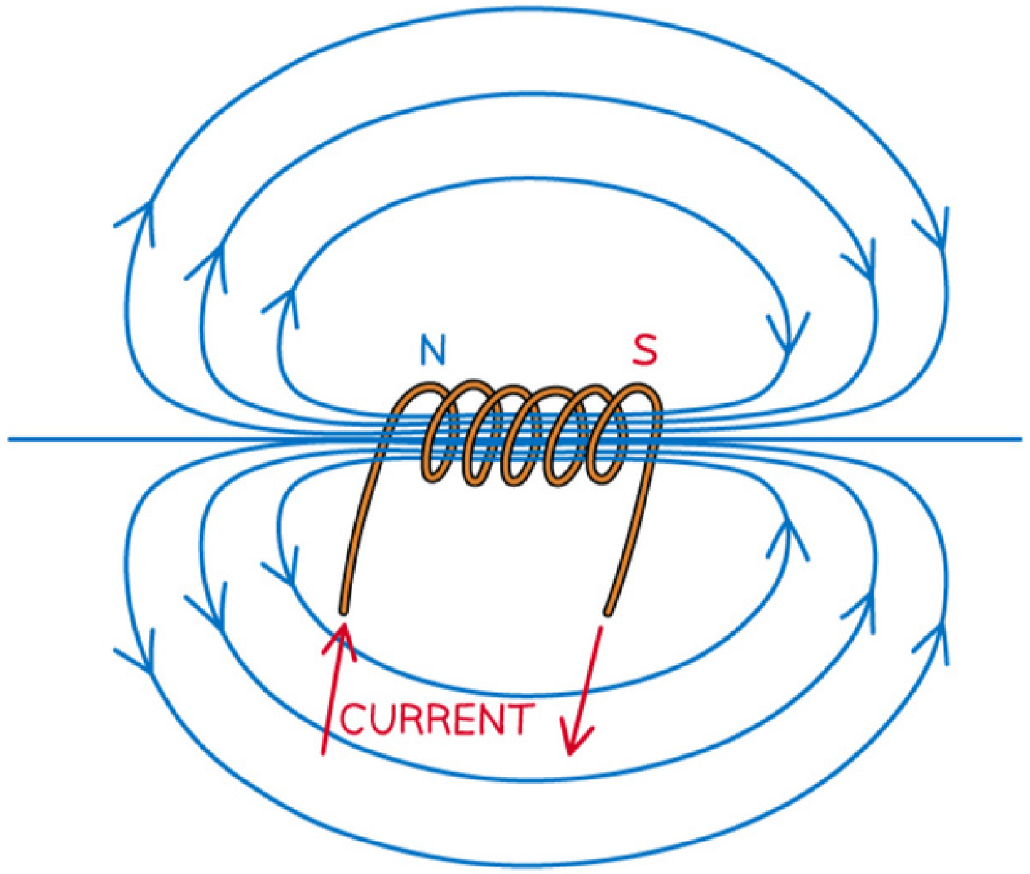


-->reversing the current reverses the direction of the field

Field Lines in a Solenoid

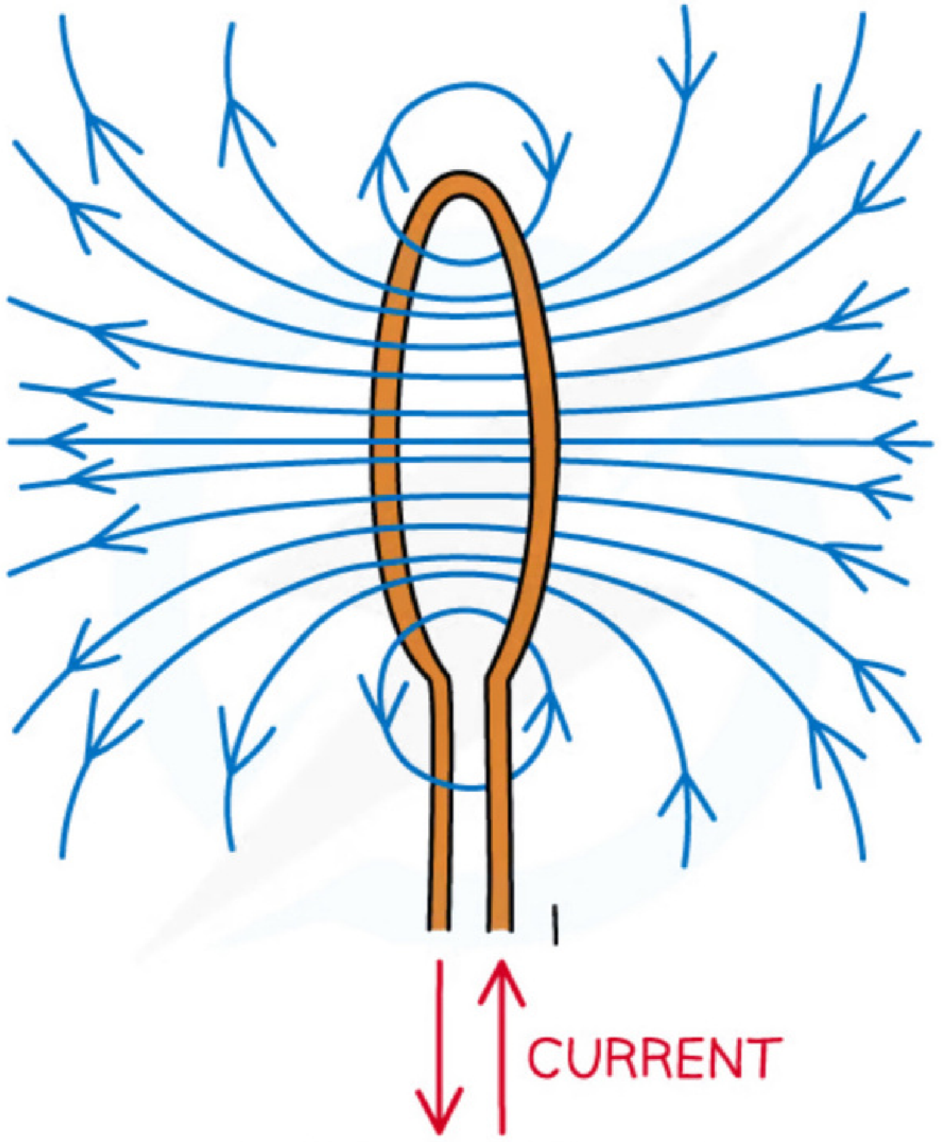
right hand grip rule

thumb point towards N



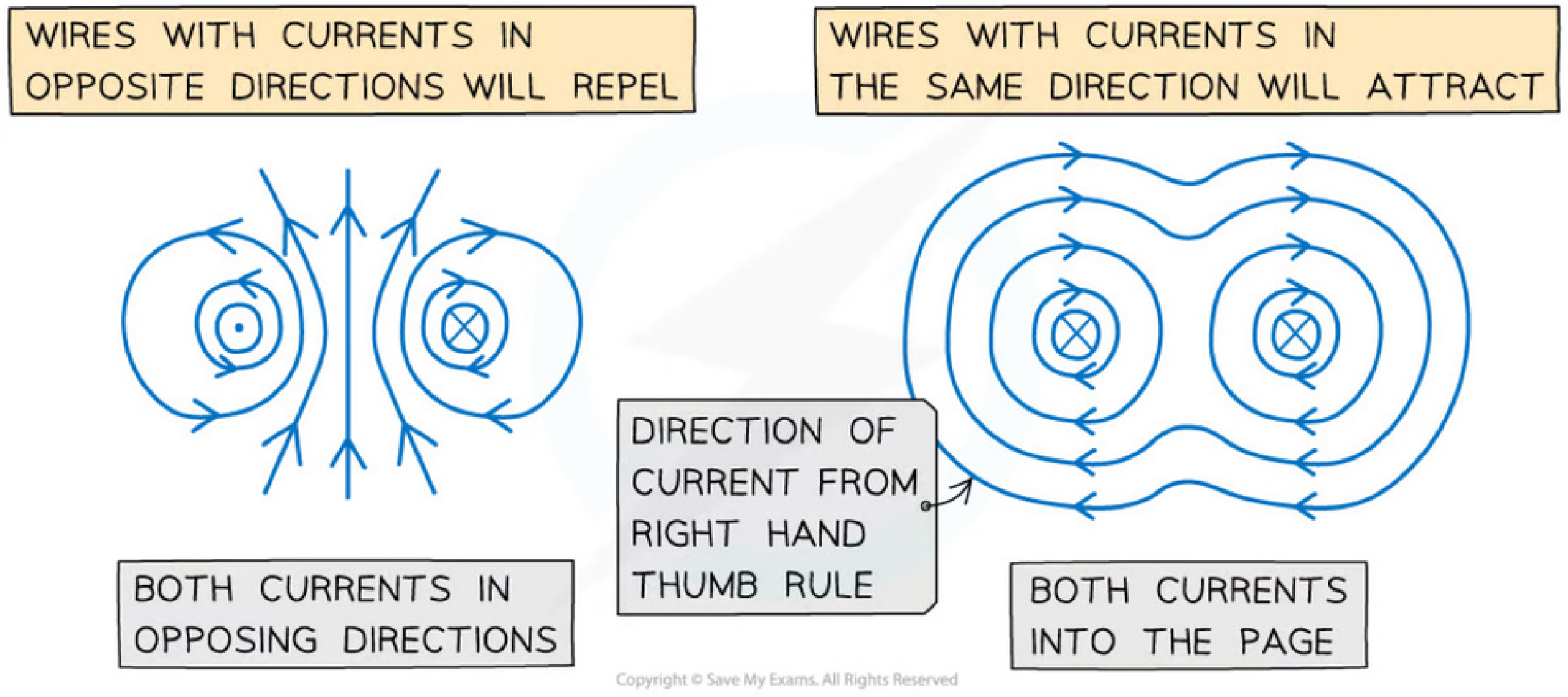
Field Lines in a Flat Circular Coil

right hand thumb rule



increase B-field strength:
1.adding a core made from a **ferrous**(iron-rich) material e.g. iron rod
2.adding more turns in the coil

Forces between CCC



a CCC such as wire produce B-field around it
-->direction of B-field depends on direction of the current(which determined by right hand thumb rule)

parallel CCC will therefore either attract or repel each other:

if currents are in the same directions in both conductors, **B-field cancle out between conductors** - conductors will **attract** each other + direction of B-fields will be toward each other

if currents are in the opposite direction in both conductors, **B-field push each other apart between conductors** - conducts will **repel** each other + direction of B-field will be away from each other

this is due to Newton 3rd law, forces on the wires act in equal but opposite directions