Past-paper walk-through

RC Circuits ▪ 11.8

eXercise

Questions in this set

- 2025 Q3
- 2023 Q2
- 2018 Q2
- 2016 Q4
- 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

2025 ▪ Q3

In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.

[Figure 1: a row of labeled equipment icons — Resistor, Capacitor (parallel plates), Battery, Switch, Ammeter, Ruler, and a bundle of Wires.]

Note: Figure not drawn to scale.

Question 3

(a) Describe a procedure for collecting data that would allow the student to determine the expected time constant τ. In your description, include the measurements to be made. Include any steps necessary to reduce experimental uncertainty.

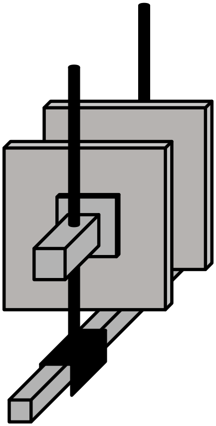
Question 3

Question 3

Question 3

$\lvert \Delta V \rvert$ (V)	$q\ (\times 10^{-10}\ \mathrm{C})$
3.0	2.4
5.0	4.2
7.2	5.6
8.0	6.6
10.0	8.0

Question 3



Question 3

2025 ▪ Q3

In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.

[Figure 1: a row of labeled equipment icons — Resistor, Capacitor (parallel plates), Battery, Switch, Ammeter, Ruler, and a bundle of Wires.]

Note: Figure not drawn to scale.

(b) Describe how the collected data could be analyzed to determine τ. Include references to appropriate equations and to relationships between measured and known quantities.

Question 3

2025 ▪ Q3

In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.

[Figure 1: a row of labeled equipment icons — Resistor, Capacitor (parallel plates), Battery, Switch, Ammeter, Ruler, and a bundle of Wires.]

Note: Figure not drawn to scale.

(c)(i) In Experiment 2, the student is asked to determine the capacitance C of a new parallel-plate capacitor. For each trial, the absolute value $|\Delta V|$ of the potential

Question 3

difference across the capacitor is varied and the charge q stored on one plate of the fully charged capacitor is measured. Table 1 contains the data collected.

Table 1

$\|\Delta V\|$ (V)	q $(\times 10^{-10}$ C)
3.0	2.4
5.0	4.2
7.2	5.6
8.0	6.6
10.0	8.0

Indicate two quantities, either measured quantities from Table 1 or additional calculated quantities, that could be graphed to produce a straight line that could be used to determine C.

Vertical axis: $H^{orizontalaxis:}$

(c)(ii) On the grid provided, create a graph of the quantities indicated in part C (i).

- Use Table 2 to record the measured or calculated quantities that you will plot.
- Clearly **label** the axes, including units as appropriate.

Question 3

- **Plot** the points you recorded in Table 2.

[Grid: a blank square-ruled graphing grid, approximately 30 by 40 small squares, provided for the student to label axes and plot points.]

(c)(iii) Draw a best-fit line for the data graphed in part C (ii).

Question 3

2025 ▪ Q3

In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.
[Figure 1: a row of labeled equipment icons — Resistor, Capacitor (parallel plates), Battery, Switch, Ammeter, Ruler, and a bundle of Wires.]

Note: Figure not drawn to scale.

(d) Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for capacitance C.

Solution 3

(a) Mark scheme

- Procedure must include measuring BOTH: (1) the dimensions of the capacitor – e.g. measure the length of one side of a capacitor plate (for the area A) and the separation distance between the plates (d); and (2) a current – e.g. construct a circuit with the battery, resistor, and capacitor, and measure the (initial) current in the resistor. The procedure must also indicate an appropriate method to reduce experimental uncertainty, e.g. repeat the measurement/procedure multiple times (discharge the capacitor and repeat the current measurement) and average the results, or take repeated trials of the dimension measurements.

Solution 3

(b) Mark scheme

- tau = Req*Ceq can be used to determine tau. Req is found from a correct relationship between resistance, the battery's emf, and the current: Req = emf/I, where I is the (initial) current in the resistor when connected to the battery. Ceq is found from a correct relationship between capacitance and the capacitor's geometry: Ceq = epsilon0*A/d, where A is the area of a capacitor plate (the square of the plate's side length) and d is the separation between the plates. Full credit requires: (1) stating tau = Req*Ceq is used to find tau; (2) both a correct R-relationship (Req = emf/I) and a correct C-relationship (Ceq = epsilon0*A/d).

Solution 3

(c)(i)

Mark scheme

- Indicate a pair of quantities whose functional relationship is linear (based on q = C*|deltaV|), e.g.: plot q as a function of |deltaV| (slope = C); or |deltaV| as a function of q (slope = 1/C); or 1/q as a function of 1/|deltaV|; or 1/|deltaV| as a function of 1/q. Any response that correctly identifies the functional dependence between the varied quantities earns credit, regardless of numerical/physical-constant coefficients or which axis each quantity is graphed on.

Solution 3

(c)(ii)

Mark scheme

- Label both axes, including units, with a linear (evenly spaced) scale – e.g. vertical axis q (x10^-10 C), horizontal axis |deltaV| (V). Plot the five data points from Table 1, converted to the chosen quantities from part C(i): (|deltaV|, q) = (3.0 V, 2.4e-10 C), (5.0 V, 4.2e-10 C), (7.2 V, 5.6e-10 C), (8.0 V, 6.6e-10 C), (10.0 V, 8.0e-10 C). The plotted points must be consistent with the quantities chosen in part C(i) (or with the table / the chosen axes).

Solution 3

(c)(iii)

Mark scheme

- Draw a single straight best-fit (trend) line through the plotted data points, approximating the overall linear trend of the five points – not a line connecting the dots point-to-point, and not required to pass through the origin or through every point.

Solution 3

(d) Mark scheme

- Using two well-separated points on the best-fit line (not raw data points) to compute the slope: slope = delta_q/delta_|deltaV| = (6.4e-10 C - 2.0e-10 C)/(8.0 V - 2.4 V) = 7.9e-11 C/V. Since q = C*|deltaV|, the slope of q vs |deltaV| equals C, so C = slope = 7.9e-11 F, approximately 8e-11 F. Full credit requires (1) correctly relating the slope of the graph to C (e.g. delta_q/delta_|deltaV| = slope = C, or the appropriate reciprocal relation for the axes chosen in C(i)), and (2) a numeric value for C approximately equal to 8e-10^-11 F, accepted in the range 7e-11 F <= C <= 9e-11 F, read from the student's own best-fit line.

Question 2

2023 ▪ Q2

(12 points, suggested time 25 minutes)
Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\ \Omega$.

(a)(i) The students are asked to experimentally determine whether the component is a resistor or an uncharged capacitor.

Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.

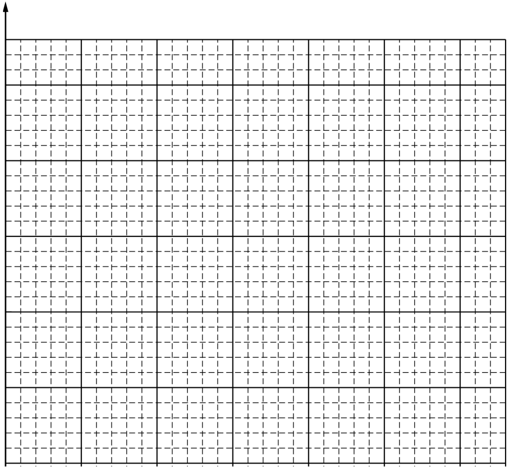
[Diagram: A circuit component box (labeled "Circuit Component") connected in series via a wire to a $500\ \Omega$ resistor, drawn with the standard zigzag resistor symbol. The circuit component is drawn as a rectangle with terminals. The student must complete the diagram with standard circuit equipment (e.g., battery, switch, meters).]

Question 2

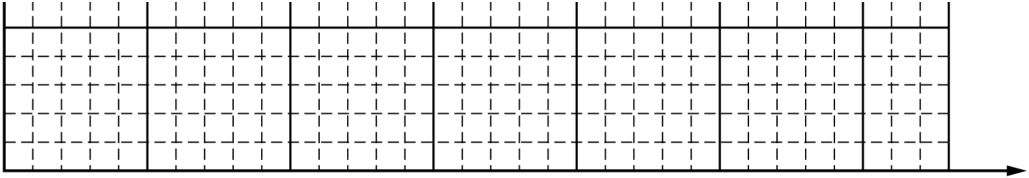
(a)(ii) Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

(a)(iii) What results would the students expect if the component is an uncharged capacitor? Support your answer in terms of potential difference and charge.

Question 2



Question 2



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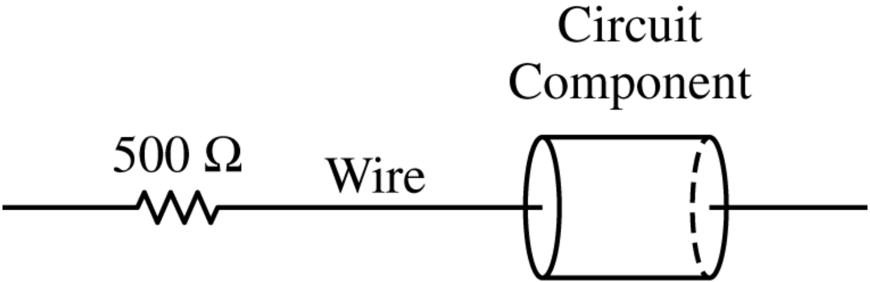
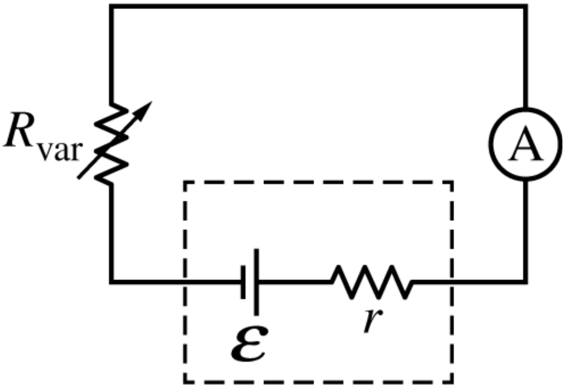


Question 2



Question 2

2023 ▪ Q2

(12 points, suggested time 25 minutes)

Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\ \Omega$.

(b)(i) [Figure: A circuit diagram showing a variable resistor R_{var} connected in series with an ammeter (circle with "A"), and a battery with emf $\mathcal{E}$ and internal resistance r (shown as a battery symbol inside a dashed box labeled $\mathcal{E}$, r).]

The students conduct a different experiment to determine the emf $\mathcal{E}$ of a battery that is not ideal and has internal resistance $r = 30\ \Omega$. The battery is connected to a variable resistor in a circuit, as shown. The students measure the current I through the circuit for different values of resistance R_{var} of the variable resistor that is connected to the battery. The following table contains the data collected.

Question 2

| I (A) | R_{var} (Ω) | |—|—| | 0.087 | 200 | | 0.060 | 300 | | 0.042 | 450 | | 0.027 | 700 | | 0.016 | 1200 |

Write an equation describing the circuit in terms of $\mathcal{E}$, I, r, and R_{var}.

(b)(ii) Which quantities could be graphed to yield a straight line that could be used to calculate a numerical value for the emf $\mathcal{E}$ of the battery?

Horizontal Axis: ____________________ Vertical Axis: ____________________

(b)(iii) Plot the data points for the quantities indicated in part (b)(ii) on the following graph. Clearly scale and label all axes, including units. Draw a straight line that best represents the data. You may use the blank columns in the table for any quantities you graph other than the given data.

[Graph: A blank grid with light dashed gridlines, with an unlabeled vertical axis (arrow pointing up) and unlabeled horizontal axis (arrow pointing right), for the student to plot and scale the chosen quantities.]

Question 2

(b)(iv) Using the graph from part (b)(iii), determine the emf $\mathcal{E}$ of the battery.

Solution 2

(a)(i) Mark scheme

- A correct circuit diagram: the unknown circuit component is connected in series with the $500\,\Omega$ resistor, a wire, and a battery/power supply, forming a complete circuit that produces current through the component (Point 1: source of potential difference in a complete circuit driving current through the component). A voltmeter is connected in parallel across the component (or across the resistor) OR an ammeter is connected in series in the circuit to measure current (a lightbulb in series is an acceptable ammeter substitute) (Point 2: an appropriately connected measurement device, e.g. voltmeter or ammeter).

Solution 2

(a)(ii) Mark scheme

- Procedure: measure one of — the potential difference across the circuit component, the current in the circuit, or the potential difference across the known $500\,\Omega$ resistor (Point 1). Take this measurement at two different times: immediately after the circuit is closed, and again a long time after the circuit is closed (or take a single measurement a long time after closing), consistent with the chosen quantity (Point 2). Example: measure the current in the ammeter immediately after the circuit is closed and a long time after the circuit is closed; or measure the potential difference across the component (or across the $500\,\Omega$ resistor) immediately after closing and a long time after closing.

Solution 2

(a)(iii) Mark scheme

- Expected results if the component is an uncharged capacitor: immediately after the circuit is closed, a nonzero current is measured; a long time after the circuit is closed, the current decreases to zero (equivalently, the charge on the capacitor's plates increases over time until fully charged) (Point 1). The electric potential difference across the capacitor increases from zero (immediately after closing) up to a value equal to the battery's potential difference a long time after closing, since the fully-charged capacitor allows no further current and (by Kirchhoff's loop rule) no potential difference remains across the other circuit elements (Point 2).

Solution 2

(b)(i)

Mark scheme

- Applying Kirchhoff's loop rule around the circuit (battery of emf $\mathcal{E}$ and internal resistance r, in series with variable resistor R_{var}, current I): $0 = +\mathcal{E} - Ir - IR_{var}$.

Solution 2

(b)(ii)

Mark scheme

- Any pair of quantities that linearizes the loop equation to let students find $\mathcal{E}$ from slope or intercept, e.g.: I vs. $\dfrac{1}{r+R_{var}}$ (slope $= \mathcal{E}$); or IR_{var} vs. I (y-intercept $= \mathcal{E}$); or R_{var} vs. $\dfrac{1}{I}$.

Solution 2

(b)(iii)

Mark scheme

- A correctly constructed graph of the chosen linearized quantities: (1) both axes carry numerical values on a linear scale with appropriate labels and units (e.g. I (A) vs. $1/(r + R_{var})$ (Ω^{-1}), or IR_{var} (V) vs. I (A)); (1) the data points are plotted so they span at least half of the grid area; (1) a straight best-fit line is drawn that reasonably approximates the trend of the plotted data points.

Solution 2

(b)(iv) Mark scheme

- Using $I = \mathcal{E}\left(\dfrac{1}{r + R_{var}}\right) = \mathcal{E}\left(\dfrac{1}{30\,\Omega + R_{var}}\right)$, the slope of I vs. $1/(r + R_{var})$ equals $\mathcal{E}$: e.g. slope $= \dfrac{(0.08\text{ A} - 0.04\text{ A})}{(0.004\,\Omega^{-1} - 0.002\,\Omega^{-1})} \approx \mathcal{E} \approx 20$ V. Equivalently, for $IR_{var} = -Ir + \mathcal{E}$, the y-intercept of IR_{var} vs. I equals $\mathcal{E} \approx 20$ V. Full credit for any correct use of the graph (slope or intercept, as appropriate to the chosen axes) giving a value with correct units between 18.0 V and 22.0 V.

Question 2

2018 ▪ Q2

[Circuit diagram: Point A connects to resistor R_1 in series, which connects to a parallel combination of resistor R_2 (top branch, drawn as a zigzag resistor symbol) and a switch S (bottom branch), which then connects to point B.]
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.
(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the

Question 2

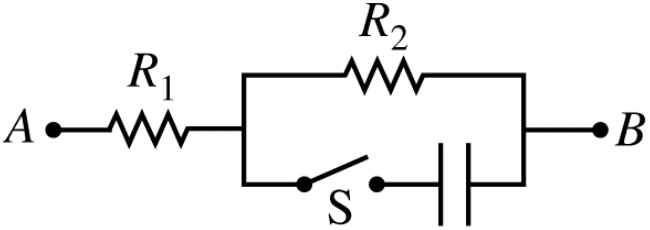
experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

Complete the Diagram / Describe the Experiment

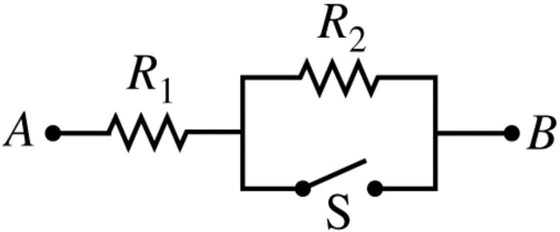
[Diagram: the same circuit (A—R_1—[R_2 parallel with switch S]—B) is shown blank, for the student to add the ammeter and battery connections.]

A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. [Diagram: circuit A—R_1—[R_2 parallel with (switch S in series with a capacitor)]—B.] The combination is placed in a circuit with a power supply so that the potential difference between A and B is maintained at 9 V. The students close the switch and immediately begin to record the current through point B. The initial current is 0.9 A, and after a long time the current is 0.3 A.

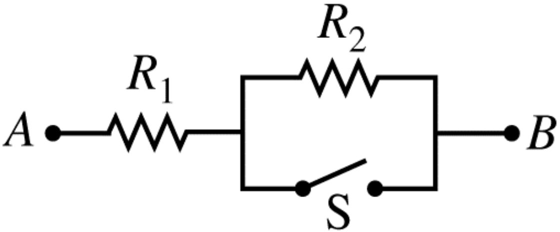
Question 2



Question 2



Question 2



Question 2

2018 ▪ Q2

[Circuit diagram: Point A connects to resistor R_1 in series, which connects to a parallel combination of resistor R_2 (top branch, drawn as a zigzag resistor symbol) and a switch S (bottom branch), which then connects to point B.]

Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(b)(i) Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

Question 2

(b)(ii) Calculate the values of R_1 and R_2.
(b)(iii) Determine the potential difference across the capacitor a long time after the switch is closed.
A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

Question 2

2018 ▪ Q2

[Circuit diagram: Point A connects to resistor R_1 in series, which connects to a parallel combination of resistor R_2 (top branch, drawn as a zigzag resistor symbol) and a switch S (bottom branch), which then connects to point B.]

Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

Solution 2

(a) Mark scheme

- Connect the ammeter in series with the 9 V battery, and connect this series combination across points A and B (in series with the R1 / [R2 parallel with switch S] combination). Take two current readings: one with the switch S closed, one with S open. With S closed, R2 is short-circuited by the closed switch, so only R1 carries current: measure that current I_1 and compute $R_1 = V/I_1$ (with $V = 9$ V). With S open, current flows through R1 in series with R2: measure that current I_2 and compute $R_2 = (V/I_2) - R_1$. [Scoring: 1 pt diagram with ammeter+battery in series with the resistor combination; 1 pt indicating current measured with switch both closed and open; 1 pt $R_1 = V/I_1$ with switch closed; 1 pt $R_2 = (V/I_2) - R_1$ with switch open.]

Solution 2

(b)(i) Mark scheme

- Immediately after the switch closes, the initially uncharged capacitor behaves like a short circuit (zero resistance), so current flows through R1 and through the switch branch, bypassing R2 entirely — the current through R2 is zero, while the current through the switch is nonzero. As time passes the capacitor charges up and current into it drops to zero, so a long time after closing, no current flows through the switch branch (blocked by the fully-charged capacitor) — all current instead flows through R1 in series with R2, so R2's current becomes nonzero while the switch's current becomes zero. Because total circuit resistance is smaller immediately after closing (just R1) than a long time after (R1 + R2), the current through R1 immediately after closing is greater than its current a long time after.

Solution 2

Summary: current through R1 is greater immediately after than a long time after; current through R2 is zero immediately after and nonzero a long time after; current through the switch is nonzero immediately after and zero a long time after.

Solution 2

(b)(ii)

Mark scheme

- Immediately after closing (0.9 A flows only through R1, since the capacitor is a momentary short): $9\ \mathrm{V} = (0.9\ \mathrm{A})R_1 \Rightarrow R_1 = 10\ \Omega$. A long time after closing (0.3 A flows through R1 and R2 in series, since the fully-charged capacitor blocks current, forcing it all through the switch branch's R2): $9\ \mathrm{V} = (0.3\ \mathrm{A})(R_1 + R_2) = (0.3\ \mathrm{A})(10\ \Omega + R_2) \Rightarrow R_2 = 20\ \Omega$.

Solution 2

(b)(iii)

Mark scheme

- A long time after the switch closes, the capacitor voltage equals the battery voltage minus the drop across R1 (which still carries the 0.3 A steady current): $V_C = V_{battery} - V_{R_1} = 9\text{ V} - (0.3\text{ A})(10\ \Omega) = 9\text{ V} - 3\text{ V} = 6\text{ V}$.

Solution 2

(c) Mark scheme

- Because the third group's 9 V battery is not ideal, it has internal resistance r, so part of the 9 V is dropped across r rather than across the external circuit — the measured current is smaller than the second group (ideal-battery) case. Since the third group still computes their 'R1' as (battery voltage)/(measured current), assuming an ideal battery, and their measured current is smaller than expected, their calculated value of R1 comes out higher than the second group's true R1 — effectively what they compute is $R_1 + r$, which is larger than the second group's correctly determined R_1.

Question 4

2016 ▪ Q4

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R, a capacitor of capacitance C, a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.
(a)(i) Determine the current in the resistor and the potential difference across the capacitor immediately after the switch is closed.
(a)(ii) Determine the current in the resistor and the potential difference across the capacitor a long time after the switch is closed.

Question 4

2016 ▪ Q4

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R, a capacitor of capacitance C, a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.

(b)(i) The switch is opened, the capacitor is discharged, and a second, identical capacitor is added to the circuit in series with the other components. The switch is then closed again.

A long time after the switch is closed, the energy stored in the single capacitor in the original circuit is U_1, and the total energy stored in the two capacitors in the new circuit is U_2. Calculate the ratio U_1/U_2.

(b)(ii) The two capacitors in series are to be replaced with a single capacitor that will have the same energy U_2. Indicate a plate area and a distance between the plates for the new capacitor, compared with one of the original capacitors, that will accomplish

Question 4

this. Support your reasoning using appropriate physics principles and/or mathematical models.

Question 4

2016 ▪ Q4

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R, a capacitor of capacitance C, a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.

(c) The students are then asked to design two circuits each containing a switch, a battery with a small internal resistance, a lightbulb, and a capacitor. In arrangement 1, the bulb should gradually light up after the switch is closed, becoming brightest after the switch has been closed a long time. In arrangement 2, the bulb should be brightest when the switch is first closed, getting dimmer with time, and going out completely when the switch has been closed for a long time.

Using standard symbols, draw two circuit diagrams, one showing a possible circuit for arrangement 1 and the other showing a possible circuit for arrangement 2. Justify your circuit diagrams with a paragraph-length explanation referring to the properties of

Question 4

lightbulbs and capacitors in circuits and the conservation of energy and/or the conservation of charge.

Solution 4

(a)(i)

Mark scheme

- Immediately after the switch is closed, the capacitor is uncharged, so there is no potential difference across it: V_C $= 0$. Since the capacitor briefly behaves like a plain wire (no opposition to current) at this instant, the entire battery EMF ε appears across the resistor, giving current I $= \varepsilon/$R. So I $= \varepsilon/$R and V_C $= 0$.

Solution 4

(a)(ii)

Mark scheme

- A long time after the switch is closed, the capacitor is fully charged and allows no more current to flow, so $I = 0$ everywhere in the series circuit. With zero current, there is no potential drop across the resistor, so the entire battery EMF appears across the capacitor: V_C $= \varepsilon$.

Solution 4

(b)(i) Mark scheme

- Original circuit: a single capacitor C fully charged to the battery EMF ε stores U1 = (1/2)Cε^2. New circuit: two identical capacitors C in series (equivalent capacitance C/2) share the battery voltage equally, so each has a potential difference of $\varepsilon/2$ across it (equivalently, the equivalent capacitance of the new circuit is half that of the original). Energy in each capacitor: (1/2)C(ε/2)^2 = Cε^2/8; total energy of both: U2 = 2 $\cdot$ (Cε^2/8) = Cε^2/4. Ratio: U1/U2 = (Cε^2/2)/(Cε^2/4) = 2. Full credit needs (1) a calculation indicating either that the potential difference across each new capacitor is half that of the original single capacitor, or that the new circuit's equivalent capacitance is half the original's

Solution 4

(giving U1 $=$ (1/2)Cε^2 and U2 $=$ Cε^2/4), and (2) correctly computing the ratio U1/U2 $=$ 2.

Solution 4

(b)(ii) Mark scheme

- Using $U = (1/2)CV\hat{}2$: if the new single capacitor is connected the same way as one original single capacitor (same potential difference across it as before), then for its stored energy to equal $U2 = (1/2$ of the original $U1)$, the new capacitor must have HALF the capacitance of the original single capacitor: $C\_new = C/2$. Since $C = \varepsilon 0\ A/d$, halving the capacitance while keeping the same plate separation d requires halving the plate area A. So: keep the same distance between plates as the original capacitor, but use half the plate area. (Any other area/spacing combination consistent with the ratio found in part (b)(i) and properly justified via $C = \varepsilon 0\ A/d$ is also acceptable.)

Solution 4

(c) Mark scheme

- Arrangement 1 (bulb gradually brightens, becomes brightest after a long time): the battery, switch, and CAPACITOR form the main series loop, with the LIGHTBULB connected in PARALLEL with the capacitor. Arrangement 2 (bulb brightest immediately, dims and goes out): the battery, switch, LIGHTBULB, and capacitor are all connected in one SERIES loop (bulb and capacitor in series with each other). General principle: the bulb is brightest when the current through it is at its maximum, and a capacitor eventually stops current from flowing in its own branch once the potential difference across its plates equals the battery's EMF. Series circuit (arrangement 2) behavior: the same current flows through both the bulb and the capacitor; right after the switch closes the capacitor is uncharged

Solution 4

and offers no opposition (acts like a wire), so maximum current flows and the bulb is brightest; as the capacitor charges, the current decreases and the bulb dims, until the capacitor is fully charged, blocks all current, and the bulb goes out. (Equivalently in terms of potential difference: right after closing, the uncharged capacitor has zero potential difference, so the bulb has the full battery potential difference and is brightest; as the capacitor charges it takes on more of the potential difference, leaving less for the bulb, until the capacitor has the entire battery potential difference and the bulb has none.) Parallel circuit (arrangement 1) behavior: current is shared between the two branches; right after the switch closes almost all current flows through the initially-uncharged, low-resistance capacitor branch and little goes through the bulb, so the bulb starts dim; as the capacitor charges it draws less current, redirecting more into the bulb branch, until the capacitor is fully charged (open circuit) and all current flows through the bulb,

Solution 4

making it brightest. (Equivalently in terms of potential difference: both branches share the same potential difference across them at all times; the bulb starts with the same zero potential difference as the initially-uncharged capacitor and ends up with the full battery potential difference once the capacitor is fully charged, so the bulb ends up brightest.) Full credit needs (1) two correct circuit diagrams each matched to the correct arrangement, (2) indicating the bulb is brightest when current through it is maximum and that the capacitor stops current in its branch once its plate potential difference equals the battery EMF, (3) a correct description of the series-circuit (arrangement 2) behavior using either current or potential-difference reasoning, (4) a correct description of the parallel-circuit (arrangement 1) behavior using either current or potential-difference reasoning, and (5) a response written with sufficient paragraph structure.

Question 2

2015 ▪ Q2

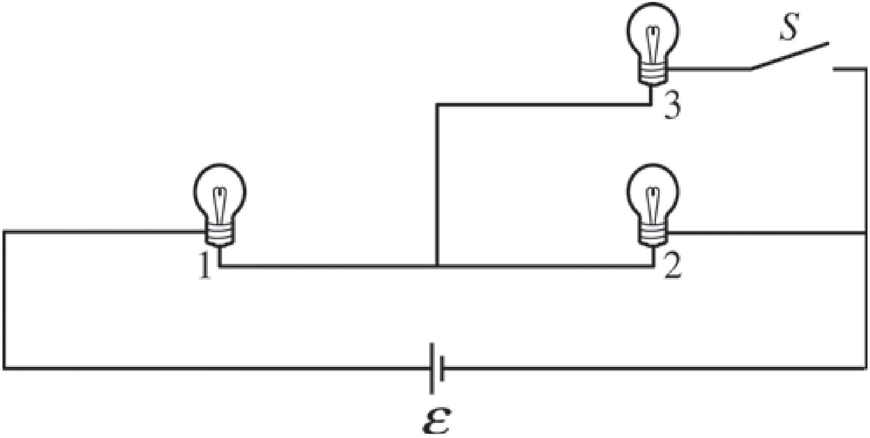
[Circuit diagram: A battery of emf $\mathcal{E}$ is connected at the bottom of the circuit. From the battery, a wire goes up the left side to a node, then splits. Bulb 1 is in the top-left branch. After bulb 1, the wire continues right to a node where the circuit splits into two parallel branches: the 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.