Past-paper walk-through

Concept of a magnetic field ▪ 20.1

eXercise

Questions in this set

- 9702/43 J23 Q6 ▪ 10 marks
- 9702/44 J25 Q6 ▪ 10 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 6

9702/43 J23 ▪ Q6 ▪ 10 marks

6

(a) State what is meant by a magnetic field. **[2]**

(b) A long, straight wire P carries a current into the page, as shown in Fig. 6.1.

On Fig. 6.1, draw four field lines to represent the magnetic field around wire P due to the current in the wire. **[3]**

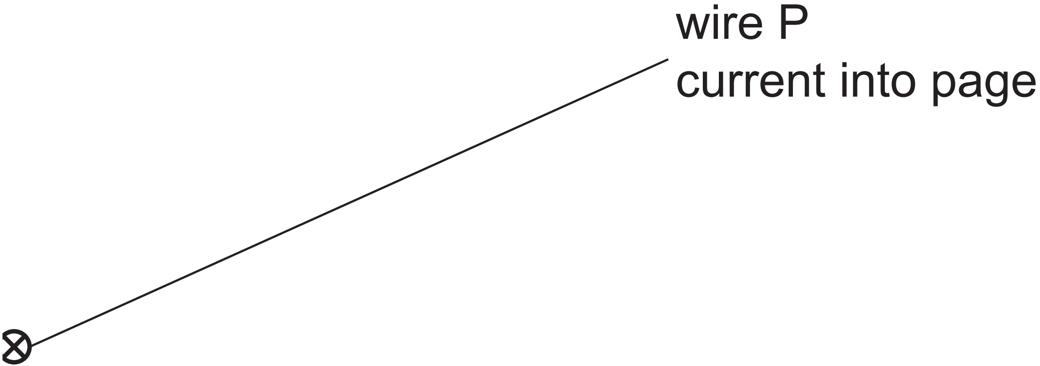
(c)(i) Calculate the magnetic force per unit length exerted on wire Q by wire P. **[2]**

(c)(ii) State the direction of the force exerted on wire Q by wire P. **[1]**

(c)(iii) The flux density of the magnetic field at wire P due to the current in wire Q is 1.5 mT.

Determine the magnitude of the current in wire P. Explain your reasoning. **[2]**

Question 6



Solution 6

(a)

Mark scheme

- a region where a force acts on
- a current-carrying conductor
- or
- a moving charge
- or
- a magnetic material / magnetic pole

Solution 6

(b) Worked steps

Know. The field around a long straight current-carrying wire is a set of **concentric circles** centred on the wire, and it gets weaker with distance.

Draw. Four circles centred on the wire, each larger than the last, with the **spacing between them increasing** as you move out — the field strength falls as $1/r$, and field lines are drawn further apart where the field is weaker.

Which way round? Grip the wire with the right hand, thumb pointing along the conventional current. Here the current goes **into the page**, so the fingers curl **clockwise**, and every circle carries a clockwise arrow.

Solution 6

Check. Three separate marks: the shape, the increasing spacing, and the arrows. Evenly spaced circles lose one; unarrowed circles lose another.

Mark scheme

- concentric circles around the wire
- spacing between circles increases with distance from wire
- arrows showing direction of field is clockwise

Solution 6

(c)(i) Worked steps

Know. A wire of length L carrying current I at right angles to a field B feels a force $F = BIL$. "Per unit length" means divide through by L.

Equation. $\dfrac{F}{L} = BI$.

Substitute. $\dfrac{F}{L} = 2.6 \times 10^{-3} \times 5.0$.

Answer. $\dfrac{F}{L} = 1.3 \times 10^{-2}\ \mathrm{N\ m^{-1}}$.

Solution 6

Check. The unit asked for is newtons per metre, so no length appears in the answer at all. If you have used a length, you have answered a different question.

Mark scheme

- $F = BIL$
- force per unit length $= BI$
- $= 2.6 \times 10^{-3} \times 5.0$
- $= 0.013$ N m^{-1}

Solution 6

(c)(ii)

Mark scheme

- to the right

Solution 6

(c)(iii) Worked steps

Know. The two wires exert forces on **each other**, and by Newton's third law those forces are equal in magnitude and opposite in direction — even though the two wires carry different currents and sit in different fields.

Reasoning. So the force per unit length on P due to Q equals the value found in (c)(i), 1.3×10^{-2} N m^{-1}, and that force is produced by Q's field acting on P's own current.

Equation. $\dfrac{F}{L} = B_{\mathrm{Q}} I_{\mathrm{P}}$, so $I_{\mathrm{P}} = \dfrac{F/L}{B_{\mathrm{Q}}}$.

Solution 6

Substitute. $I_P = \dfrac{1.3 \times 10^{-2}}{1.5 \times 10^{-3}}$.

Answer. $I_P = 8.7$ A.

Check. The third-law step is worth a mark on its own and must be **stated**, not assumed. Without it there is no route from Q's field to P's current.

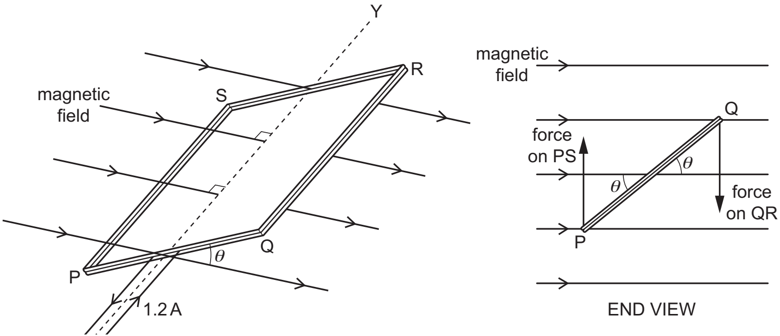
Mark scheme

- force (per unit length) has the same magnitude due to Newton's 3rd law
- $0.013 = 1.5 \times 10^{-3} \times I$
- current $= 8.7$ A

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

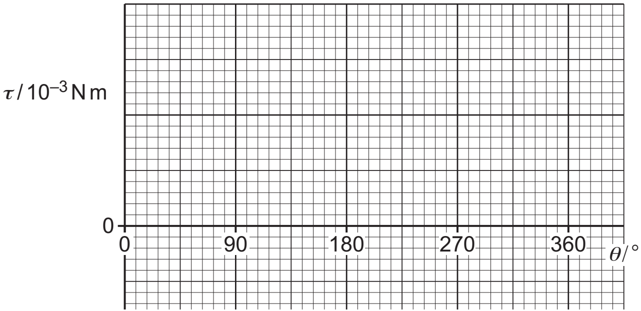
(ii) Use your answer in **(a)(i)** to show that the torque τ on the coil is given by

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

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

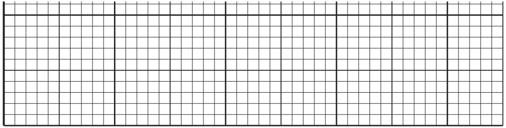


Fig. 6.2

[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
- $= 0.064 \times 0.025 \cos\theta = (1.6 \times 10\text{–}3) \cos\theta$ 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 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