Past-paper walk-through

Force on a current-carrying conductor ▪ 20.2

eXercise

Questions in this set

- 9702/43 J25 Q7 ▪ 10 marks
- 9702/44 J25 Q6 ▪ 10 marks
- 9702/43 N23 Q6 ▪ 12 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

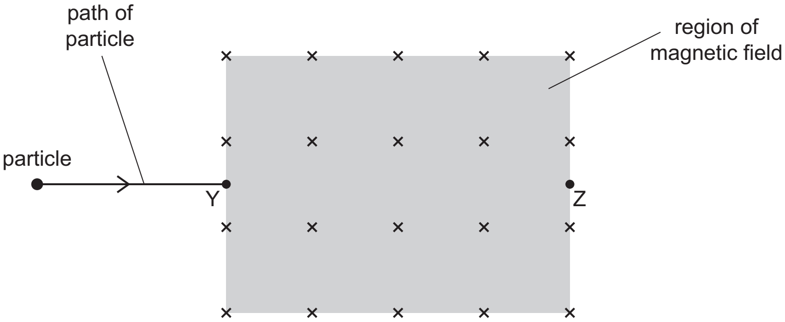
Question 7

9702/43 J25 ▪ Q7 ▪ 10 marks

7 **(a)** Define magnetic flux density.

Question 7

(b) A particle of mass m and charge $+Q$ moves at speed v into a region where there is a uniform magnetic field, as shown in Fig. 7.1.



Question 7

Question 7

Fig. 7.1

The uniform magnetic field is into the page and has flux density B. The particle enters the region of the field at point Y.

(i) State an expression, in terms of some or all of m, Q, B and v, for the magnetic force F that acts on the particle when it is at point Y.

Question 7

(ii) On Fig. 7.1, draw an arrow at point Y to indicate the direction of the force in **(b)(i)**. [1]

(iii) On Fig. 7.1, draw a line to show a possible path for the particle through the region of the magnetic field. [1]

(c) **(i)** Explain how an electric field can be used with the magnetic field to ensure that the particle in **(b)** now passes through point Z.

Question 7

(ii) Derive an expression for v in terms of B and the electric field strength E.

Question 7

[Total: 10]

Solution 7

(a) Worked steps

Magnetic flux density is **defined by the force it exerts**, so the definition has to say force per unit of *what*, and under what condition. Build it from $F = BIL$ rearranged as $B = \dfrac{F}{IL}$ — every term in that fraction becomes a phrase.
Three separate points are credited, and two of them earn the marks:

- force **per unit length** (of the conductor) — the L in the denominator;
- force **per unit current** — the I;
- with the **current perpendicular to the field** — the condition under which $F = BIL$ holds at all.

Solution 7

So: *the force per unit length per unit current on a straight conductor placed at right angles to the field.*
The condition is what makes it a definition rather than a rough description. At any other angle the force is $BIL\sin\theta$, so the quotient $\dfrac{F}{IL}$ would not give B, and "perpendicular" is the word that fixes it. **Mark scheme**

- ▪
- force per unit length
- ▪
- force per unit current

Solution 7

- ▪
- length / current perpendicular to field
- 1 mark for any two points, 2 marks for all three points.

Solution 7

(b)(i)

Mark scheme

- $F = BQv$

(b)(ii)

Mark scheme

- arrow at Y pointing vertically upwards

Solution 7

(b)(iii)

Mark scheme

- upwards deflection showing circular path

Solution 7

(c)(i)

Mark scheme

- electric field applied vertically downwards (may be shown on a labelled diagram)
- electric force on particle in opposite direction to magnetic force (may be shown on a labelled diagram)
- particle undeflected when magnitudes of electric and magnetic forces are equal

Solution 7

(c)(ii) Worked steps

A charged particle passes through a velocity selector undeflected when the electric and magnetic forces on it are equal and opposite.

- Electric force: $F_E = EQ$
- Magnetic force on a charge moving perpendicular to the field: $F_B = BQv$
- Undeflected means $F_E = F_B$, so $EQ = BQv$.
- The charge Q cancels: $v = \dfrac{E}{B}$

Solution 7

Two things this result tells you, and both are worth writing down. The selected speed does **not** depend on the charge or the mass — every particle at that speed passes, whatever it is made of. And the two forces must be **antiparallel**, not merely equal in size, which is why the field directions in the diagram are arranged the way they are.

Solution 7

Substitute with E in $\mathrm{V\,m^{-1}}$ and B in tesla, and the speed comes out in $\mathrm{m\,s^{-1}}$ with no conversion.

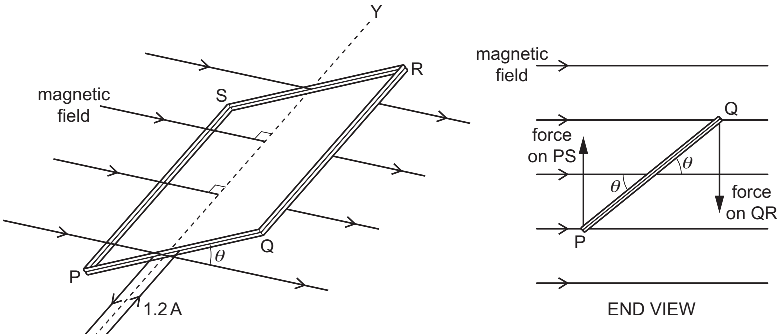
Mark scheme

- $\mathrm{EQ = BQv}$
- $\mathrm{v = E\,/\,B}$
- 9702/43
- May/June 2025

Question 6

9702/44 J25 ▪ Q6 ▪ 10 marks

6 A rectangular coil PQRS of wire is free to rotate about its axis XY, as shown in Fig. 6.1.



Question 6

Fig. 6.1 (not to scale)

The coil has length QR of 5.4 cm, width PQ of 2.5 cm and has 190 turns of wire.
The plane of the coil is at an angle θ to a uniform magnetic field of flux density 5.2×10^{-3} T.
The axis XY of the coil is normal to the field.
The current in the coil is 1.2 A.

(a) **(i)** Calculate the magnitude of the force on side QR of the coil.

Question 6

Question 6

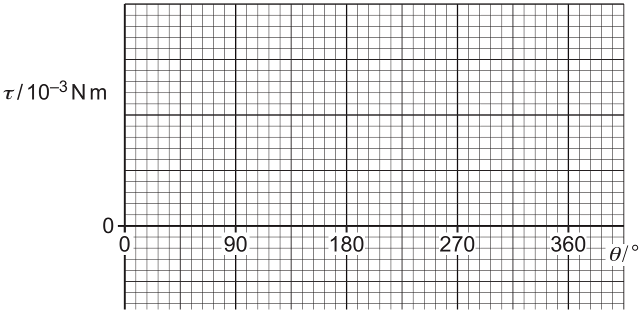
(ii) Use your answer in **(a)(i)** to show that the torque τ on the coil is given by

$$\tau = 1.6 \times 10^{-3} \cos\theta \text{ N m.}$$

Question 6

[2]

(iii) Using the expression in **(a)(ii)** sketch, on the axes of Fig. 6.2, a graph to show the variation of the torque τ with angle θ for values of θ between 0 and 360°. Label the τ axis with an appropriate scale.



Question 6

Question 6

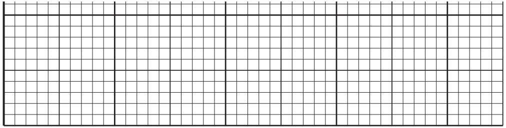


Fig. 6.2

[3]

(b) The coil is now replaced by an identical coil wound on a ferrous core.

Suggest, with a reason, how the torque on this coil compares with the torque on the original coil.

Question 6

[Total: 10]

Solution 6

(a)(i) Worked steps

The force on a wire in a magnetic field is $F = BIL$, and it is a maximum when the current is perpendicular to the field. QR runs along the coil's length, and the end view shows the current in QR staying perpendicular to the field as the coil turns — which is why the angle does not appear here.

- One turn: $F = BIL = 5.2 \times 10^{-3} \times 1.2 \times 0.054$
- The coil has 190 turns carrying the same current along the same side, so multiply by N: $F = 5.2 \times 10^{-3} \times 1.2 \times 0.054 \times 190$
- $F = 0.064$ N

Solution 6

Two habits that protect the marks: convert **5.4 cm to 0.054 m** before substituting, and put the 190 in. Forgetting the number of turns gives 3.4×10^{-4} N, which is the single most common wrong answer to this type.

Mark scheme

- F = BIL
- force on QR = 5.2 × 10–3 × 1.2 × 0.054 × 190
- = 0.064 N

Solution 6

(a)(ii) Worked steps

PS carries the same current the opposite way, so it feels an equal and opposite force. Two equal, opposite, non-collinear forces are a **couple**, and the torque of a couple is the force times the perpendicular distance between the two lines of action.

- The forces are separated by the coil's width $PQ = 2.5$ cm, but only the component of that separation perpendicular to the forces counts, which is $PQ\cos\theta$.
- $\tau = F \times PQ\cos\theta = 0.064 \times 0.025\cos\theta$
- $\tau = (1.6 \times 10^{-3})\cos\theta$ N m

Solution 6

Do **not** multiply by 190 again — it is already inside F. And do not halve the width: the torque of a couple uses the full separation, not the distance to the axis, because both forces contribute.

Mark scheme

- torque $=$ force $\times$ perpendicular distance between forces
- $= 0.064 \times 0.025 \cos\theta = (1.6 \times 10–3) \cos\theta$ N m

Solution 6

(a)(iii) Worked steps

Sketch the expression you have just derived, $\tau = (1.6 \times 10^{-3}) \cos\theta$, over 0 to $360°$. The mark scheme asks for three separate features:

1. **One complete cycle of a sinusoidal curve** between 0 and $360°$.
2. **The τ axis labelled** with the maximum and minimum, $\pm 1.6 \times 10^{-3}$ N m — the amplitude is the answer from (b).
3. **Maximum at 0 and $360°$, minimum at $180°$**, with the curve crossing zero at $90°$ and $270°$.

Solution 6

A cosine starting at its maximum is what the algebra says, so let the equation draw the graph. A curve that starts at zero is a sine, and it loses the third mark.

Mark scheme

- one complete cycle of a sinusoidal curve between 0 and 360°
- τ axis labelled to show maximum and minimum torques at $\pm\, 1.6 \times 10$–$3\,\mathrm{N\,m}$
- maximum at 0 and 360° and minimum at 180° (or vice versa), with torque shown as zero at 90° and 270°

Solution 6

(b) Worked steps

Adding a ferrous core changes one quantity in the chain, and everything else follows.

- Iron is ferromagnetic, so it **increases the magnetic flux density** through the coil.
- $F = BIL$ rises with B, so the force on each side rises.
- $\tau = F \times PQ \cos\theta$, so the **amplitude of the torque increases**.

Solution 6

The *shape* of the graph does not change — the angles of the maxima, minima and zeros are fixed by $\cos\theta$, not by B. Saying the curve shifts is the way to lose the mark.

Mark scheme

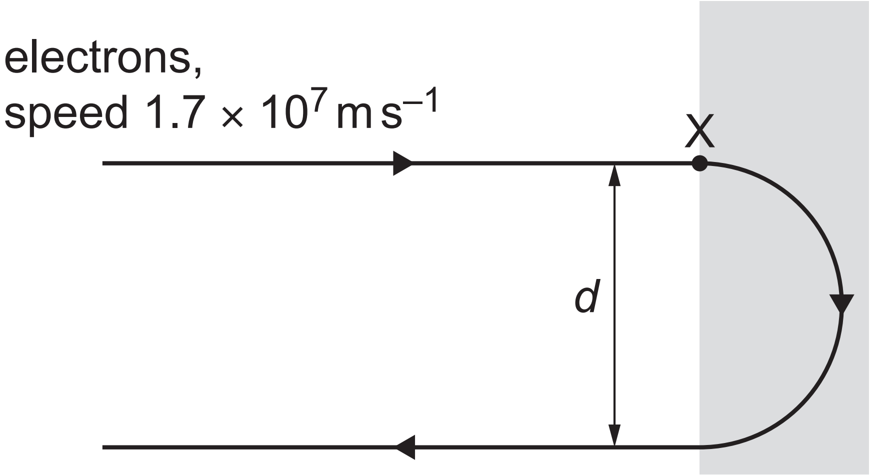
- (ferrous core) increases magnetic flux density
- amplitude of torque increases
- 9702/44
- May/June 2025

Question 6

9702/43 N23 ▪ Q6 ▪ 12 marks

(a) Define magnetic flux density. **[2]**

Question 6



Question 6

9702/43 N23 ▪ Q6 ▪ 12 marks

(b)(i) State the direction of the magnetic field. **[1]**

(b)(ii) Show that the magnitude of the force exerted on each electron by the magnetic field is 1.3×10^{-14} N. **[2]**

(b)(iii) On Fig. 6.1, draw an arrow to indicate the direction of the centripetal acceleration of the electron where it enters the magnetic field at point X. **[1]**

(b)(iv) Use the information in (b)(ii) to calculate the distance *d* between the path of the electrons entering the magnetic field and the path of the electrons leaving it. **[3]**

Question 6

9702/43 N23 ▪ Q6 ▪ 12 marks

(c) The electrons in (b) are replaced with positrons that are moving with speed 3.4×10^7 m s^{-1} along the same initial path as the electrons.
The positrons enter the magnetic field at point X on Fig. 6.1.
On Fig. 6.1, draw a line to show the path of the positrons through the magnetic field. **[3]**

Solution 6

(a)

Mark scheme

- ▪ force per unit length
- ▪ force per unit current
- ▪ length / current perpendicular to field
- 1 mark for any two points, 2 marks for all three points **B2**

Solution 6

(b)(i)

Mark scheme

- into the page **B1**

Solution 6

(b)(ii) Worked steps

Know. A charge moving at right angles to a magnetic field feels a force set by the field, the charge and the speed.
Equation. $F = Bqv$.
Substitute. $F = (4.8 \times 10^{-3})(1.6 \times 10^{-19})(1.7 \times 10^{7})$.
Answer. $F = 1.3 \times 10^{-14}$ N, as required.

Solution 6

Check. This form of the equation assumes the velocity is **perpendicular** to the field. If it were at an angle θ, a factor $\sin\theta$ would appear, and a beam travelling *along* the field would feel no force at all.

Mark scheme

- F = Bqv **C1**
- = 4.8 × 10–3 × 1.6 × 10–19 × 1.7 × 107 = 1.3 × 10–14 N **A1**

Solution 6

(b)(iii)

Worked steps

Know. The magnetic force on a charged particle is always at right angles to its velocity, so it does no work and only bends the path. That force **is** the centripetal force, and centripetal always means **towards the centre of the circle**.

Draw. An arrow at X, at right angles to the electron's velocity there, pointing **down the page** towards the centre of the curved path.

Check. The acceleration is not along the direction of motion, and not backwards along it either. The speed never changes in a magnetic field; only the direction does.

Mark scheme

- arrow at point X pointing down the page **B1**

Solution 6

(b)(iv) Worked steps

Know. The magnetic force supplies the centripetal force, so equate the two and solve for the radius of the circular path.

Equation. $F = \dfrac{mv^2}{r}$, so $r = \dfrac{mv^2}{F}$.

Substitute. $r = \dfrac{(9.11 \times 10^{-31})(1.7 \times 10^{7})^2}{1.3 \times 10^{-14}}$, giving $r = 0.020$ m.

Solution 6

Geometry. The beam enters and leaves the field region having turned through half a circle, so the two paths are separated by a **diameter**: $d = 2r$.
Answer. $d = 0.040$ m.
Check. The last mark is the doubling. Quoting the radius, 0.020 m, answers a question that was not asked and loses it.

Mark scheme

- F = mv2 / r **C1**
- 1.3 × 10–14 = (9.11 × 10–31) × (1.7 × 107)2 / r **C1**
- (r = 0.020 m) d = 2r d = 0.040 m **A1**

Solution 6

(c) Worked steps

Know. A positron has the same mass as an electron but the **opposite** charge, so at the same point in the same field it is pushed the opposite way. The radius of the path is $r = \dfrac{mv}{Bq}$, so doubling the speed doubles the radius.

Direction. The electrons curved downwards; the positrons therefore curve **upwards**, with the curvature anticlockwise all the way through the field.

Size. The speed is 3.4×10^7 m s^{-1}, twice the electrons' speed, so the radius is twice as large and the path is a noticeably gentler curve.

Solution 6

Where it leaves. Half a circle of twice the radius means the exit path is $2 \times 2r$ from the entry path, that is a distance $2d$ vertically from X.

Solution 6

Check. All three marks are visible in the drawing: the right direction, the larger radius, and the exit point. A path drawn with the same radius as the electrons' is the commonest slip, because the change of speed is easy to miss in the wording.

Mark scheme

- path shows upwards deflection such that the curvature is always anticlockwise within the field **B1**
- circular path with larger radius **B1**
- line enters field at X and leaves field at distance 2d vertically from X **B1**