Past-paper walk-through

Electric Current ▪ 11.1

eXercise

Questions in this set

- 2015 Q2
- 2015 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 2

2015 ▪ Q2

[Figure: A circuit diagram. At the top, a voltmeter (circle labeled V) is connected across a variable resistor (labeled R, drawn as a resistor symbol with a diagonal arrow through it, indicating it is adjustable). Below, in a dashed box, a battery is shown as an internal resistance r (resistor symbol) in series with an emf source $\mathcal{E}$. The battery (dashed box) is connected in series with the variable resistor R, and the voltmeter is connected across R.]

A student performs an experiment to determine the emf $\mathcal{E}$ and internal resistance r of a given battery. The student connects the battery in series to a variable resistance R, with a voltmeter across the variable resistor, as shown in the figure above, and measures the voltmeter reading V as a function of the resistance R. The data are shown in the table below.

Question 2

Trial	Resistance (Ω)	Voltage (V)	$1/R$ ($1/\Omega$)	$1/V$ (1/V)
1	0.50	5.6	2.00	0.179
2	1.0	7.4	1.00	0.135
3	2.0	9.4	0.50	0.106
4	3.0	10.6	0.33	0.094
5	5.0	10.9	0.20	0.092
6	10	11.4	0.10	0.088

(a)(i) Derive an expression for the measured voltage V. Express your answer in terms of R, $\mathcal{E}$, r, and physical constants, as appropriate.

(a)(ii) Rewrite your expression from part (a)-i to express $1/V$ as a function of $1/R$.

Question 2

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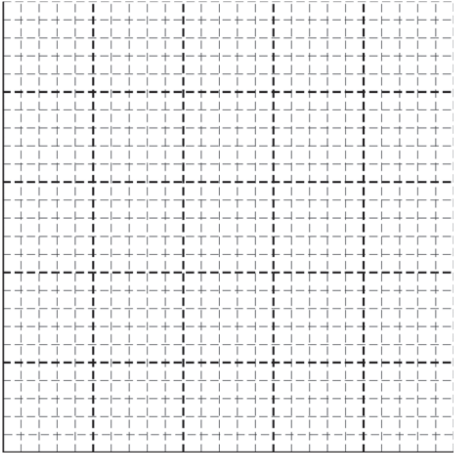
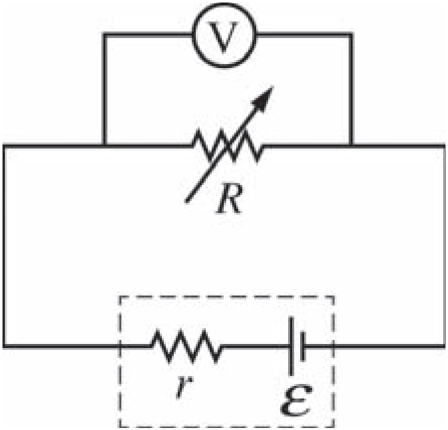
Question 2



Question 2



Question 2

2015 ▪ Q2

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Question 2

(b) On the grid below, plot data points for the graph of $1/V$ as a function of $1/R$. Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.
[Figure: A blank grid (approximately 30 x 30 gridlines with heavier gridlines every 6 squares) for plotting $1/V$ vs. $1/R$.]

Question 2

2015 ▪ Q2

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(c)(i) Use the straight line from part (b) to obtain a value for $\mathcal{E}$.

Question 2

(c)(ii) Use the straight line from part (b) to obtain a value for r.

Question 2

2015 ▪ Q2

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Question 2

(d) Using the results of the experiment, calculate the maximum current that the battery can provide.

Question 2

2015 ▪ Q2

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A student performs an experiment to determine the emf $\mathcal{E}$ and internal resistance r of a given battery. The student connects the battery in series to a variable resistance R, with a voltmeter across the variable resistor, as shown in the figure above, and measures the voltmeter reading V as a function of the resistance R. The data are shown in the table below.

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Question 2

(e) A voltmeter is to be used to determine the emf of the battery after removing the battery from the circuit. Two voltmeters are available to take this measurement—one with low internal resistance and one with high internal resistance. Indicate which voltmeter will provide the most accurate measurement.

______ The voltmeter with low resistance will provide the most accurate measurement.

______ The voltmeter with high resistance will provide the most accurate measurement.

______ The two voltmeters will provide equal accuracy.

Justify your answer.

Solution 2

(a)(i) Mark scheme

- Apply Kirchhoff's loop rule around the circuit containing the battery (emf $\mathcal{E}$, internal resistance r) and the variable resistor R: $\mathcal{E} = Ir + IR$ (1 point for a correct application of Kirchhoff's loop rule), so $I = \dfrac{\mathcal{E}}{r + R}$. The voltmeter reads the voltage across the variable resistor, so by Ohm's law $V = IR = \dfrac{\mathcal{E}}{r + R} R = \dfrac{\mathcal{E} R}{r + R}$ (1 point for a correct expression for the measured voltage across the variable resistor).

Solution 2

(a)(ii) Mark scheme

- Take the reciprocal of $V = \dfrac{\mathcal{E}R}{r+R}$ from part (a)-i and rearrange into a form linear in $1/R$: $\dfrac{1}{V} = \dfrac{r+R}{\mathcal{E}R} = \left(\dfrac{r}{\mathcal{E}}\right)\dfrac{1}{R} + \dfrac{1}{\mathcal{E}}$ (1 point; the expression must be consistent with the answer from part (a)-i). This is a straight line in $1/R$ with slope $r/\mathcal{E}$ and y-intercept $1/\mathcal{E}$.

Solution 2

(b) Mark scheme

- Plot $1/V$ (vertical axis, units of $1/\mathrm{V}$) versus $1/R$ (horizontal axis, units of $1/\Omega$) using the given data table. Credit: 1 point for correctly labeling both axes with variables and units; 1 point for correctly scaling both axes with an acceptable and appropriate scale (spanning the data, e.g. $1/R$ from 0 to about $2.5\ \Omega^{-1}$ and $1/V$ from 0 to about $0.25\ \mathrm{V}^{-1}$); 1 point for correctly plotting the given data points; 1 point for drawing a single straight best-fit line through the data (not simply connecting the dots). The reference line in the scoring guidelines has a y-intercept near $0.080\ \mathrm{V}^{-1}$ and rises to about $0.20\ \mathrm{V}^{-1}$ near $1/R = 2.3\ \Omega^{-1}$.

Solution 2

(c)(i) Mark scheme

- Read the y-intercept of the best-fit line drawn in part (b): $b \approx 0.080\ \mathsf{V}^{-1}$ (1 point; the value must be consistent with the line drawn in part (b)). From the linear form in part (a)-ii, $\dfrac{1}{V} = \left(\dfrac{r}{\mathcal{E}}\right)\dfrac{1}{R} + \dfrac{1}{\mathcal{E}}$, the intercept equals $b = 1/\mathcal{E}$ (1 point for correctly substituting into the equation from part (a)-ii), so $\mathcal{E} = \dfrac{1}{b} = \dfrac{1}{0.080\ \mathsf{V}^{-1}} = 12.5\ \mathsf{V}$.

Solution 2

(c)(ii)

Mark scheme

- Calculate the slope of the best-fit line from part (b) using two points that lie on the line itself, not the raw data points, e.g. $(0.40,\ 0.100)$ and $(1.50,\ 0.151)$: $m = \dfrac{0.151 - 0.100}{1.50 - 0.40} = 0.0463\ \Omega/\mathrm{V}$ (1 point for calculating the slope using the line, not data points). From part (a)-ii, the slope equals $r/\mathcal{E}$, so $r = m\mathcal{E}$ (1 point for correctly substituting into the equation from part (a)-ii); using $\mathcal{E} = 12.5\ \mathrm{V}$ from part (c)-i, $r = (0.0463\ \Omega/\mathrm{V})(12.5\ \mathrm{V}) = 0.58\ \Omega$.

Solution 2

(d)

Mark scheme

- The maximum current the battery can supply occurs when $R = 0$ (short circuit), so Ohm's law applied to the internal resistance alone gives $\mathcal{E} = Ir$ (1 point for using Ohm's law). Substituting the values found in part (c): $(12.5\ \text{V}) = I(0.58\ \Omega)$ (1 point for a correct substitution of the values from part (c)), giving $I = 21.6$ A.

Solution 2

(e) Mark scheme

- Select the voltmeter with high internal resistance (1 point). Justification: a real voltmeter behaves like a resistor placed in the circuit with the battery, and it measures the potential difference across its own internal resistance. The higher that internal resistance, the smaller the current it draws from the battery, and the closer the voltmeter's reading comes to the actual emf of the battery (1 point for a correct justification). Example from the scoring guidelines: 'The voltmeter acts like a resistor in a circuit with the battery. It will measure the potential difference across its own internal resistance. The higher its internal resistance, the closer its potential difference will be to the emf of the battery.'

Question 3

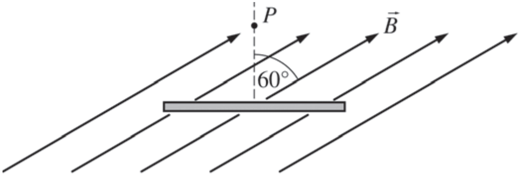
2015 ▪ Q3

[Figure, "Edge View": A point P is shown above a horizontal rod/loop segment (drawn edge-on as a thin shaded bar). Several parallel arrows labeled $\vec{B}$ point up and to the right, representing the magnetic field. A dashed vertical line from P down to the bar makes a $60°$ angle with the direction of $\vec{B}$.]
[Figure, "Perspective View": A point P is shown above a circular loop (drawn as a tilted ellipse/ring to indicate perspective), with the same parallel arrows labeled $\vec{B}$ pointing up and to the right through the loop, and a dashed vertical line from P down to the loop.]
A circular wire loop with radius 0.10 m and resistance 50 Ω is held in place horizontally in a magnetic field $\vec{B}$ directed upward at an angle of $60°$ with the vertical, as shown in the figure above. The magnetic field in the direction shown is given as a function of time t by $B(t) = a(1 - bt)$, where $a = 4.0$ T and $b = 0.20$ s^{-1}.

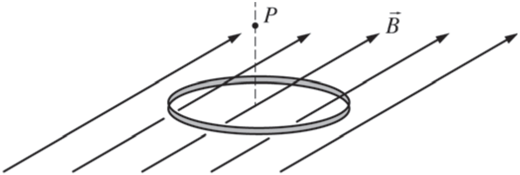
Question 3

(a) Derive an expression for the magnetic flux through the loop as a function of time t.

Question 3



Edge View



Perspective View

Question 3

2015 ▪ Q3

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A circular wire loop with radius 0.10 m and resistance 50 Ω is held in place horizontally in a magnetic field $\vec{B}$ directed upward at an angle of $60°$ with the vertical, as shown in the figure above. The magnetic field in the direction shown is given as a function of time t by $B(t) = a(1 - bt)$, where $a = 4.0$ T and $b = 0.20$ s^{-1}.

(b) Calculate the numerical value of the induced emf in the loop.

Question 3

2015 ▪ Q3

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(c)(i) Calculate the numerical value of the induced current in the loop.

Question 3

(c)(ii) What is the direction of the induced current in the loop as viewed from point P?

______ Clockwise ______ Counterclockwise

Justify your answer.

Question 3

2015 ▪ Q3

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Question 3

(d) Assuming the loop stays in its current position, calculate the energy dissipated in the loop in 4.0 seconds.

Question 3

2015 ▪ Q3

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Question 3

(e) Indicate whether the net magnetic force and net magnetic torque on the loop are zero or nonzero while the loop is in the magnetic field.

Net magnetic force: _____ Zero _____ Nonzero

Net magnetic torque: _____ Zero _____ Nonzero

Justify both of your answers.

Solution 3

(a) Mark scheme

- Calculate the magnetic flux through the circular loop using $\Phi_B = \int \vec{B} \cdot d\vec{A}$ (1 point for properly using a correct equation for flux). Since $\vec{B}$ is uniform over the loop's area at any instant, this becomes $\Phi_B = BA\cos\theta = B\pi r^2 \cos\theta$ (1 point for the correct substitution of the loop area and the trigonometric factor for the angle between $\vec{B}$ and the loop's area vector). Substituting the given time-dependent field magnitude $B = 4(1 - 0.2t)$ T, loop radius $r = 0.10$ m, and the fixed angle $\theta = 60°$ between the field and the loop's normal: $\Phi_B = 4(1 - 0.2t)\,\pi(0.10 \text{ m})^2(\cos 60°)$ (1 point for correct substitution into the flux equation), which simplifies to

Solution 3

$\Phi_B = 0.063 - 0.013t$ (in Wb, with t in s); equivalently, in terms of the given constants a and b if $B = a(1 - bt)$, $\Phi_B = a(1 - bt)(0.016)$.

Solution 3

(b)

Mark scheme

- Use Faraday's law to solve for the induced emf: $\mathcal{E} = -\frac{d\Phi_B}{dt}$ (1 point for using the correct equation). Substitute the flux expression from part (a), $\Phi_B = 0.063 - 0.013t$: $\mathcal{E} = -\frac{d}{dt}(0.063 - 0.013t) = 0.013$ V (1 point; the answer must be consistent with part (a) — the scoring guidelines note that any sign on the answer is ignored).

Solution 3

(c)(i)

Mark scheme

- Apply Ohm's law to the loop (resistance $R = 50\ \Omega$) using the magnitude of the emf from part (b): $V = IR$, so $I = \dfrac{V}{R} = \dfrac{0.013\ \text{V}}{50\ \Omega} = 2.6 \times 10^{-4}$ A (1 point for a substitution into Ohm's law consistent with the answer from part (b)).

Solution 3

(c)(ii) Mark scheme

- The correct direction is counterclockwise, as viewed from point P. Justification: looking down at the loop from P, the vertical (upward) component of the magnetic field passing through the loop is decreasing with time (1 point for a justification that incorporates that the original magnetic field is changing). By Lenz's law the induced current opposes this decrease, so it must create its own magnetic field directed upward at point P inside the loop; by the right-hand rule, a current producing an upward field as seen from P must flow counterclockwise as viewed from P (1 point for a justification that correctly relates the induced current's direction to the direction of the new magnetic field created by that current). Example from the scoring guidelines: 'Looking down at the loop from P,

Solution 3

the vertical component of the magnetic field of the loop is upward and decreasing. To oppose this change, the current in the loop must create a magnetic field that is directed upward at point P. This requires a counterclockwise current in the loop.'

Solution 3

(d) Mark scheme

- Calculate the power dissipated and multiply by the time interval: $E = Pt = I^2Rt$, or equivalently, using the emf directly, $E = Pt = \left(\frac{\mathcal{E}^2}{R}\right)t$ (1 point for using a correct equation for the energy dissipated). Substitute the numerical results from part (c)-i or part (b): $E = (2.6 \times 10^{-4}\ \mathrm{A})^2(50\ \Omega)(4.0\ \mathrm{s})$, or equivalently $E = \frac{(0.013\ \mathrm{V})^2}{50\ \Omega}(4.0\ \mathrm{s})$ (1 point for a correct substitution into either equation using the answer from part (c)-i or part (b)), giving $E = 1.4 \times 10^{-5}\ \mathrm{J}$. This leaf also carries the question's global 1-point Units credit from the scoring guidelines: full marks additionally require correct SI units reported on at least two of this

Solution 3

question's numerical parts (e.g. V, A, J) with no incorrect units given anywhere in the response.

Solution 3

(e) Mark scheme

- Classify the net magnetic force and net magnetic torque on the loop while it is in the field. The correct answers are: net magnetic force = Zero, net magnetic torque = Nonzero (1 point for selecting both correctly). Justification: since the current's direction relative to the (fixed-direction) magnetic field changes as you go around the loop, the field exerts forces of equal magnitude but opposite direction on diametrically opposite sides of the loop (1 point for indicating that the forces on directly opposite sides of the loop are in opposite directions). These opposite forces cancel pairwise all the way around the loop, so the net force on the loop is zero (1 point for concluding that the forces cancel and the net force is zero). However, because the opposing forces act on opposite sides of the loop,

Solution 3

they produce torques that add rather than cancel (they all act to rotate the loop in the same sense), so the net torque on the loop is nonzero (1 point for indicating that the torques add and the net torque is nonzero). Example from the scoring guidelines: 'Since the current changes direction relative to the magnetic field as you go around the loop, the magnetic field will exert force of equal magnitude but opposite direction on opposite sides of the loop. These forces all cancel out resulting in zero net force. However, since this force is up on one side of the loop and down on the other side of the loop, this will create torques that rotate the loop in the same direction. Therefore, the net torque is not zero.'