Motion in Electromagnetic Fields

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Course	HL IB Physics
Section	Fields
Topic	Motion in Electromagnetic Fields
Difficulty	Medium

To be used by all students preparing for HL IB Physics
Students of other boards may also find this useful

1

The correct answer is **B** because:

- The magnetic force on a current carrying conductor is calculated using the formula:
  - $F = BIL \sin\theta$ where B is the magnetic field strength, I is the current, L is the length of the wire and θ is the angle between the current and field
- Since the angle θ is 90°, sin 90 = 1
- Therefore, the equation becomes:
  - $F = BIL$
- Substituting in the values gives:
  - $F = 4 \times (3 \times 10^{-3}) \times 2 \times 1 = 0.024$ N

A is incorrect as the formula is $F = BIL \sin\theta$ and not just $F = BI$

C is correct as the formula is $F = BIL \sin\theta$ and not just $F = BL$

D is correct as the current is 3 mA = 3×10^{-3} A and not 3 A

Remember that sin(90) = 1, so the maximum force is present in the conductor when it is at 90° to the magnetic field. This is a value you must just remember without needing your calculator.

2

The correct answer is **C** because:

- The magnetic force on a moving charged particle is
  - $F = qvB \sin\theta$
- Where
  - q is the charge of the proton
  - v is the speed of the proton
  - B is the magnetic flux density
  - θ = 90° (the proton moves **normally**)
- Therefore,
  - sin 90 = 1
- The equation becomes:
  - $F = qvB$

- The charge of the proton, q is the same as the charge of an electron
  - This is 1.6×10^{-19} C (in your data booklet)
- So, the answer is $F = (1.6 \times 10^{-19}) Bv$

A is incorrect as $F = qvB \sin \theta$ is the formula for the magnetic force on a moving charged particle. In the formula q represents charge. The charge on a proton is 1.6×10^{-19} and not p

B is incorrect as whilst $F = BIL \sin \theta$ is also an equation for magnetic force it is not the correct equation with the variables given

D is incorrect as the formula is $F = BIL \sin \theta$ and not just $F = BI$

This question requires you to recognise the correct formula for magnetic force using the quantities given. You will be expected to always remember that the charge of the proton is the same as the charge of an electron. This is because atoms are always neutral (they have no charge) and neutrons have no charge. Therefore, there are the same number of protons and electrons in a neutral atom.

3

The correct answer is **D** because:

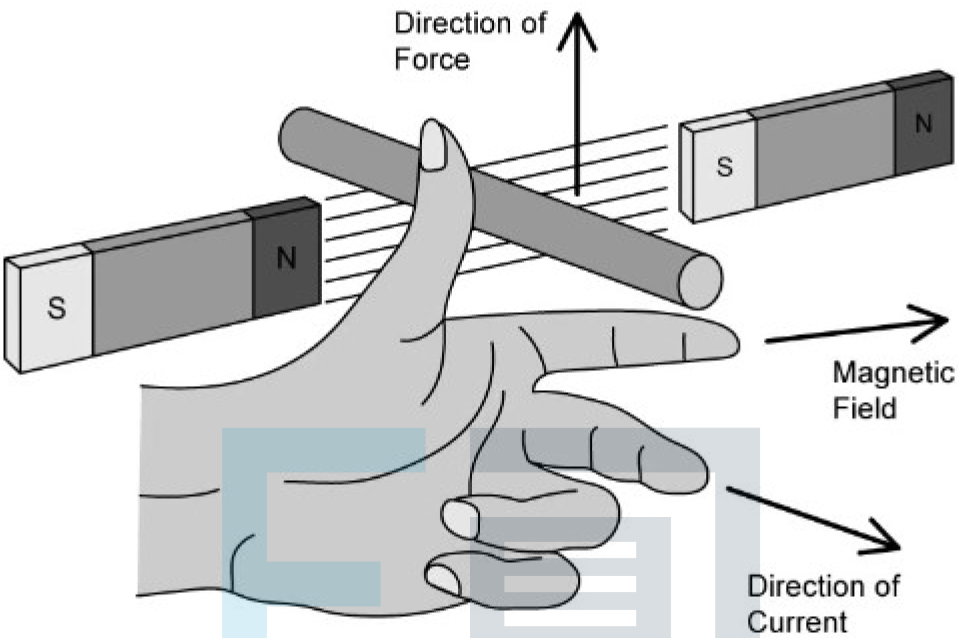
- If the particle is at rest, then $v = 0$
- The magnetic force is defined by the equation
  - $F = qvB \sin \theta$
- Force F is directly proportional to speed v
  - Therefore, when $v = 0$ then $F = 0$

The main difference between how particles experience forces in electric and magnetic fields is that there is an electric force whether the particle is stationary or moving, whilst there is only a magnetic force when the particle is moving and **not** when it is stationary.

4

The correct answer is **C** because:

- Using Fleming's Left Hand Rule, direction of the force on the electron can be determined:



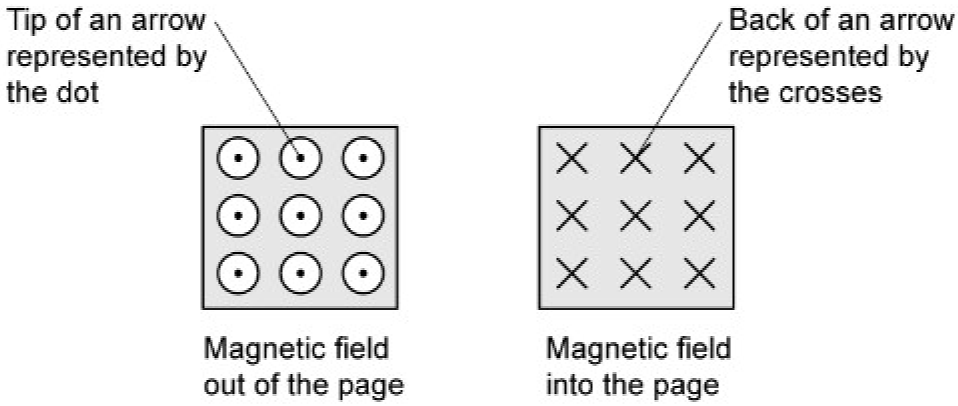
  - Line your first finger up with the direction of the magnetic field lines
  - Line your second finger up with the direction of the current, this is the opposite direction of the movement of the electron
  - The thumb will then indicate the direction of the force, this needs to be going down the page

- Answer option **C** is the only one that works indicating the force on the electron going down the page

A is incorrect as using Fleming's Left Hand Rule the magnetic field lines are coming out of the page and the current is going right to left across the page. The force on the electron is then going **up** the page and not down the page as required

B & **D** are incorrect as the force on the electron, the current and magnetic fields must all be perpendicular to each other. If the current is to the left, and the force to be downwards, the field lines must be into or out of the page

It is important to recognise the symbols for the direction of magnetic fields into and out of the page.

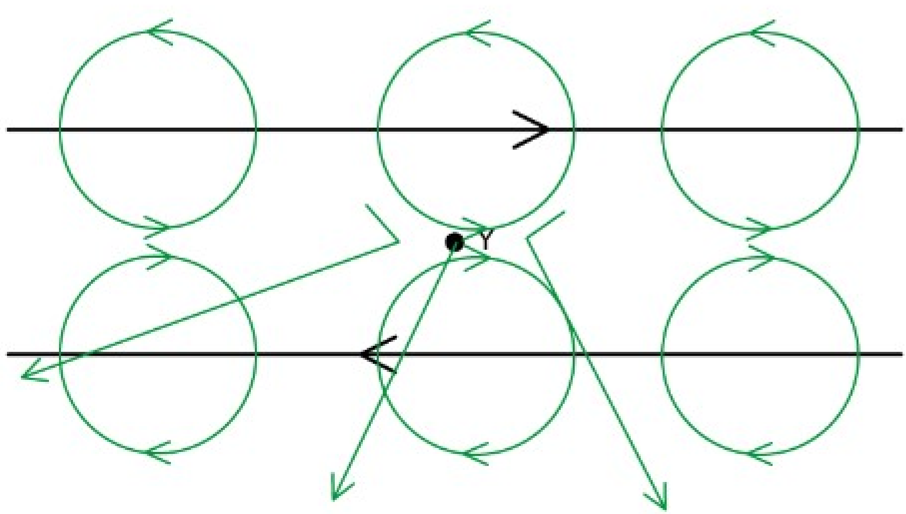


The important thing to notice is that current is always the direction of **positive** charge flow. Therefore, if there is a negative particle, such an electron, remember the current flow is in the **opposite** direction to the direction of a negative charge.

5

The correct answer is **A** because:

- The two wires contain current travelling in opposite directions
- The directions of the currents can be determined by the right hand grip rule
- This means the magnetic fields generated around the wires repel each other

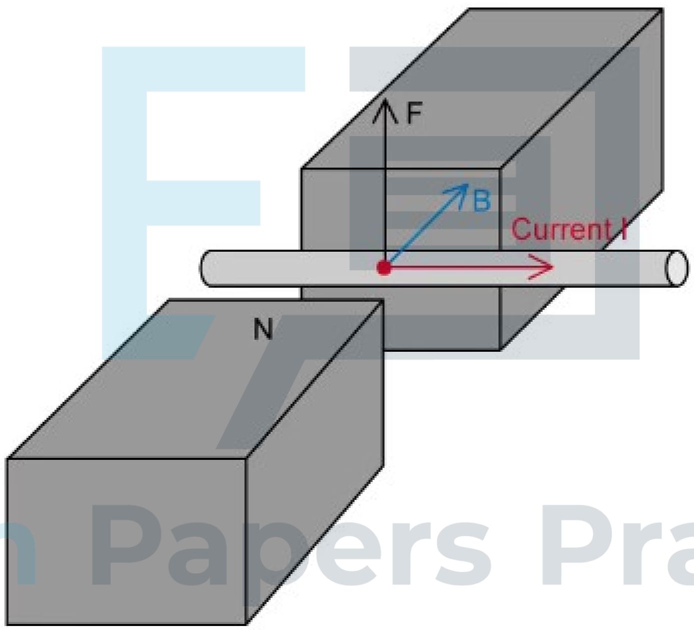


- The field generated is at right angles to the plane of the page
    - It will technically be going into the page

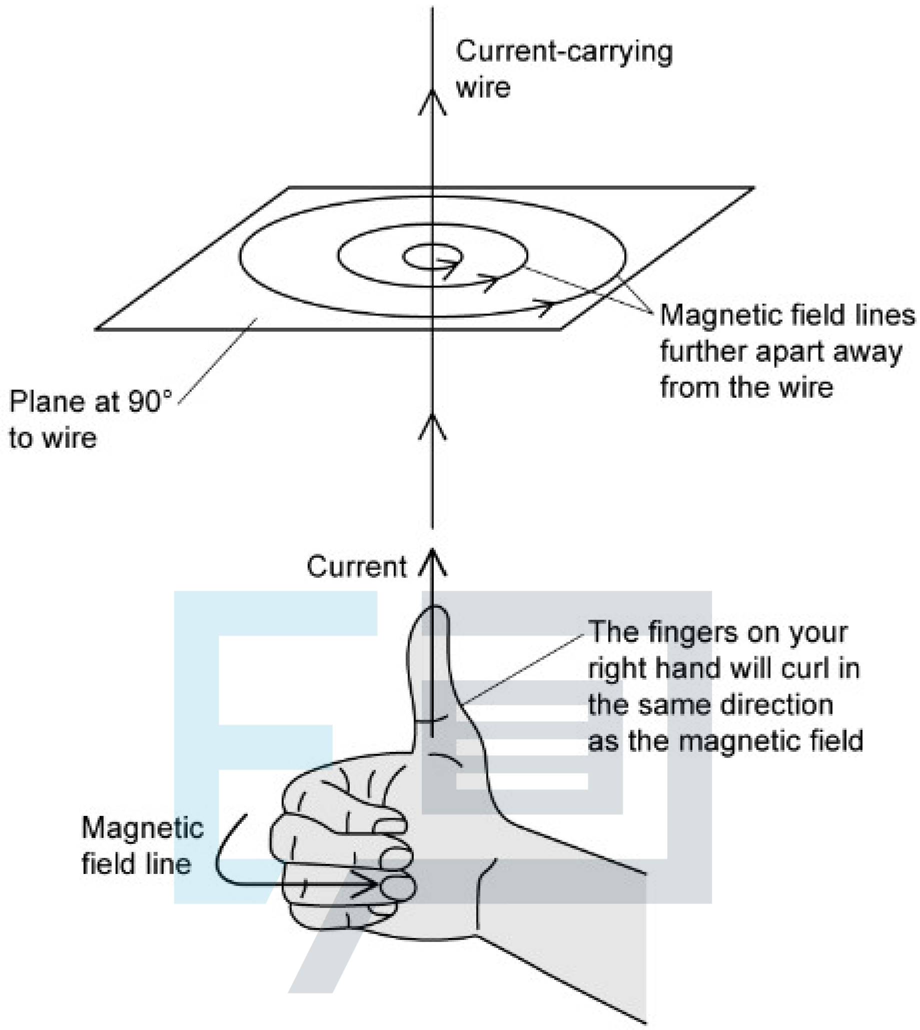
B & C are incorrect as a current carrying wire generates a magnetic field around it and not an electric field

D is incorrect as the magnetic field generated is at right angles to the direction of the current in the wire and not in the same direction

If magnetic field lines are perpendicular to the direction of the current, then the force produced is also at right angles to this.



Remember the right-hand grip rule is used to determine the direction of circular magnetic field lines around a current-carrying conductor! You should be able to direct your thumb downwards (the direction of current flows 'down', from A to B in the wire) and observe your fingers curling in a **clockwise** direction. Therefore, the magnetic field lines around a current from A to B are in a clockwise direction.



6

The incorrect answer is **B** because:

- The electric force on an electron $F_E = EQ = Ee$
  - Where E is the electric field strength and e is the electron charge
- The magnetic force on an electron moving perpendicular to a magnetic field is given by:
  - $F_B = Bev$ where B is the magnetic flux density and v is the electron's velocity
- Therefore, since the electron remains undeflected, the resultant force on it must be zero
- This means the electric force equals the magnetic field
  - $Ee = Bev$

- Rearranging for the velocity, v gives:
  - $v = \frac{E}{B}$
- The velocity of the electrons is equal to the ratio of the electric field strength E to the magnetic flux density B, not the other way around
  - Therefore, **B** is incorrect

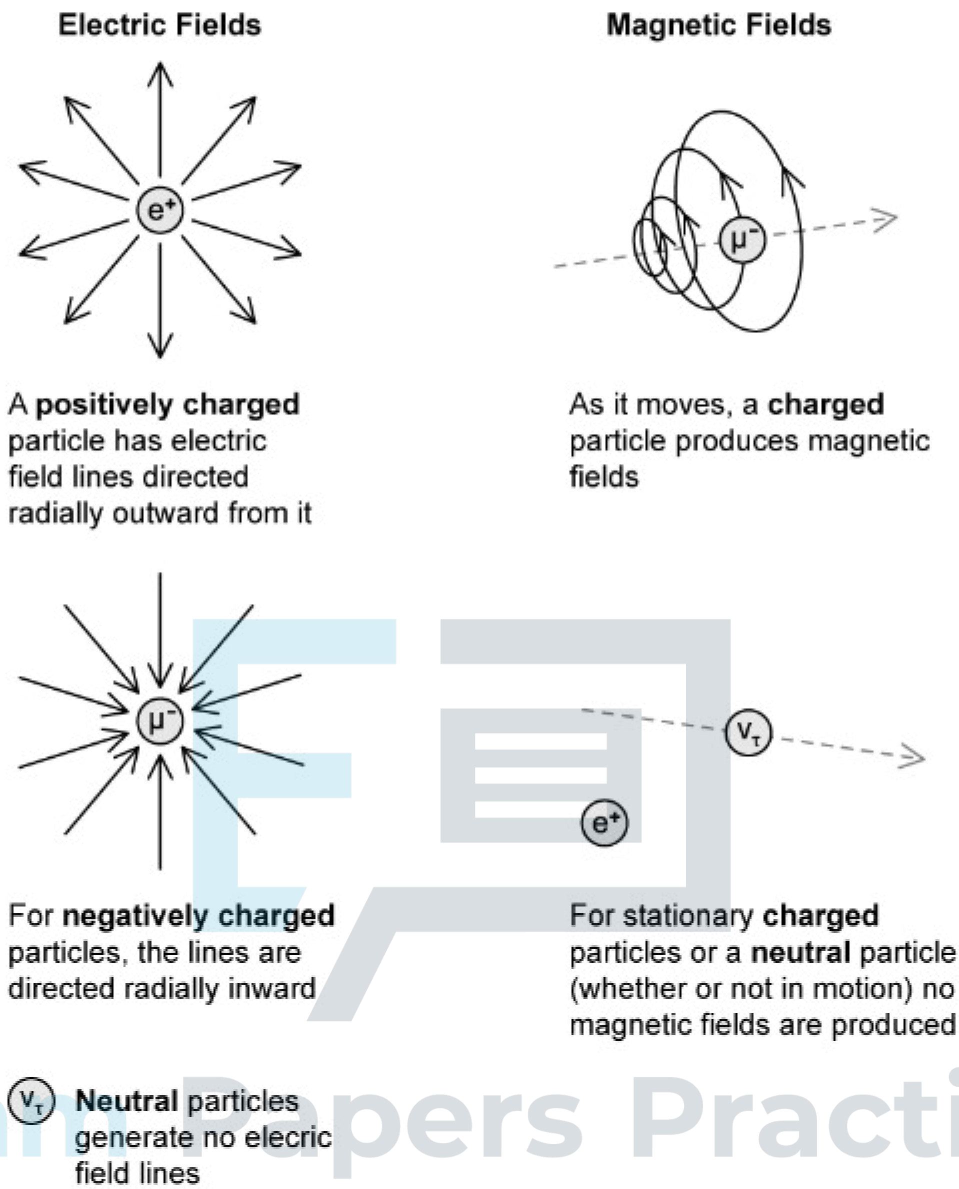
A is correct asthe electrons flow from left to right in this diagram, so conventional current (the flow of positive charge) is flowing from right to left

C is correct as using Fleming's Left-Hand Rule to work out the direction of the magnetic force on a charged particle:

- your first finger should be directed into the page (the direction of the magnetic field)
- your second finger should be pointing to the left, because electrons moving to the right is equivalent to a conventional current moving to the left
- You should see your thumb points downward, or 'south', which is the direction of the magnetic force on the electrons

D is correct as electric field lines show the direction of the electric field strength – that is, the direction of the electric force on a positive test charge. Since the electric field lines are directed 'south', the electric force on a negatively charged electron is in the 'north' direction

You may be required to answer questions linking between magnetic and electric fields. Make sure you familiarise yourself with how these two fields interact with each other.



7

The correct answer is **D** because:

- The magnetic force on an electron moving in a magnetic field is:
  - $F = qvB\sin\theta$
- Since it is moving perpendicular, $\theta = 90°$ so $\sin\theta = 1$
- The equation becomes:
  - $F = qvB$
- If the charge on an alpha particle is q so the charge on an electron is $\frac{-q}{2}$

- Changing v to v/2, B to B/2, and q to $\frac{-q}{2}$ gives:
  - New force = $\frac{-q}{2}$

  × v/2 × B/2 = −qvB/8
- Therefore, the force is 8 times less than before and is negative
  - New force = −F / 8

A is incorrect as the electron is moving perpendicular, not parallel, to the magnetic field lines so it does experience some force

B is incorrect as the numerator has been incorrectly calculated as 6 instead of 8

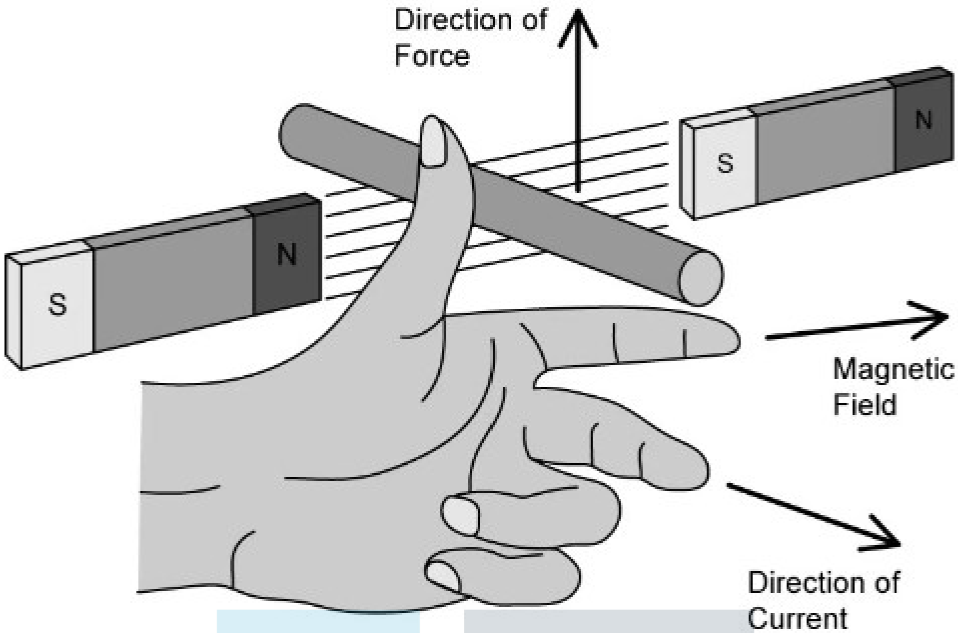
C is incorrect as the electron doesn't have the same charge as the alpha particle. The alpha particle has a charge of +2q and the electron has -q

Always check the difference particles now involved when comparing two. They may not have the same charge, so don't just go off the changes given for the numbers in the question but also make sure you've got all the charges in charge, velocity and field strength.

8

The correct answer is **D** because:

- The direction of the field lines is from N to S pole
- Using Fleming's Left Hand Rule, direction of the force on the proton can be determined:



Left Hand Rule

- Line your first finger up with the direction of the magnetic field lines. This is from N to S, so from left to right
- Line your second finger up in the direction of the current, this is downwards, in the same direction as the proton (since it is a positive charge)
- The thumb will then indicate the direction of the force, this is towards you, or out of the page

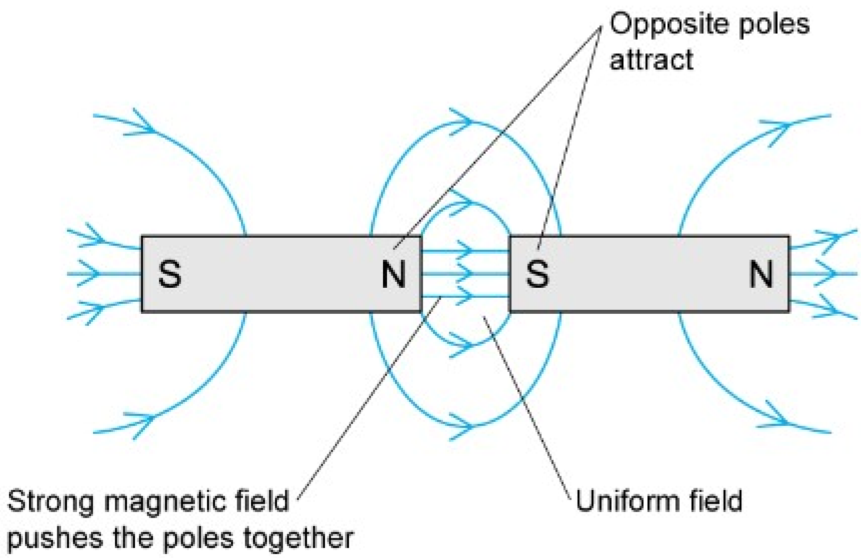
A is incorrect as the force acting on it would be going from top to bottom, if the proton was moving into the page

B is incorrect as this situation it is not possible to have the force and magnetic field in the same direction. This situation does not exist

C is incorrect as a proton is a charged particle and is moving through a magnetic field, so it will experience a force. It wouldn't if it was stationary.

Remember also that the direction of movement of a proton is the same as the direction of movement of a current (i.e direction of positive charge).

Remembering how magnetic fields between attracting magnets work can help answer similar questions too.



Two attracting bar magnets

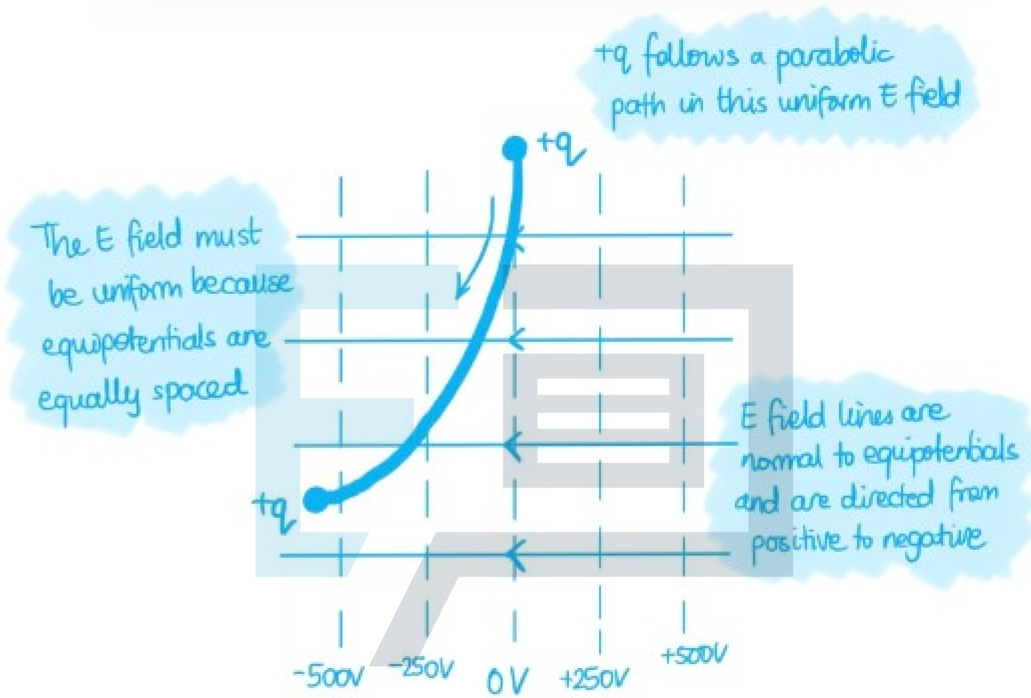
9

The correct answer is **A** because:

- The small point charge +*q* is positively charged, therefore it will move toward areas of negative charge
  - Negative charge creates a negative potential
  - Therefore, the point charge should move **toward** negative potential in the image
  - Only options **A** or **B** could be correct
- The equipotentials are equally spaced, which means the electric field strength is constant
  - This is because the gradient of the potential is constant
  - Therefore, the point charge will follow a **parabolic** path, because the electric force is constant
  - Hence, the correct path shown is path **A**

Electric field lines are always directed from areas of positive charge to areas of negative charge. Recognising that you can visualise the shape and direction of the electric field - because you are given information about the equipotentials - is crucial for this question.

Since the equipotentials are uniformly spaced (more specifically, the change in potential ΔV is **constant** for equal changes in distance), then the **gradient** of the potential is constant; which means the **electric field strength** is constant. Thus, this electric field must be **uniform.** A vertically falling charged particle will therefore follow a parabola, as shown in the image below:



Note that this is exactly analogous to a projectile of mass m "falling" into a uniform gravitational field. You should remember that such projectile motion is parabolic, for the same reasons as above.

10

The correct answer is **A** because:

- Particle **X** is deflected towards the positive plate, so that **X** must be a negatively charged particle
  - Alpha particles contain 2 protons and 2 neutrons since they are a helium nucleus, so the alpha particle carries positive charge
  - Neutrons are neutral, carrying no charge
  - This eliminates options **B** and **C**

- Particle **Y** passes straight though, suggesting that it probably has no charge (it could have such small charge it isn't deflected)
  - Electrons carry negative charge
  - Beta-plus particles carry positive charge
  - Assuming that the question is 'fair' (not a trick question), this (probably) eliminates options **C** and **D**
- Particle **Z** is deflected towards the negative plate, so that **Z** must be a positively charged particle
  - All nuclei are positively charged
  - Photons and neutrons do not carry charge
  - This eliminates **B** and **D**
- Only option **A** remains, even with the slight doubt over particle **Y**

You should be comfortable knowing that 'like charges repel' and 'unlike charges attract'. You also need to be able to confidently state whether particles such as photons, beta-minus and beta-plus and nuclei carry charge and of which type.

11

The correct answer is **C** because:

- The force on the proton can be found using two different equations from the data booklet:
  - From Topic 5.4, $F = qvB\ sin\ \theta$ and from Topic 6.1, $F = \frac{mv^2}{r}$
- Combining these equations shows that; $qvB\ sin\ \theta = \frac{mv^2}{r}$
  - The angle $\theta = 90°$ therefore sin $\theta = 1$ and can be cancelled out
  - Velocity v is on both sides and can be cancelled
  - The remaining equation can be arranged to make the radius, r, the subject
  - $q\cancel{v}B\ \cancel{sin\ \theta} = \frac{mv^{\cancel{2}}}{r}$
  - $r = \frac{mv}{qB}$
- The data booklet lists the mass of the proton, $m = 1.67 \times 10^{-27}$ kg and the charge on the proton, $q = 1.67 \times 10^{-19}$ kg

- The velocity, v, of the proton is given as 1.5×10^7 m s^{-1}, and the flux density, B, as 0.30 T
- Substituting the known values leads to an estimate for the final answer
  - $r = \frac{(1.6 \times 10^{-27}) \times (1.5 \times 10^7)}{(1.6 \times 10^{-19}) \times 0.30} = \frac{1.6}{1.6} \times \frac{1.5}{0.30} \times \frac{(10^7 \times 10^{-27})}{10^{-19}}$
  - The 1.6 in the numerator and denominator cancel out
  - $15 \div 3 = 5$
  - Therefore, $r = \frac{\cancel{1.6}}{\cancel{1.6}} \times \frac{5}{\cancel{0.30}} \times \frac{10^{-20}}{10^{-19}} = 5 \times 10^{-1} = 0.5 \text{ m}$
- This is answer **C**