Past-paper walk-through

Electric Power ▪ 11.4

eXercise

Questions in this set

- 2024 Q3
- 2021 Q3
- 2015 Q2

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 3

2024 ▪ Q3

[Figure 1: A circuit diagram. An ideal battery of emf $\mathcal{E}$ is connected on the left. From the top of the battery, a wire goes right through resistor R_1 to a node. From that node, resistor R_2 branches down in parallel back to the bottom rail. Also from that same node, a wire continues right to another node, from which resistors R_3 (upper) and R_4 (lower) branch down in parallel, both returning to the bottom rail, which connects back to the battery.]

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(a)(i) For parts (a)(i) and (a)(ii), express your answers in terms of numerical values, $\mathcal{E}$, and R only.

Derive an expression for the current I_1 in Resistor R_1.

(a)(ii) Derive an expression for the current I_3 in Resistor R_3.

Question 3

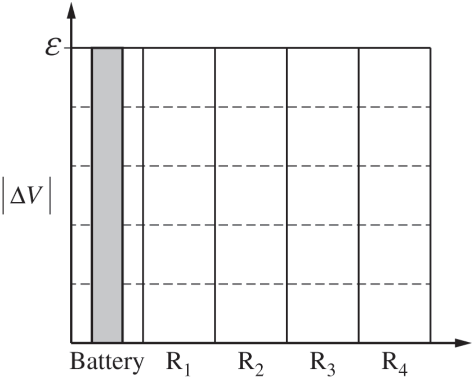


Figure 2

Question 3

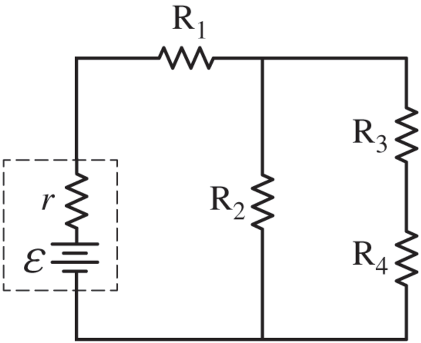


Figure 3

Question 3

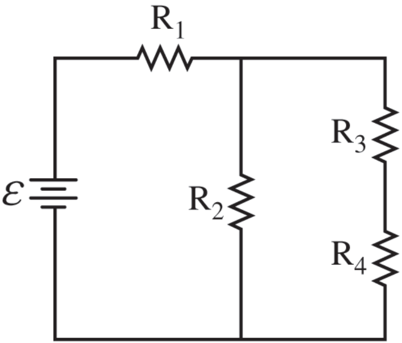


Figure 1

Question 3

2024 ▪ Q3

[Figure 1: A circuit diagram. An ideal battery of emf $\mathcal{E}$ is connected on the left. From the top of the battery, a wire goes right through resistor R_1 to a node. From that node, resistor R_2 branches down in parallel back to the bottom rail. Also from that same node, a wire continues right to another node, from which resistors R_3 (upper) and R_4 (lower) branch down in parallel, both returning to the bottom rail, which connects back to the battery.]

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(b) [Figure 2: A partially completed bar chart. The vertical axis is labeled $|\Delta V|$ with a horizontal dashed reference line marked $\mathcal{E}$ near the top. The horizontal axis lists categories "Battery", R_1, R_2, R_3, R_4. A single shaded bar is drawn above "Battery" reaching up to the $\mathcal{E}$ line; the bars for R_1, R_2, R_3, R_4 are blank for the student to draw.]

Question 3

The partially completed bar chart in Figure 2 shows a bar that represents the absolute value $|\Delta V|$ of the potential difference across the ideal battery.
- In Figure 2, **draw** a bar to represent $|\Delta V|$ across **each** resistor, relative to the emf $\mathcal{E}$ of the ideal battery. - The height of each bar should be proportional to the value of $|\Delta V|$ represented by that bar. If $|\Delta V|$ is zero, write a "0" in that column.
A student claims that the rate at which energy is dissipated (power) by the circuit can be expressed as $P = \dfrac{3\mathcal{E}^2}{5R}$.

Question 3

2024 ▪ Q3

[Figure 1: A circuit diagram. An ideal battery of emf $\mathcal{E}$ is connected on the left. From the top of the battery, a wire goes right through resistor R_1 to a node. From that node, resistor R_2 branches down in parallel back to the bottom rail. Also from that same node, a wire continues right to another node, from which resistors R_3 (upper) and R_4 (lower) branch down in parallel, both returning to the bottom rail, which connects back to the battery.]

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(c) State whether the expression for P is correct or incorrect. **Justify** your answer by referring to the derivations from part (a) or the bar chart from part (b).

Question 3

2024 ▪ Q3

[Figure 1: A circuit diagram. An ideal battery of emf $\mathcal{E}$ is connected on the left. From the top of the battery, a wire goes right through resistor R_1 to a node. From that node, resistor R_2 branches down in parallel back to the bottom rail. Also from that same node, a wire continues right to another node, from which resistors R_3 (upper) and R_4 (lower) branch down in parallel, both returning to the bottom rail, which connects back to the battery.]

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(d) [Figure 3: The same circuit as Figure 1, but the ideal battery is replaced by a nonideal battery, drawn as an emf $\mathcal{E}$ in series with an internal resistance r enclosed in a dashed box. The rest of the circuit (resistors R_1, R_2, R_3, R_4 in the same configuration) is unchanged.]

Question 3

When the ideal battery is connected in the original circuit, the rate at which energy is dissipated by Resistor R_1 is $P_{original}$. The ideal battery is now replaced with a nonideal battery of emf $\mathcal{E}$ and internal resistance r to form the new circuit shown in Figure 3. The rate at which energy is dissipated by Resistor R_1 in the new circuit is P_{new}.

Indicate whether P_{new} is greater than, less than, or equal to $P_{original}$.

______ $P_{new} > P_{original}$ ______ $P_{new} < P_{original}$ ______ $P_{new} = P_{original}$

Briefly **justify** your answer.

Solution 3

(a)(i) Mark scheme

- Total resistance: the right-most branch (Resistors R_3 and R_4 in series) has $R_s = R + R = 2R$. This branch is in parallel with R_2: $\dfrac{1}{R_p} = \dfrac{1}{R} + \dfrac{1}{2R} = \dfrac{3}{2R}$, so $R_p = \dfrac{2R}{3}$. This parallel combination is in series with R_1: $R_{total} = R + \dfrac{2R}{3} = \dfrac{5R}{3}$. Applying Ohm's law to the whole circuit with the ideal battery's emf $\mathcal{E}$: $I_1 = \dfrac{\Delta V}{R_{total}} = \dfrac{\mathcal{E}}{5R/3} = \dfrac{3\mathcal{E}}{5R}$. Scoring: 1 pt for correctly determining $R_{total} = 5R/3$; 1 pt for a multi-step derivation with correct substitution of $\mathcal{E}$ and R_{total} into Ohm's law, consistent with the first point (giving $I_1 = 3\mathcal{E}/5R$).

Solution 3

(a)(ii) Mark scheme

- I_3 is the current through the series branch R_3-R_4. Since R_2 and the $(R_3 + R_4)$ branch are in parallel (same potential difference): $I_2 R_2 = I_3(R_3 + R_4) \Rightarrow I_2 R = I_3(2R) \Rightarrow I_2 = 2I_3$. By the junction rule, $I_1 = I_2 + I_3 = 2I_3 + I_3 = 3I_3$, so $I_3 = I_1/3$. Substituting $I_1 = 3\mathcal{E}/5R$ from part (a)(i): $I_3 = \dfrac{3\mathcal{E}/5R}{3} = \dfrac{\mathcal{E}}{5R}$. (Equivalently: one-third of the total current I_1 flows through R_3, since R_2 carries twice the current of the R_3-R_4 branch.) Scoring: 1 pt for applying Kirchhoff's/Ohm's law to relate I_3 to the current in or potential difference across R_1, R_2, or R_3; 1 pt for a correct final expression from a multi-step derivation, consistent with part (a)(i), giving $I_3 = \mathcal{E}/(5R)$.

Solution 3

(b) Mark scheme

- Bar chart of $|\Delta V|$ for each element (Battery bar already shown at $\mathcal{E}$): the R_1 bar is nonzero, at $\Delta V_1 = I_1 R = (3\mathcal{E}/5R)(R) = 3\mathcal{E}/5$. Since R_2 is in parallel with the R_3-R_4 series branch, $\Delta V_2 = \Delta V_3 + \Delta V_4$, and this equals $\mathcal{E} - \Delta V_1 = 2\mathcal{E}/5$. R_3 and R_4 carry the same current and have equal resistance, so $\Delta V_3 = \Delta V_4$, each equal to half of ΔV_2, i.e. $\mathcal{E}/5$. Final bar heights: Battery $= \mathcal{E}$, $R_1 = 3\mathcal{E}/5$, $R_2 = 2\mathcal{E}/5$, $R_3 = \mathcal{E}/5$, $R_4 = \mathcal{E}/5$. Scoring: 1 pt for a bar showing ΔV_3 is nonzero and equal to ΔV_4; 1 pt for a bar showing ΔV_2 is nonzero and equal to $\Delta V_3 + \Delta V_4$; 1 pt for drawing ALL bars correctly (including correct relative heights of Battery, R_1, R_2, R_3, R_4).

Solution 3

(c) Mark scheme

- The equation $P = \dfrac{3\mathcal{E}^2}{5R}$ is CORRECT. Justification: power dissipated can be written $P = (\Delta V)^2/R$. From the bar chart in part (b), the potential difference across the (ideal) battery is $\mathcal{E}$; from part (a)(i), the total resistance is $R_{total} = 5R/3$. Therefore the total power delivered by the battery is $P = \dfrac{(\Delta V)^2}{R_{total}} = \dfrac{\mathcal{E}^2}{5R/3} = \dfrac{3\mathcal{E}^2}{5R}$, matching the given expression, so it is correct. Scoring: 1 pt for stating the equation is correct/incorrect (consistent with the student's own part (a) derivations or part (b) bar chart) with an attempted justification; 1 pt for a justification relating P to at least one of the potential

Solution 3

difference across the battery, the current in the battery, or R_1, R_2, R_3, R_4; 1 pt for a justification that relates the equation $P = 3\mathcal{E}^2/5R$ to the bar chart from (b) or the derivations from (a)(i)/(a)(ii).

Solution 3

(d) Mark scheme

- $P_{new} < P_{original}$. Justification: the emf $\mathcal{E}$ of the battery is the same in the new circuit, but the new circuit has additional internal resistance r, so its total resistance is greater than in the original circuit. A larger total resistance with the same emf means a smaller total (and branch) current, so the current in R_1 is less in the new circuit than in the original — equivalently, the potential difference across R_1 is less. Since the power dissipated in R_1 depends on I_1^2R (or $(\Delta V_1)^2/R$), a decrease in I_1 (or ΔV_1) means $P_{new} < P_{original}$. Scoring: 1 pt for correctly selecting $P_{new} < P_{original}$ with an attempted justification; 1 pt for a correct justification citing that the current in R_1 (or the potential difference across R_1) is less in the new circuit than in the original.

Question 3

2021 ▪ Q3

[Graph 1: axes with B (vertical) vs. I (horizontal). Dashed horizontal lines at B_1 (labeled "B_1 (Out of Page)") and at $-B_1$ (labeled "$-B_1$ (Into Page)"), with corresponding dashed vertical lines at I_1 and $-I_1$. A straight line of positive slope passes through the origin O and through the points $(-I_1, -B_1)$ and (I_1, B_1).]

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.

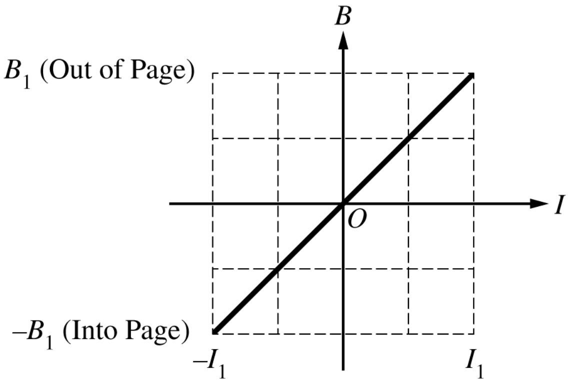
[Diagram: an upward-pointing arrow labeled "Velocity" and a leftward-pointing arrow labeled "F_B", both attached to a point labeled "Particle".]

(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B

Question 3

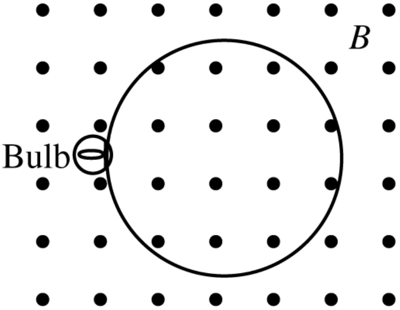
toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted on the particle equal to $2F_B$ and the direction of the force to the right? Support your answer using physics principles.

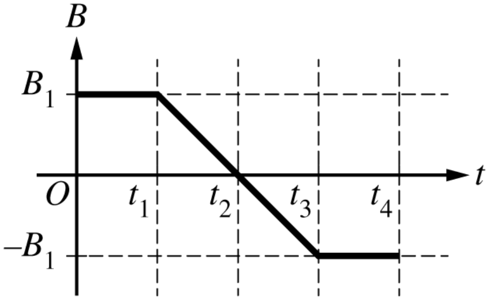
Question 3



Graph 1

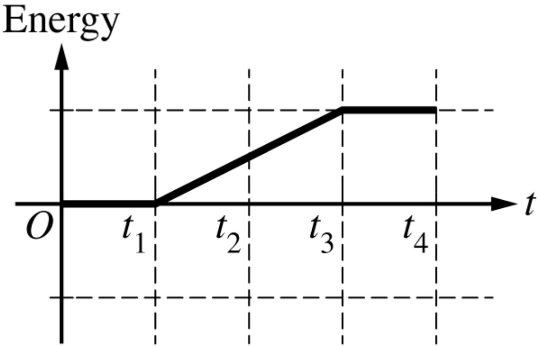
Question 3





Graph 2

Question 3



Graph 3

Question 3

2021 ▪ Q3

[Graph 1: axes with B (vertical) vs. I (horizontal). Dashed horizontal lines at B_1 (labeled "B_1 (Out of Page)") and at $-B_1$ (labeled "$-B_1$ (Into Page)"), with corresponding dashed vertical lines at I_1 and $-I_1$. A straight line of positive slope passes through the origin O and through the points $(-I_1, -B_1)$ and (I_1, B_1).]

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.

[Diagram: an upward-pointing arrow labeled "Velocity" and a leftward-pointing arrow labeled "F_B", both attached to a point labeled "Particle".]

(b) [Diagram: a circular loop of wire containing a grid of dots (representing a magnetic field out of the page), with a circle labeled "Bulb" on the left side of the loop, and an arrow labeled "B" pointing to the top-right of the loop's boundary.

Question 3

Graph 2: axes with B_1 (vertical, dashed line above origin) vs. t (horizontal), with dashed vertical lines at t_1, t_2, t_3, t_4 and a dashed horizontal line at $-B_1$ below the origin. The plotted curve starts at B_1 for $t < t_1$, decreases linearly crossing zero and continuing down to $-B_1$ by t_2, remains constant at $-B_1$ from t_2 to t_3, then increases linearly back up to B_1 by t_4 and remains constant at B_1 after t_4.
Graph 3: axes with Energy (vertical) vs. t (horizontal), with dashed vertical lines at t_1, t_2, t_3, t_4. The plotted curve is flat (zero slope, cumulative energy constant) for $t < t_1$, then rises with increasing (concave-up) slope from t_1 to t_2, continues rising linearly (constant slope) from t_2 to t_3, then flattens out (zero slope, constant) after t_3 through t_4 and beyond.]
A circuit is made by connecting an ohmic lightbulb of resistance R and a circular loop of area A made of a wire with negligible resistance. The circuit is placed with the plane of the loop perpendicular to the field of the electromagnet, as shown above on the left.

Question 3

The magnetic field changes as a function of time, as shown in Graph 2. The bulb dissipates energy during the interval $t_1 < t < t_3$. Graph 3 below shows the cumulative energy dissipated by the bulb (the total energy dissipated since $t = 0$) as a function of time.

The original bulb is replaced by a new ohmic lightbulb with a greater resistance, but everything else stays the same. How would the cumulative energy graph for the new bulb be different, if at all, from Graph 3 above? Support your answer using physics principles.

Question 3

2021 ▪ Q3

[Graph 1: axes with B (vertical) vs. I (horizontal). Dashed horizontal lines at B_1 (labeled "B_1 (Out of Page)") and at $-B_1$ (labeled "$-B_1$ (Into Page)"), with corresponding dashed vertical lines at I_1 and $-I_1$. A straight line of positive slope passes through the origin O and through the points $(-I_1, -B_1)$ and (I_1, B_1).]

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.

[Diagram: an upward-pointing arrow labeled "Velocity" and a leftward-pointing arrow labeled "F_B", both attached to a point labeled "Particle".]

(c) The new lightbulb is removed and replaced by the original lightbulb. The magnetic field now changes from $2B_1$ to $-2B_1$ during the same interval $t_1 < t < t_3$. A new

Question 3

cumulative energy graph is created for this situation. How would the new graph be different, if at all, from Graph 3? Support your answer using physics principles.

Question 3

2021 ▪ Q3

[Graph 1: axes with B (vertical) vs. I (horizontal). Dashed horizontal lines at B_1 (labeled "B_1 (Out of Page)") and at $-B_1$ (labeled "$-B_1$ (Into Page)"), with corresponding dashed vertical lines at I_1 and $-I_1$. A straight line of positive slope passes through the origin O and through the points $(-I_1, -B_1)$ and (I_1, B_1).]

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.

[Diagram: an upward-pointing arrow labeled "Velocity" and a leftward-pointing arrow labeled "F_B", both attached to a point labeled "Particle".]

(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

Question 3

$$\text{Energy} = \frac{A^2 B_1 R}{4(t_3 - t_1)}$$

Whether or not the equation is correct, does the functional dependence of cumulative energy on the elapsed time $(t_3 - t_1)$ make physical sense? Support your answer using physics principles.

Solution 3

(a) Mark scheme

- Since the magnetic force on a moving charge is $F = qvB$, doubling the force magnitude (to 2F_B) at the same particle speed requires doubling the magnetic field magnitude B (1 point). From the given current–field graph, doubling the current doubles the magnetic field, so the current magnitude must also be doubled — the explanation must contain no incorrect statements (1 point). To reverse the force direction (from left to right) while the particle's velocity is unchanged, the magnetic field direction must reverse, which requires reversing the current direction, i.e. making the current negative relative to its original direction (1 point).

Solution 3

(b) Mark scheme

- The induced emf is unchanged when the lightbulb is swapped, since emf depends only on the rate of change of magnetic flux through the loop, which is unchanged (1 point). The new bulb has larger resistance, so for the same emf, $P = emf^2/R$ (or $I = emf/R$, $P = I^2R$) gives less current and less power dissipated — explanation must contain no incorrect statements (1 point). Since the slope of the cumulative-energy-vs-time graph represents power, the new graph's slope between t and t is smaller than in Graph 3 (the horizontal line segment after t would lie below the one shown) (1 point).

Solution 3

(c) Mark scheme

- Changing the magnetic field from 2B to $-$2B (a magnitude-4B change) over the same time interval t $<$t$<$t is a greater change in magnetic flux than before, producing a larger induced emf ($|\text{emf}| = |\Delta\Phi/\Delta t|$, by Faraday's law) (1 point). Since dissipated power is proportional to the square of the emf ($P = \text{emf}^2/R$), the larger emf means more power and more energy dissipated over the same interval — or an answer consistent with the first point (1 point). Therefore the slope of the new cumulative-energy-vs-time graph between t and t is GREATER than in Graph 3 (the horizontal line segment at the right would lie above the one shown), or an answer consistent with the first point (1 point).

Solution 3

(d) Mark scheme

- For the expression Energy $= A^2B\ R\ /\ [4(t - t\ )]$ to make sense, the cumulative energy dissipated must depend on the elapsed time $(t - t\ )$ in some way — any indication of this dependence earns credit (1 point). Physically, induced emf depends on the RATE of change of magnetic flux, so a larger elapsed time (slower change) gives a SMALLER emf, i.e. emf is inversely proportional to the elapsed time (1 point). Since power is proportional to emf squared ($P \propto \text{emf}^2$) and energy is power times time (Energy $= P \cdot \Delta t$), energy should scale as $(1/\Delta t)^2 \cdot \Delta t = 1/\Delta t$, i.e. energy should be inversely proportional to the elapsed time — NOT directly proportional to it as the student's expression (which has Energy $\propto (t - t\ )$ in the denominator inverted incorrectly / does not reflect a $1/\Delta t$ dependence)

Solution 3

suggests; a correct expression would decrease, not increase, as $(t - t)$ grows only if it truly varies as $1/(t - t)$ (1 point).

Question 2

2015 ▪ Q2

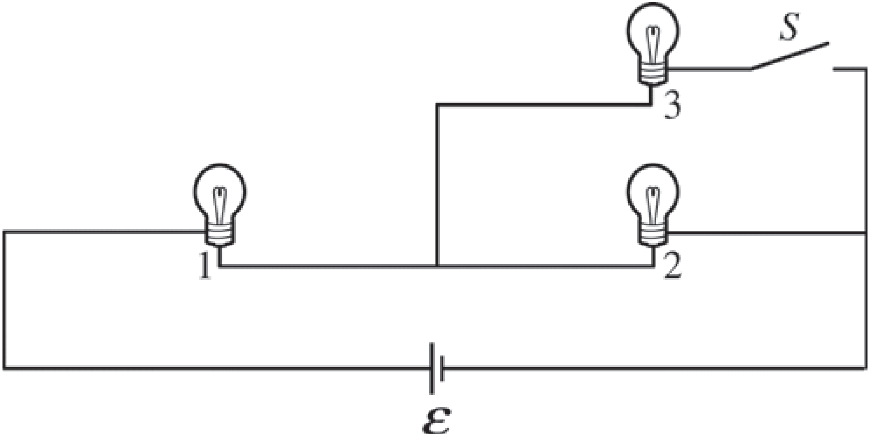
[Circuit diagram: A battery of emf $\mathcal{E}$ is connected at the bottom of the circuit. From the battery, a wire goes up the left side to a node, then splits. Bulb 1 is in the top-left branch. After bulb 1, the wire continues right to a node where the circuit splits into two parallel branches: the upper branch contains bulb 3 in series with switch S (initially open); the lower branch contains bulb 2. Both branches reconnect and return down the right side to the battery. So bulb 1 is in series with the parallel combination of (bulb 3 + switch S) and bulb 2.]

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

Question 2

(a)(i) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."
Do you agree or disagree with the student's prediction about bulb 1? Qualitatively explain your reasoning.
(a)(ii) Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed, in terms of P_1.
(a)(iii) How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

Question 2



Question 2

2015 ▪ Q2

[Circuit diagram: A battery of emf $\mathcal{E}$ is connected at the bottom of the circuit. From the battery, a wire goes up the left side to a node, then splits. Bulb 1 is in the top-left branch. After bulb 1, the wire continues right to a node where the circuit splits into two parallel branches: the upper branch contains bulb 3 in series with switch S (initially open); the lower branch contains bulb 2. Both branches reconnect and return down the right side to the battery. So bulb 1 is in series with the parallel combination of (bulb 3 + switch S) and bulb 2.]

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(b)(i) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

Question 2

Do you agree or disagree with the student's prediction about bulb 2? Explain your reasoning in words.

(b)(ii) Justify your explanation with a calculation.

Question 2

2015 ▪ Q2

[Circuit diagram: A battery of emf $\mathcal{E}$ is connected at the bottom of the circuit. From the battery, a wire goes up the left side to a node, then splits. Bulb 1 is in the top-left branch. After bulb 1, the wire continues right to a node where the circuit splits into two parallel branches: the upper branch contains bulb 3 in series with switch S (initially open); the lower branch contains bulb 2. Both branches reconnect and return down the right side to the battery. So bulb 1 is in series with the parallel combination of (bulb 3 + switch S) and bulb 2.]

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(c)(i) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

Question 2

How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

(c)(ii) How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

Solution 2

(a)(i) Mark scheme

- Disagree with the student — bulb 1 does not decrease in brightness; it increases. Reasoning chain, each part worth a point: (1) closing the switch puts bulb 3 in parallel with bulb 2, so the resistance of the bulb2+bulb3 combination (and hence the equivalent resistance R_eq of the whole circuit) decreases. (2) By Ohm's law, a decreased R_eq across the fixed EMF increases the total current I_tot, so the current through (and potential difference across) bulb 1 increases, not decreases. (3) Since bulb 1 now carries more current/has a larger potential difference across it, it delivers more power, so its brightness increases — consistent with the current/PD change identified.

Solution 2

(a)(ii) Mark scheme

- Before the switch closes, bulb 1 is in series with bulb 2 only (each resistance R), so $I = \mathcal{E}/2R$ and $P_1 = I^2 R = \frac{1}{4}\left(\frac{\mathcal{E}^2}{R}\right)$ (1 point). When the switch closes, bulb 3 (resistance R) is added in parallel with bulb 2, so the bulb2+3 combination has resistance $R/2$, giving new total equivalent resistance $R_{eq,new} = R + R/2 = \frac{3}{2}R$ (1 point; credit also earned if this was already found in part (a)i and reused here). Manipulating equations: the new current is $I_{new} = \mathcal{E}/R_{eq,new} = \frac{2\mathcal{E}}{3R}$, so the new power in bulb 1 is $P_{new} = I_{new}^2 R = \frac{4\mathcal{E}^2}{9R} = \frac{16}{9}P_1$ (1 point for correctly showing $P_{new} = \frac{16}{9}P_1$).

Solution 2

(a)(iii)

Mark scheme

- Since $\frac{16}{9} > 1$, $P_{new} > P_1$, so bulb 1 expends more power after the switch closes and therefore gets brighter, not dimmer. This confirms part (a)i: a lower circuit resistance raises the current/PD through bulb 1, increasing its power consumption and brightness. Full credit requires explicitly using or referencing the (a)ii expression (e.g. citing $16/9 > 1$) and connecting greater power consumption to greater brightness.

Solution 2

(b)(i)

Mark scheme

- Bulb 2's brightness decreases after the switch is closed. Explanation: once bulb 3 is added in parallel with bulb 2, the current that previously flowed entirely through bulb 2 is now shared between bulb 2 and bulb 3, so the current through (and potential difference across) bulb 2 decreases. Bulb 2 therefore expends less power than before and dims.

Solution 2

(b)(ii)

Mark scheme

- A numeric calculation supporting part (b)i is required, e.g.: before the switch closes, the current through bulb 2 is $I_2 = I_1 = \mathcal{E}/2R$. After closing, $I_{tot} = \mathcal{E}/R_{eq,new} = 2\mathcal{E}/3R$ splits evenly between the two identical parallel bulbs (2 and 3), so $I_2' = I_{tot}/2 = \mathcal{E}/3R$. Since $\mathcal{E}/3R < \mathcal{E}/2R$, bulb 2 carries less current after the switch closes, confirming it is dimmer.

Solution 2

(c)(i) Mark scheme

- (This leaf and 2cii together are worth 3 points on the official scheme: 1 shared point for indicating, in either part, that brightness depends on the potential difference across or current through the bulb, plus 1 point for each part's own justification — allocated here as 2 points to this leaf and 1 to 2cii.) Immediately after the switch closes, bulb 1 is brighter than bulb 2. Reasoning: an uncharged capacitor has zero potential difference across it the instant the switch closes, so it behaves like a short circuit (a wire). Since the capacitor sits in parallel with bulb 2, this diverts current away from bulb 2, so the current through bulb 2 is momentarily zero (or greatly reduced) — less than the current through bulb 1. No

Solution 2

credit for the 'bulb 1 brighter' conclusion without this justification via current/potential difference.

Solution 2

(c)(ii)

Mark scheme

- A long time after the switch closes, bulb 1 has the same brightness as bulb 2. Reasoning: as the capacitor charges, the current through that branch decreases toward zero, and a fully charged capacitor behaves like an open circuit (blocks steady current) after a long time. With (essentially) no current diverted into the capacitor branch, the same current that flows through bulb 1 must also flow through bulb 2, so the two bulbs are equally bright. No credit for the 'same brightness' conclusion without this justification via current/potential difference.