Past-paper walk-through

Magnetism and Moving Charges ▪ 12.2

eXercise

Questions in this set

- 2026 Q1
- 2025 Q4
- 2023 Set 2 Q2
- 2019 Set 2 Q3
- 2018 Q3

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

2026 ▪ Q1

Two very long, cylindrical, current-carrying Wires S and T are oriented parallel to the y-axis, as shown in Figure 1. The centers of the wires are in the xy-plane. The wires are described as follows.

- Wire S has radius $2a$ and is centered at $x = 0$. Wire S has nonuniform current density and carries total current I_0 in the $+y$-direction. The magnitude of the current density in Wire S as a function of the radial distance r from the center of the wire is described by $J = Cr$, where C is a positive constant.
- Wire T has radius a and is centered at $x = 10a$. Wire T has uniform current density and carries total current I_0 in the $-y$-direction.

Question 1

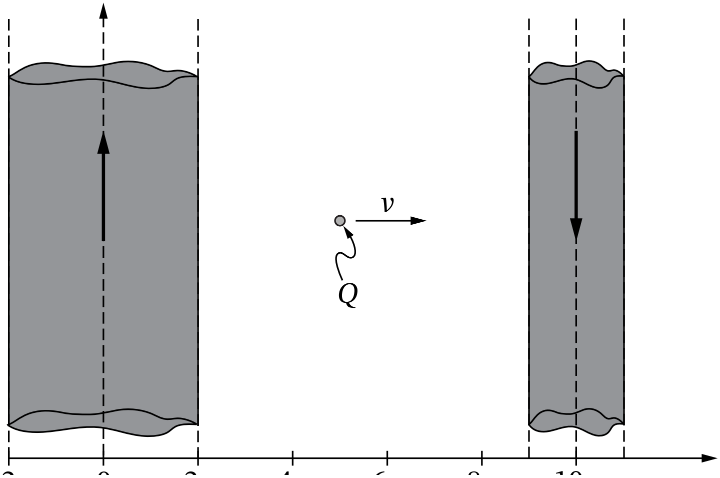
[Figure 1: Cross-section diagram in the xy-plane. Wire S is a shaded cylindrical bar centered at $x = 0$ spanning from $-2a$ to $2a$, with a y-axis arrow through its center pointing up (current I_0 in $+y$-direction) and a label $J = Cr$ pointing to the wire. Point P is marked inside Wire S, above the center axis, at horizontal position $x = a$. Wire T is a shaded cylindrical bar centered at $x = 10a$ spanning from $9a$ to $11a$, with a downward arrow through its center (current I_0 in $-y$-direction). The x-axis is marked with gridlines at $-2a, 0, 2a, 4a, 6a, 8a, 10a$.]

(a)(i) Point P is located inside of Wire S at horizontal position $x = a$. **Derive** an expression for the magnitude of the magnetic field at Point P due only to the current in Wire S in terms of C, a, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

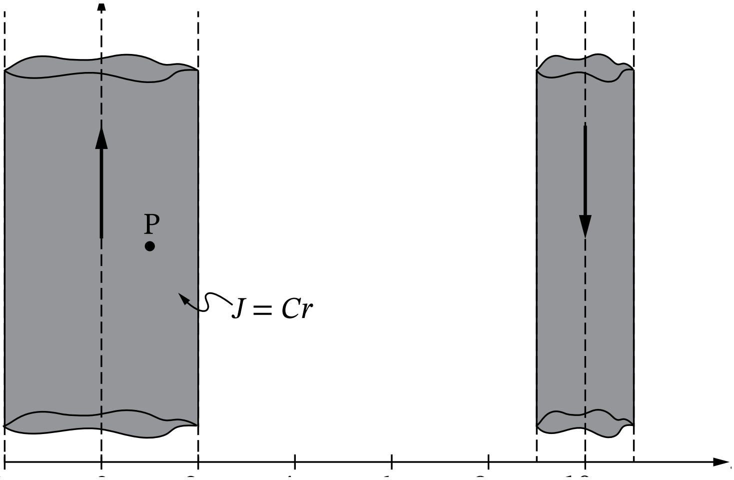
Question 1

(a)(ii) On the axes shown in Figure 2, **sketch** a graph of the magnitude B of the magnetic field due to the currents in both wires as a function of x along the x-axis in the region $2a \leq x \leq 9a$. Sketches made in the shaded region will not be graded. [Figure 2: A blank graph grid with vertical axis B and horizontal axis x, gridlines marked at $O, 2a, 3a, 4a, 5a, 6a, 7a, 8a, 9a$. The region from O to $2a$ is shaded (not to be used); the region from $2a$ to $9a$ is the graded sketch area.]

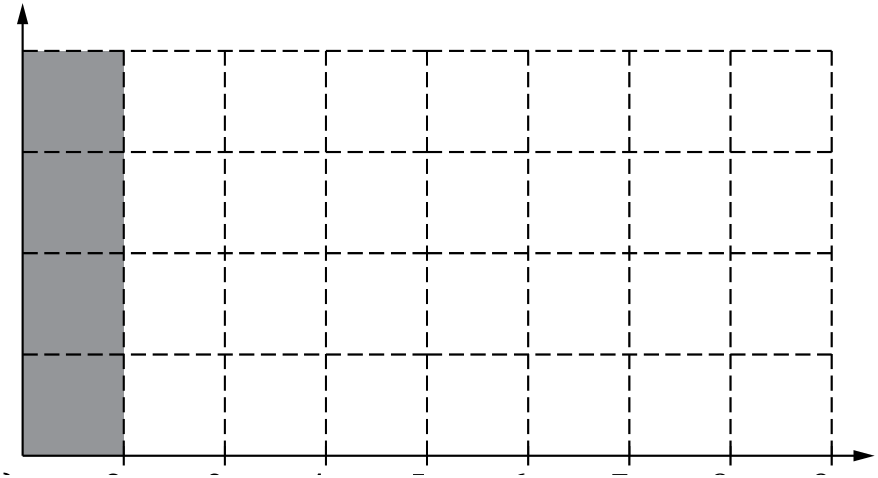
Question 1



Question 1



Question 1



Question 1

2026 ▪ Q1

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(b) At the instant shown in Figure 3, a small sphere with charge Q is at horizontal position $x = 5a$ and moving in the xy-plane with speed v in the $+x$-direction. At this instant, the net magnetic force exerted on the sphere due to the currents in Wires S and T has magnitude F.

[Figure 3: Same wire configuration as Figure 1 (Wire S centered at $x = 0$ with current I_0 in $+y$-direction, Wire T centered at $x = 10a$ with current I_0 in $-y$-direction). A

Question 1

small circle labeled Q is shown at $x = 5a$, midway between the wires, with an arrow labeled v pointing in the $+x$-direction.]
Derive an expression for F in terms of a, Q, I_0, v, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 4

2025 ▪ Q4

Long, parallel wires S and T are a distance $2d$ apart. Both wires carry equal currents I, but the currents are in opposite directions. Both wires are parallel to the x-axis. At the instant shown in Figure 1, Sphere 1 is a distance d above Wire S, Sphere 2 is a distance d below Wire S, and both spheres are moving with speed v in the $+x$-direction. Each sphere has positive charge $+Q$. Gravitational effects are negligible. [Figure 1: Sphere 1 is shown a distance d above Wire S, moving with velocity v in the $+x$-direction and carrying charge $+Q$. Wire S runs horizontally carrying current I to the right. A distance d below Wire S is Sphere 2, also moving with velocity v in the $+x$-direction and carrying charge $+Q$. A further distance d below Sphere 2 is Wire T, carrying current I to the left. A small 3D axis to the right shows $+y$ up, $+x$ to the right, and $+z$ out of the page (circle with a dot).]

Question 4

(a) F_1 is the magnitude of the magnetic force exerted on Sphere 1 due to the currents in wires S and T. F_2 is the magnitude of the magnetic force exerted on Sphere 2 due to the currents in wires S and T.

Indicate whether F_2 is greater than, less than, or equal to F_1 by writing one of the following.

- $F_2 > F_1$
- $F_2 < F_1$
- $F_2 = F_1$

Justify your answer.

Question 4

2025 ▪ Q4

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[Figure 1: Sphere 1 is shown a distance d above Wire S, moving with velocity v in the $+x$-direction and carrying charge $+Q$. Wire S runs horizontally carrying current I to the right. A distance d below Wire S is Sphere 2, also moving with velocity v in the $+x$-direction and carrying charge $+Q$. A further distance d below Sphere 2 is Wire T, carrying current I to the left. A small 3D axis to the right shows $+y$ up, $+x$ to the right, and $+z$ out of the page (circle with a dot).]

Question 4

(b) **Derive** an expression for the magnitude B_{tot} of the magnetic field at the location of Sphere 2 due to the currents in wires S and T in terms of d, I, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 4

2025 ▪ Q4

Long, parallel wires S and T are a distance $2d$ apart. Both wires carry equal currents I, but the currents are in opposite directions. Both wires are parallel to the x-axis. At the instant shown in Figure 1, Sphere 1 is a distance d above Wire S, Sphere 2 is a distance d below Wire S, and both spheres are moving with speed v in the $+x$-direction. Each sphere has positive charge $+Q$. Gravitational effects are negligible.

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Question 4

(c) Later, Wire T carries current $3I$ in the $+x$-direction. At the instant shown in Figure 2, Sphere 2 is a distance d below Wire S and is moving with speed v in the $+x$-direction. F_{new} is the new magnitude of the magnetic force exerted on Sphere 2 due to the currents in wires S and T.
[Figure 2: Wire S runs horizontally carrying current I to the right. A distance d below Wire S is Sphere 2, moving with velocity v in the $+x$-direction and carrying charge $+Q$. A further distance d below Sphere 2 is Wire T, now carrying current $3I$ to the right (same direction as Wire S). A small 3D axis to the right shows $+y$ up, $+x$ to the right, and $+z$ out of the page (circle with a dot).]
Indicate whether F_{new} is greater than, less than, or equal to F_2 by writing one of the following. - $F_{\text{new}} > F_2$ - $F_{\text{new}} < F_2$ - $F_{\text{new}} = F_2$
Briefly **justify** your answer by referencing your derivation in part B.

Solution 4

(a) Mark scheme

- $F_2 > F_1$. ThemagneticforceonamovingchargehasmagnitudeF $=$ QvB, andQandvarethesameforbothspheres, sothedifferenceinforcemagnitudescomesentirelyfrom
  F_1.Points : (1)indicating$F_2 >$
  F_1, (2)correctlyrelatingforcemagnitudetofieldmagnitude($F \propto B$, viaF $=$
  QvB), (3)justifyingthatBisgreateratSphere2′slocationthanSphere1′s, referencingrelativedistance

Solution 4

(b) Mark scheme

- Start from Ampere's law $\oint \vec{B}\cdot d\vec{\ell} = \mu_0 I_{enc}(ortheBiot - Savartlawd\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{\ell}\times\hat{r})}{r^2}; vectornotationnotrequired).Forasinglelongstraightwire: B(2\pi d) = \mu_0 I, soB = \mu_0 I/(2\pi d) -$
$-thefieldatSphere2duetoonewire.SincebothwiresSandTcarrycurrentIandtheirfieldsaddatSphere2$
$B_{tot} = \frac{\mu_0 I}{2\pi d} + \frac{\mu_0 I}{2\pi d} = \frac{\mu_0 I}{\pi d}.Points:$
$(1)multistepderivationincludingAmpere'sorBiot - Savartlaw(aderivationreachingB =$
$\mu_0 I/(2\pi d)alsoearnsthis), (2)correctexpressionforthefieldatSphere2duetoonewire, (3)indicatingt$
$wirefield.$

Solution 4

(c) Mark scheme

- $F_{new} = F_2. Now Wire T carries 3I; the field at Sphere 2 due to Wire T is in the opposite direction to the field due to W$
  $\frac{3\mu_0 I}{2\pi d} - \frac{\mu_0 I}{2\pi d} = \frac{\mu_0 I}{\pi d} (OR:$
  $stated directly that the net field magnitude at Sphere 2 stays the same even though the field from Wire T cha$
  $F_{new} = F_2. Points: (1) indicating F_{new} = F_2, (2) indicating B_{tot} = \frac{3\mu_0 I}{2\pi d} -$
  $\frac{\mu_0 I}{2\pi d} OR indicating that the net field magnitude at Sphere 2 remains the same even though the field from W$

Question 2

2023 Set 2 ▪ Q2

[Figure, Perspective View (at time $t = 0$): A sloped section of two parallel conducting rails at height H, with a resistor R at the top of the slope. The rails transition to a horizontal section. A region of magnetic field B_1 (dots, pointing out of the page, +y-direction) covers part of the horizontal rails near the bottom of the slope. Farther along, a separate region of magnetic field B_2 (arrows pointing into the page, +z-direction, shown as downward-slanting field lines with arrowheads) covers another part of the rails. Axes shown: $+x$, $+y$, $+z$ in a right-handed orientation.]

[Figure, Top View (at time t_B): Two horizontal parallel rails separated by distance d, viewed from above. A resistor R is at the left end (position x_0). The bar is shown as a vertical rectangle. Positions marked along the x-axis: x_0, x_1, x_B, x_2, x_3, x_4. The region between x_1 and x_2 is shaded with dots labeled B_1 (field out of the page). The region

Question 2

between x_3 and x_4 has downward arrows labeled B_2 (field into the page). The bar is shown at position x_B, between x_1 and x_2.]
Two parallel conducting rails are separated by distance $d = 0.30$ m. A resistor of resistance $R = 0.20\ \Omega$ connects the rails. A conducting bar is placed on a sloped section of the rails at height H above the horizontal section of the rails. Frictional forces and the resistances of the bar and rails are negligible.
- At time $t = 0$, the bar is released from rest from position x_0 and slides down the sloped section of the rails, as shown in the Perspective View. - At time t_1, the bar reaches position x_1 and smoothly transitions to the horizontal section of the rails and enters a uniform magnetic field of magnitude $B_1 = 0.40$ T that is directed in the $+$y-direction. - At time t_2, the bar reaches position x_2 and enters a region with no magnetic field. - At time t_3, the bar reaches position x_3 and enters a uniform magnetic

Question 2

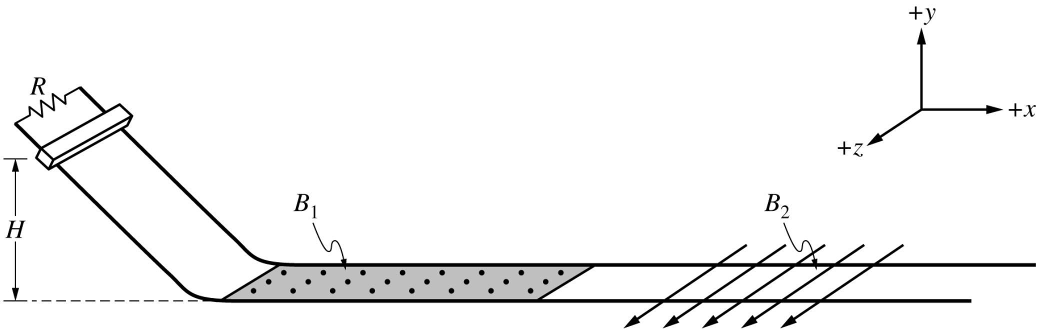
field of magnitude $B_2 = 0.60$ T that is directed in the +z-direction. - At time t_4, the bar reaches position x_4 and enters a region with no magnetic field.

The bar is at position x_B (shown in Top View) at time t_B such that $t_1 < t_B < t_2$.

(a) [Diagram: a vertical rectangle representing the bar, viewed from the Top View perspective, with no arrows drawn.]

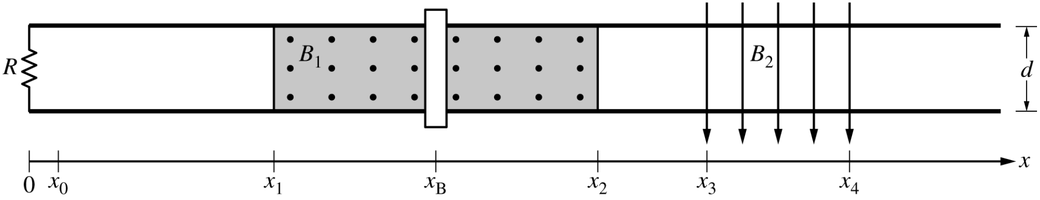
On the following diagram of the bar, as observed from the Top View, draw an arrow indicating the direction of the net force F_{net} exerted on the bar at time t_B. If the net force is zero, write $F_{\text{net}} = 0$.

Question 2



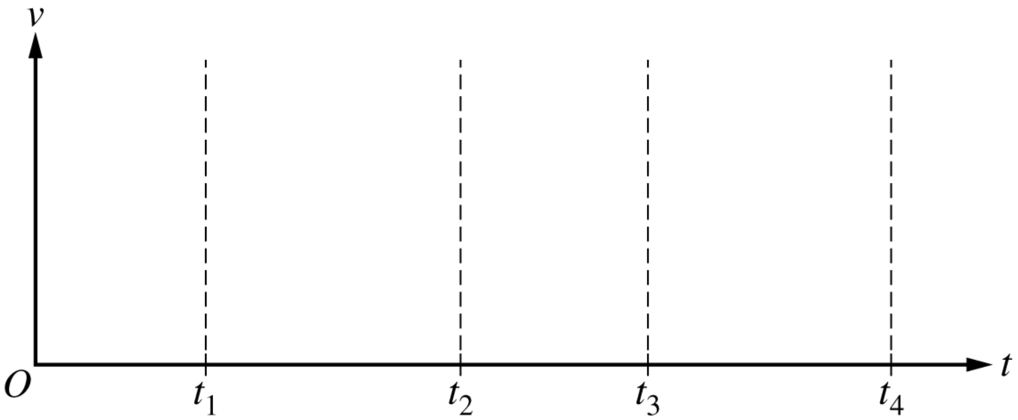
Perspective View (at time $t = 0$)

Question 2



Top View (at time t_B)

Question 2



Question 2

2023 Set 2 ▪ Q2

[Figure, Perspective View (at time $t = 0$): A sloped section of two parallel conducting rails at height H, with a resistor R at the top of the slope. The rails transition to a horizontal section. A region of magnetic field B_1 (dots, pointing out of the page, +y-direction) covers part of the horizontal rails near the bottom of the slope. Farther along, a separate region of magnetic field B_2 (arrows pointing into the page, +z-direction, shown as downward-slanting field lines with arrowheads) covers another part of the rails. Axes shown: $+x$, $+y$, $+z$ in a right-handed orientation.]

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Question 2

Two parallel conducting rails are separated by distance $d = 0.30$ m. A resistor of resistance $R = 0.20\ \Omega$ connects the rails. A conducting bar is placed on a sloped section of the rails at height H above the horizontal section of the rails. Frictional forces and the resistances of the bar and rails are negligible.
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The bar is at position x_B (shown in Top View) at time t_B such that $t_1 < t_B < t_2$.

(b)(i) At time t_B, the speed of the bar is $v = 2.5$ m/s.

Question 2

Calculate the magnitude of the current in the bar at time t_B.

(b)(ii) Calculate the magnitude of the net force F_{net} exerted on the bar at time t_B.

Question 2

2023 Set 2 ▪ Q2

[Figure, Perspective View (at time $t = 0$): A sloped section of two parallel conducting rails at height H, with a resistor R at the top of the slope. The rails transition to a horizontal section. A region of magnetic field B_1 (dots, pointing out of the page, +y-direction) covers part of the horizontal rails near the bottom of the slope. Farther along, a separate region of magnetic field B_2 (arrows pointing into the page, +z-direction, shown as downward-slanting field lines with arrowheads) covers another part of the rails. Axes shown: $+x$, $+y$, $+z$ in a right-handed orientation.]

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Question 2

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The bar is at position x_B (shown in Top View) at time t_B such that $t_1 < t_B < t_2$.

Question 2

(c) On the following axes, sketch a graph of the speed v of the bar as a function of time t between $t = 0$ and t_4.
[Graph: y-axis labeled "v", x-axis labeled "t" with tick marks at t_1, t_2, t_3, t_4 (dashed vertical gridlines at each); axes otherwise unlabeled with numeric values, origin at O.]

Question 2

2023 Set 2 ▪ Q2

[Figure, Perspective View (at time $t = 0$): A sloped section of two parallel conducting rails at height H, with a resistor R at the top of the slope. The rails transition to a horizontal section. A region of magnetic field B_1 (dots, pointing out of the page, $+$y-direction) covers part of the horizontal rails near the bottom of the slope. Farther along, a separate region of magnetic field B_2 (arrows pointing into the page, $+$z-direction, shown as downward-slanting field lines with arrowheads) covers another part of the rails. Axes shown: $+x$, $+y$, $+z$ in a right-handed orientation.]

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Question 2

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The bar is at position x_B (shown in Top View) at time t_B such that $t_1 < t_B < t_2$.

Question 2

(d)(i) The original scenario is repeated but with a new bar that has the same mass but with a nonnegligible resistance $R = 0.20\ \Omega$. The new bar is released from rest and smoothly transitions to the horizontal section of the rails and enters the first uniform magnetic field.

Determine the total resistance of the closed circuit.

(d)(ii) In the original scenario, the magnitude of the acceleration of the bar immediately after the bar enters the first uniform magnetic field is a_{original}. In the new scenario, the magnitude of the acceleration of the bar immediately after the bar enters the first uniform magnetic field is a_{new}. Is a_{new} greater than, less than, or equal to a_{original}? Justify your answer.

Question 2

2023 Set 2 ▪ Q2

[Figure, Perspective View (at time $t = 0$): A sloped section of two parallel conducting rails at height H, with a resistor R at the top of the slope. The rails transition to a horizontal section. A region of magnetic field B_1 (dots, pointing out of the page, +y-direction) covers part of the horizontal rails near the bottom of the slope. Farther along, a separate region of magnetic field B_2 (arrows pointing into the page, +z-direction, shown as downward-slanting field lines with arrowheads) covers another part of the rails. Axes shown: $+x$, $+y$, $+z$ in a right-handed orientation.]

[Figure, Top View (at time t_B): Two horizontal parallel rails separated by distance d, viewed from above. A resistor R is at the left end (position x_0). The bar is shown as a vertical rectangle. Positions marked along the x-axis: x_0, x_1, x_B, x_2, x_3, x_4. The region between x_1 and x_2 is shaded with dots labeled B_1 (field out of the page). The region between x_3 and x_4 has downward arrows labeled B_2 (field into the page). The bar is shown at position x_B, between x_1 and x_2.]

Question 2

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The bar is at position x_B (shown in Top View) at time t_B such that $t_1 < t_B < t_2$.

Question 2

(e) Describe a modification to H, B_1, or d that will result in a larger induced current in the new bar immediately after the bar enters the first magnetic field. Justify your answer.

Solution 2

(a)

Mark scheme

- On the Top View diagram of the bar, draw a single arrow pointing to the LEFT (with no extraneous arrows) representing the direction of the net force F_{net} on the bar at time t_B. This is the magnetic braking force from the induced current interacting with the field, which by Lenz's law opposes the bar's motion; on the horizontal rail section (no gravity component along the rails) it is the only horizontal force, so F_{net} points opposite the bar's velocity, i.e. to the left in the given view.

Solution 2

(b)(i) Mark scheme

- Calculate the magnitude of the current in the bar at t_B, where $v = 2.5$ m/s. (1) Use Faraday's law for the induced emf: $\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d(B_1 dx)}{dt}$ (this point may be earned without the negative sign or a numerical answer). (2) Substitute v for $\frac{dx}{dt}$: $\mathcal{E} = -B_1 d\frac{dx}{dt} = -B_1 dv$ (a student may also earn both of the first two points by starting directly from $\mathcal{E} = B_1 dv$). (3) Substitute the correct resistance into Ohm's law to solve for current. Full solution: $\mathcal{E} = -(0.40\,\mathrm{T})(0.30\,\mathrm{m})(2.5\,\mathrm{m/s}) = -0.30$ V; $I = \frac{|\mathcal{E}|}{R} = \frac{0.30\,\mathrm{V}}{0.20\,\Omega} = 1.5$ A.

Solution 2

(b)(ii)

Mark scheme

- Calculate the magnitude of the net force F_{net} on the bar at t_B by substituting the current (or an expression for it) from part (b)(i) into $F = IdB_1$: $F = (1.5\,\mathrm{A})(0.3\,\mathrm{m})(0.4\,\mathrm{T}) = 0.18\ \mathrm{N}$. (Equivalently, deriving symbolically: $F = \dfrac{B_1^2 d^2 v}{R} = \dfrac{(0.4)^2(0.3)^2(2.5)}{0.2} = 0.18\ \mathrm{N}$.)

Solution 2

(c) Mark scheme

- Sketch v vs t from $t = 0$ to t_4 with four required features (1 point each): (1) a straight line with POSITIVE slope starting at the origin from $t = 0$ to t_1 (bar speeding up before/while entering the field region); (2) a curve that is DECREASING and CONCAVE UP from t_1 to t_2 (bar decelerating due to the speed-dependent magnetic braking force, asymptotically slowing its rate of decrease); (3) a NONZERO horizontal line from t_2 to t_3 (constant nonzero speed); (4) a NONZERO horizontal line from t_3 to t_4 (constant nonzero speed continues, possibly at a different level than segment 3). Net shape: rises linearly, then curves down concave-up leveling off, then two flat nonzero segments.

Solution 2

(d)(i)

Mark scheme

- Determine the total resistance of the closed circuit for the new bar ($R = 0.20\ \Omega$) in series with the fixed rail/other resistance of $0.2\ \Omega$: $R_s = \sum_i R_i = (0.2\,\Omega) + (0.2\,\Omega) = 0.4\ \Omega$. Correct answer with units (0.4 Ω) earns the point; it may be earned without supporting calculations.

Solution 2

(d)(ii) Mark scheme

- Determine whether a_{new} is greater than, less than, or equal to $a_{original}$, and justify: the correct answer is $a_{new} < a_{original}$. Full credit requires a chain of correct statements (1 point each, and full credit can be earned with a justification consistent with the resistance calculated in part (d)(i)): (1) inverse relation between resistance and current — as resistance increases, current decreases; (2) direct relation between current and magnetic force — as current decreases, magnetic force $F = IdB$ decreases; (3) direct relation between force and acceleration — by Newton's second law $F = ma$, as force decreases (same mass), acceleration decreases. Example justification: the new bar has greater total

Solution 2

resistance, so it carries less current, so the magnetic force on it is less, so (same mass) its acceleration is less than the original.

Solution 2

(e) Mark scheme

- Describe ONE modification to H, B_1, or d that results in a LARGER induced current in the new bar immediately after entering the first magnetic field, and justify it. (1 point) Correctly identify one of: increasing H, increasing B_1, or increasing d, with an attempted relevant justification. (1 point) Correctly justify why that change increases current. Any one of: Increasing H — a higher release height gives greater potential energy, hence greater kinetic energy/speed entering the field, giving a greater rate of change of flux, so by Faraday's law a greater emf and thus greater current. OR Increasing B_1 — a stronger field increases the flux through the circuit and its rate of change, giving a greater induced emf and thus greater current. OR Increasing d — a larger bar width increases the area enclosed

Solution 2

by the circuit, increasing flux and its rate of change, giving a greater induced emf and thus greater current.

Question 3

2019 Set 2 ▪ Q3

[Figure: Two vertical parallel plates connected at the top to a battery symbol labeled ΔV. To the left of and between the plates is a small filled circle labeled "mass $= m$, charge $= e^-$" with an arrow pointing right (toward the plates/opening). To the right of the plates is a grid of $\times$ symbols labeled B, representing a uniform magnetic field directed into the page.]

Two plates are set up with a potential difference V between them. A small sphere of mass m and charge $-e$ is placed at the left-hand plate, which has a negative charge, and is allowed to accelerate across the space between the plates and pass through a small opening. After passing through the small opening, the sphere enters a region in which there is a uniform magnetic field of magnitude B directed into the page, as shown above. Ignore gravitational effects. Express all algebraic answers in terms of V, m, e, B, and fundamental constants, as appropriate.

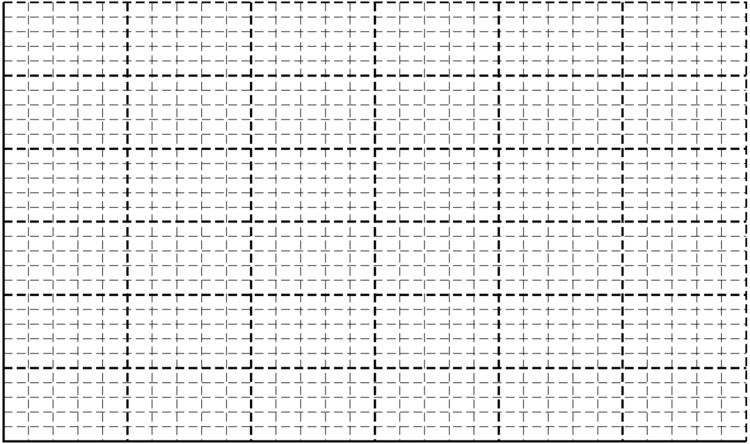
Question 3

(a)(i) What is the initial direction of the force on the sphere as it enters the magnetic field?

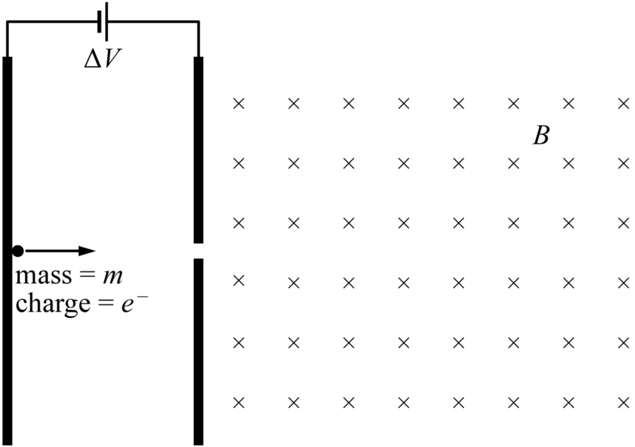
_____ Into the page _____ Out of the page _____ Toward the top of the page _____ Toward the bottom of the page

(a)(ii) Describe the path taken by the sphere after it enters the magnetic field.

Question 3



Question 3



Question 3

Potential difference (V)	60	70	100	110	120	140
Magnetic field $\left(\mathrm{T} \times 10^{-3}\right)$	2.62	2.78	3.39	3.54	3.78	3.99

Question 3

2019 Set 2 ▪ Q3

[Figure: Two vertical parallel plates connected at the top to a battery symbol labeled ΔV. To the left of and between the plates is a small filled circle labeled "mass = m, charge = e^-" with an arrow pointing right (toward the plates/opening). To the right of the plates is a grid of $\times$ symbols labeled B, representing a uniform magnetic field directed into the page.]

Two plates are set up with a potential difference V between them. A small sphere of mass m and charge $-e$ is placed at the left-hand plate, which has a negative charge, and is allowed to accelerate across the space between the plates and pass through a small opening. After passing through the small opening, the sphere enters a region in which there is a uniform magnetic field of magnitude B directed into the page, as shown above. Ignore gravitational effects. Express all algebraic answers in terms of V, m, e, B, and fundamental constants, as appropriate.

(b) Derive an expression for the speed of the sphere as it passes through the small opening.

Question 3

2019 Set 2 ▪ Q3

[Figure: Two vertical parallel plates connected at the top to a battery symbol labeled ΔV. To the left of and between the plates is a small filled circle labeled "mass $= m$, charge $= e^-$" with an arrow pointing right (toward the plates/opening). To the right of the plates is a grid of $\times$ symbols labeled B, representing a uniform magnetic field directed into the page.]

Two plates are set up with a potential difference V between them. A small sphere of mass m and charge $-e$ is placed at the left-hand plate, which has a negative charge, and is allowed to accelerate across the space between the plates and pass through a small opening. After passing through the small opening, the sphere enters a region in which there is a uniform magnetic field of magnitude B directed into the page, as shown above. Ignore gravitational effects. Express all algebraic answers in terms of V, m, e, B, and fundamental constants, as appropriate.

(c) Derive an expression for the radius of the path taken by the sphere as it moves through the magnetic field.

Question 3

2019 Set 2 ▪ Q3

[Figure: Two vertical parallel plates connected at the top to a battery symbol labeled ΔV. To the left of and between the plates is a small filled circle labeled "mass $= m$, charge $= e^-$" with an arrow pointing right (toward the plates/opening). To the right of the plates is a grid of $\times$ symbols labeled B, representing a uniform magnetic field directed into the page.]

Two plates are set up with a potential difference V between them. A small sphere of mass m and charge $-e$ is placed at the left-hand plate, which has a negative charge, and is allowed to accelerate across the space between the plates and pass through a small opening. After passing through the small opening, the sphere enters a region in which there is a uniform magnetic field of magnitude B directed into the page, as shown above. Ignore gravitational effects. Express all algebraic answers in terms of V, m, e, B, and fundamental constants, as appropriate.

(d) An experiment is performed in which a beam of electrons is accelerated across the space between the plates and passes through the small opening. After passing through

Question 3

the opening, the electrons travel in a semicircular path and strike the right-hand plate. The potential difference between the plates is varied in regular increments, as shown in the table below. For each potential difference, the magnetic field is varied in order to cause the beam to strike the right-hand plate at a distance of 0.020 m from the opening.

Potential difference (V)	60	70	100	110	120	140
Magnetic field (T $\times 10^{-3}$)	2.62	2.78	3.39	3.54	3.78	3.99

Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the mass-to-charge ratio of an electron.

Vertical axis:

Horizontal axis:

Question 3

Use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given. Label each column you use and include units.

Question 3

2019 Set 2 ▪ Q3

[Figure: Two vertical parallel plates connected at the top to a battery symbol labeled ΔV. To the left of and between the plates is a small filled circle labeled "mass = m, charge = e^-" with an arrow pointing right (toward the plates/opening). To the right of the plates is a grid of $\times$ symbols labeled B, representing a uniform magnetic field directed into the page.]

Two plates are set up with a potential difference V between them. A small sphere of mass m and charge $-e$ is placed at the left-hand plate, which has a negative charge, and is allowed to accelerate across the space between the plates and pass through a small opening. After passing through the small opening, the sphere enters a region in which there is a uniform magnetic field of magnitude B directed into the page, as shown above. Ignore gravitational effects. Express all algebraic answers in terms of V, m, e, B, and fundamental constants, as appropriate.

Question 3

(e) On the graph below, plot the relationship determined in part (d). Clearly scale and label all axes, including units, if appropriate. Draw a straight line that best represents the data.
[Blank grid graph for plotting data.]

Question 3

2019 Set 2 ▪ Q3

[Figure: Two vertical parallel plates connected at the top to a battery symbol labeled ΔV. To the left of and between the plates is a small filled circle labeled "mass $= m$, charge $= e^-$" with an arrow pointing right (toward the plates/opening). To the right of the plates is a grid of $\times$ symbols labeled B, representing a uniform magnetic field directed into the page.]

Two plates are set up with a potential difference V between them. A small sphere of mass m and charge $-e$ is placed at the left-hand plate, which has a negative charge, and is allowed to accelerate across the space between the plates and pass through a small opening. After passing through the small opening, the sphere enters a region in which there is a uniform magnetic field of magnitude B directed into the page, as shown above. Ignore gravitational effects. Express all algebraic answers in terms of V, m, e, B, and fundamental constants, as appropriate.

(f) Using the straight line from part (e), determine the mass-to-charge ratio of an electron.