# Past-paper walk-through

## Magnetism and Current-Carrying Wires ▪ 12.3

eXercise

# Questions in this set

- 2025 Q1
- 2022 Q4

# 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 1

2025 ▪ Q1

Very long Wire 1 carries current $I$ in the $+x$-direction along the line $y = 0$. Very long Wire 2 carries current $I$ in the $+x$-direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the $xy$-plane.
[Figure 1: Two horizontal wires drawn in the xy-plane, both carrying current $I$ in the $+x$-direction (arrows point right, toward $+x$). Wire 2 lies along the line $y = +d$, above Wire 1, which lies along the line $y = 0$. Wire 1 passes through the origin, marked with a dot labeled P. A vertical $y$-axis passes through the point where Wire 1 crosses it, with the $x$-axis pointing right along Wire 1.]
Note: Figure not drawn to scale.
**(a)(i)** Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

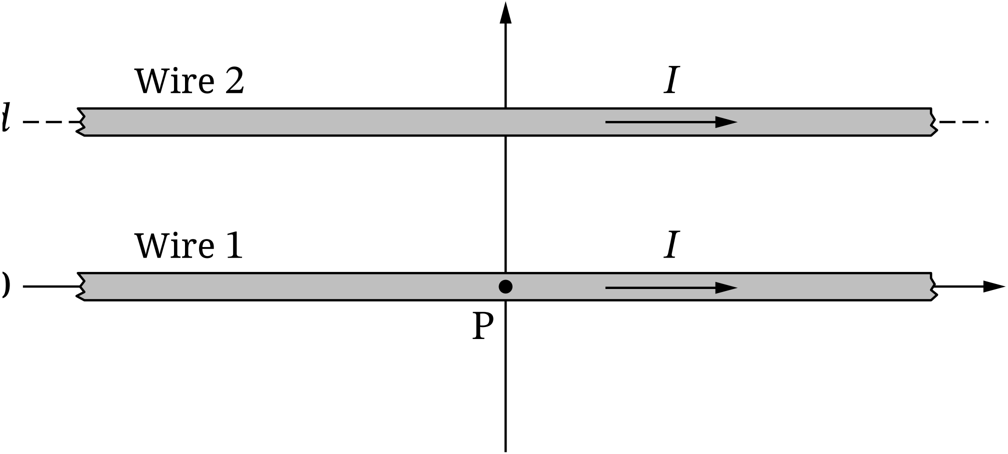
# Question 1

Symbols: X $=$ Into the page, $=$ Out of the page

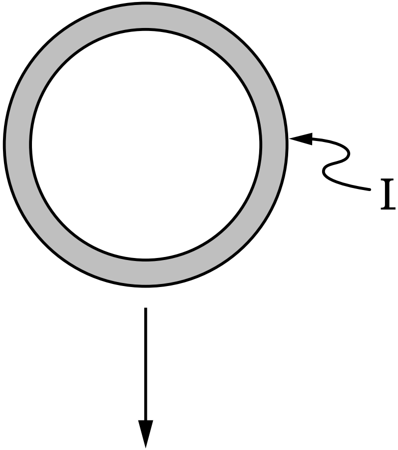
- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

[Figure 2: an empty square box labeled "Magnetic Field from Wire 2 at Point P" for the student to draw the field direction.]
[Figure 3: an empty square box labeled "Magnetic Force on Wire 1 by Wire 2" for the student to draw the force direction.]
**(a)(ii)** Very long Wire 3 carrying current $2I$ in the $+x$-direction is placed in the $xy$-plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.
**Derive** an expression for $y_3$ in terms of $d$. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

# Question 1



# Question 1



# Question 1

2025 ▪ Q1

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[Figure 1: Two horizontal wires drawn in the xy-plane, both carrying current $I$ in the $+x$-direction (arrows point right, toward $+x$). Wire 2 lies along the line $y = +d$, above Wire 1, which lies along the line $y = 0$. Wire 1 passes through the origin, marked with a dot labeled P. A vertical $y$-axis passes through the point where Wire 1 crosses it, with the $x$-axis pointing right along Wire 1.]

Note: Figure not drawn to scale.

**(b)** Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the $xy$-plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$-direction, as shown in Figure 4.

# Question 1

[Figure 4: Wire 2 (carrying current $I$ in the $+x$-direction) is above Wire 1 (also carrying current $I$ in the $+x$-direction); a $+y$-axis arrow points upward on the right. Below Wire 1 is a circular conducting Loop, with an arrow below it pointing further in the $-y$-direction, showing the loop's direction of motion away from the wires.]

Note: Figure not drawn to scale.

**Indicate** whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

_______ Clockwise

_______ Counterclockwise

_______ There is no induced current in the loop.

**Justify** your answer.

# Solution 1

## (a)(i)

**Mark scheme**

- The magnetic field from Wire 2 at Point P (Figure 2) is directed INTO the page (X symbol). The magnetic force exerted on Wire 1 by Wire 2 (Figure 3) is directed in the $+y$-direction (upward arrow) — since wires 1 and 2 carry parallel currents (both in $+x$), they attract, so Wire 1 is pulled toward Wire 2. (If a student instead indicates the field out of the page in Figure 2, full credit for the force requires it be shown in the -y-direction, i.e. consistent with an attractive force toward Wire 2.)

# Solution 1

## (a)(ii) Mark scheme

- Derive y3 using B = mu0*I/(2*pi*r) and Newton's second law (sum of forces = 0, since the net force on Wire 1 must be zero). Field from Wire 2 at Wire 1 (separation d): B2 = mu0*I/(2*pi*d). Field from Wire 3 at Wire 1 (current 2I, separation d3): B3 = mu0*(2I)/(2*pi*d3). Setting the magnitudes equal so the forces cancel (consistent direction requirement): mu0*I/(2*pi*d) = mu0*(2I)/(2*pi*d3), which gives d3 = 2d. Because Wire 3 must lie on the opposite side of Wire 1 from Wire 2 for its force to cancel Wire 2's force, y3 = -2d. Full credit requires: (1) a multistep derivation starting from B = mu0*I/(2*pi*r) and sum(F) = 0 or an equivalent relevant equation; (2) a correct expression for the field from Wire 2 along Wire 1, e.g. B2 = mu0*I/(2*pi*d); (3)

# Solution 1

substituting 2I into an analogous expression for Wire 3 (field or force); (4) equating the magnitudes of the two fields/forces consistently; (5) the correct final expression $y3 =$ -2d (magnitude $|y3| =$ 2d). A correct isolated final expression alone earns all remaining points.

# Solution 1

## (b) Mark scheme

- The induced current in the loop is clockwise. The magnetic field due to the currents in Wires 1 and 2 is directed into the page within the loop (both wires carry current in $+x$, and the loop is below them). As the loop moves in the -y-direction (away from the wires), the magnitude of the (into-the-page) magnetic flux through the loop decreases. By Lenz's law, the induced current opposes this decrease, so the induced current must produce its own magnetic field into the page inside the loop — by the right-hand rule this requires the induced current to flow clockwise (as viewed in the given orientation). Full credit requires: (1) stating the induced current is clockwise; (2) correctly identifying the field/flux from wires 1 and 2 as into the page within the loop; (3) correctly applying Lenz's

# Solution 1

law to relate the decreasing |flux| to the direction of the induced field (into the page) produced by the induced current.

# Question 4

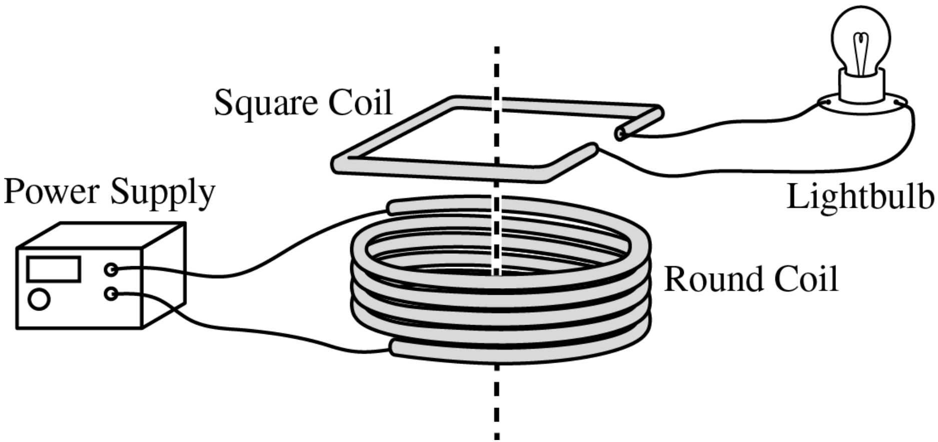
2022 ▪ Q4

[Diagram: A long straight horizontal wire carrying current $I$ directed to the left (shown with a dashed line and an arrow labeled $I$ pointing left). Above the wire, at a distance $d$, is a dot representing a charged object. Two force vectors are drawn from the dot: $F_M$ pointing straight up, and $F_E$ pointing straight down (toward the wire). A velocity vector $v$ points to the left from the charged object.]

At the instant shown above, a negatively charged object is moving to the left with constant velocity $v$ near a long, straight wire that has a current $I$ directed to the left. The region contains a uniform electric field of magnitude $E$, and the charged object is at a distance $d$ from the wire. The figure shows the electric and magnetic forces, $F_E$ and $F_M$, respectively, exerted on the charged object.

**(a)** Derive an expression for $v$ in terms of $E$, $d$, $I$, and physical constants, as appropriate.

# Question 4



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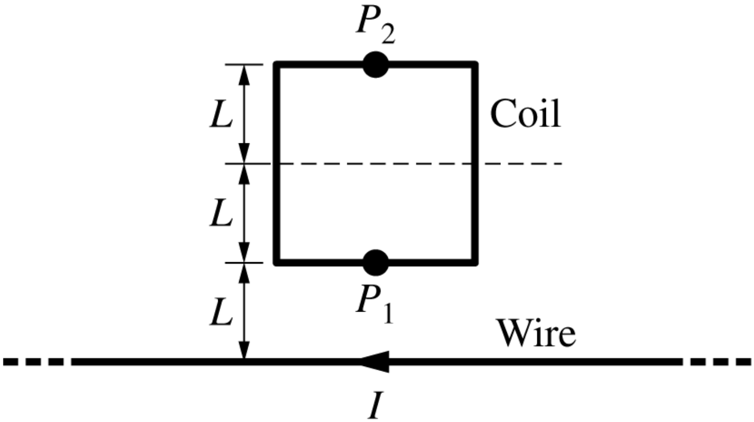

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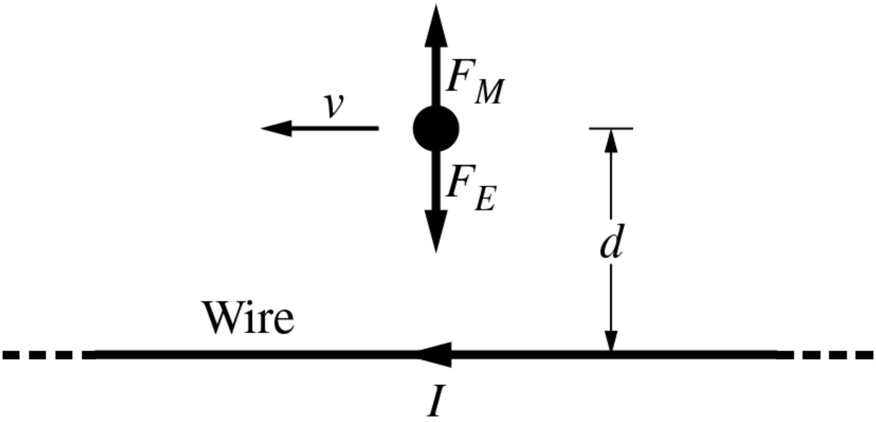

# Question 4

2022 ▪ Q4

[Diagram: A long straight horizontal wire carrying current $I$ directed to the left (shown with a dashed line and an arrow labeled $I$ pointing left). Above the wire, at a distance $d$, is a dot representing a charged object. Two force vectors are drawn from the dot: $F_M$ pointing straight up, and $F_E$ pointing straight down (toward the wire). A velocity vector $v$ points to the left from the charged object.]

At the instant shown above, a negatively charged object is moving to the left with constant velocity $v$ near a long, straight wire that has a current $I$ directed to the left. The region contains a uniform electric field of magnitude $E$, and the charged object is at a distance $d$ from the wire. The figure shows the electric and magnetic forces, $F_E$ and $F_M$, respectively, exerted on the charged object.

**(b)(i)(n)(t)(r)(o)** [Diagram: The charged object has been removed. A square coil labeled "Coil" with side length $2L$ is shown above the same long straight wire carrying

# Question 4

current $I$ (dashed line, arrow pointing left). The bottom side of the coil is a distance $L$ above the wire; a point $P_1$ is marked on the bottom side of the coil, and a point $P_2$ is marked on the top side of the coil. Vertical distance markers show $L$ from the wire to the bottom of the coil, and $L$ for each half of the coil's height (labeled $L$, $L$, $L$ from the wire up to $P_2$), with a horizontal dashed midline shown across the coil.]

The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance $L$ from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point $P_1$ and $B_0$ at point $P_2$.

**(b)(i)** Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

**(b)(ii)** Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is $5.0 \times 10^{-5}$ T $\cdot$ m$^2$ and the final magnetic flux through

# Question 4

the coil is $1.0 \times 10^{-5}$ T $\cdot$ m$^2$. The coil has a total resistance of 10 $\Omega$. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.

# Question 4

2022 ▪ Q4

[Diagram: A long straight horizontal wire carrying current $I$ directed to the left (shown with a dashed line and an arrow labeled $I$ pointing left). Above the wire, at a distance $d$, is a dot representing a charged object. Two force vectors are drawn from the dot: $F_M$ pointing straight up, and $F_E$ pointing straight down (toward the wire). A velocity vector $v$ points to the left from the charged object.]

At the instant shown above, a negatively charged object is moving to the left with constant velocity $v$ near a long, straight wire that has a current $I$ directed to the left. The region contains a uniform electric field of magnitude $E$, and the charged object is at a distance $d$ from the wire. The figure shows the electric and magnetic forces, $F_E$ and $F_M$, respectively, exerted on the charged object.

**(c)** [Diagram: A power supply connects via wires to a round coil of wire. A square coil is positioned directly above and concentric with the round coil, oriented horizontally

# Question 4

with a dashed vertical axis line through the center of both coils. A part of the square coil is cut/removed, and the two ends from that gap are connected by wires to a lightbulb, which is shown lit.]

The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

During a short time interval, the current in the power supply is constantly increasing.

Use physics principles to explain why the lightbulb is lit during the entire time interval.

# Solution 4

## (a) Mark scheme

- (1 point) Set the magnetic force equal to the electric force (velocity selector, zero net force), an appropriate use of Newton's laws: $\Sigma F = ma = 0 \Rightarrow F_M - F_E = 0 \Rightarrow F_M = F_E$. (1 point) Use correct force expressions: $qvB = qE$. (1 point) Substitute the magnetic field of a long straight wire, $B = \frac{\mu_0 I}{2\pi d}$, to get an expression including $v$ and the given quantities: $v\left(\frac{\mu_0 I}{2\pi d}\right) = E \Rightarrow v = \frac{2\pi d E}{\mu_0 I}$.

# Solution 4

## (b)(i)(n)(t)(r)(o)

### Mark scheme

- Introductory/diagram-description text only — no scorable response required. Describes that the charged object has been removed and a square coil of side $2L$ is positioned above the same long straight current-carrying wire, with the coil's bottom side a distance $L$ above the wire, point $P_1$ marked on the bottom side, and point $P_2$ marked on the top side (distance $2L$ from the wire). Sets up parts (b)(i) and (b)(ii).

# Solution 4

## (b)(i) Mark scheme

- (1 point) Mark an "X" on the figure at a location strictly between point $P_1$ (distance $L$ from the wire) and the coil's dashed centerline (distance $1.5L$ from the wire) — i.e. between $L$ and $1.5L$ from the wire, where the field equals $2B_0$. (1 point) Justify using $B \propto 1/r$ for a long straight wire. Model response: "Magnetic field is inversely proportional to the distance from a long, straight current carrying wire: $B = \dfrac{\mu_0 I}{2\pi r}$. Doubling the distance from the wire from $L$ to $2L$ would reduce the magnetic field from $3B_0$ to $1.5B_0$. Therefore, the magnetic field would be equal to $2B_0$ somewhere between $L$ and $2L$."

# Solution 4

## (b)(ii) Mark scheme

- (1 point) Use the change in flux, with correct substitutions, to determine the magnitude of the emf (an independent numerical value for emf is not required to earn later points):
  $$|\mathcal{E}| = \left|-\frac{\Delta\Phi_B}{\Delta t}\right| = \frac{(5.0\times10^{-5} - 1.0\times10^{-5})\ \mathsf{T}\cdot\mathsf{m}^2}{2.0\ \mathsf{s}} = 2.0\times10^{-5}\ \mathsf{V}.\ \text{(1 point)}$$
  Correctly apply Ohm's law with correct substitutions:
  $$I = \frac{|\mathcal{E}|}{R} = \frac{2.0\times10^{-5}\ \mathsf{V}}{10\ \Omega} = 2.0\times10^{-6}\ \mathsf{A}.$$

# Solution 4

## (c) Mark scheme

- Coherent explanation earning 3 points for indicating: (1 point) the current in the round coil produces a magnetic field; (1 point) that magnetic field from the round coil produces a flux through the square coil; (1 point) the changing flux (as the power-supply current, and hence the round coil's field, changes) produces an emf/current in the square coil circuit throughout the entire interval (a response saying the flux only changes during part of the interval does not earn this point). Model response: "The current in the round coil produces a magnetic field. The magnetic field from the round coil passes through the square coil, producing a flux. As the current in the power supply increases, so does the current in the round coil, and, therefore, the magnetic field created by the current increases.

# Solution 4

Since the magnetic field changes, the flux through the square coil changes. The constantly changing magnetic flux through the square coil produces an emf and, therefore, current in the square coil to light the lightbulb."