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Draw a cross through the box (☒) if you have NOT written in this booklet

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Physics 2025

91526 Demonstrate understanding of electrical systems

Credits: Six

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of electrical systems.	Demonstrate in-depth understanding of electrical systems.	Demonstrate comprehensive understanding of electrical systems.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

Make sure that you have Resource Booklet L3–PHYSR.

In your answers use clear numerical working, words, and/or diagrams as required.

Numerical answers should be given with an appropriate SI unit.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–12 in the correct order and that none of these pages is blank.

Do not write in the margins (⁄⁄⁄). This area will be cut off when the booklet is marked.

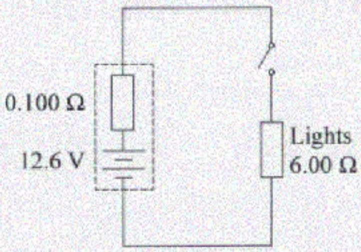
YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Merit

TOTAL 16

QUESTION ONE: DC CIRCUITS

Mereana has a caravan, which has a simple battery-powered circuit for the lighting with a total resistance of 6.00 Ω. The battery has an EMF of 12.6 V, and an internal resistance of 0.100 Ω.



(a) When the switch is closed, the current from the battery is 2.07 A.

Show that the terminal voltage of the battery is 12.4 V.

$V_T = \varepsilon - Ir$

$= 12.6\text{ V} - (2.07\text{ A})(0.100\ \Omega)$

$= 12.6\text{V} - 0.207$

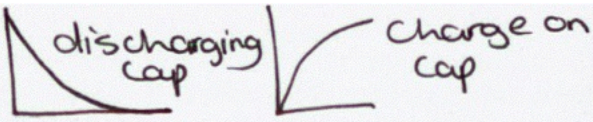
$= 12.393$

$= 12.4\text{V}$

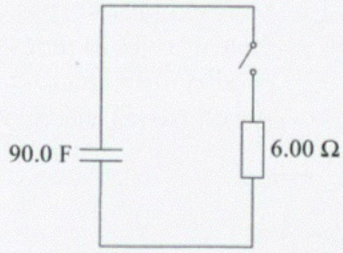
(b) As the battery is used over time, its internal resistance will increase.

Explain the effect that this will have on the terminal voltage of the battery.

As internal resistance increases terminal voltage will decrease as there will be a larger potential drop across the batter leaving less of the EMF voltage as terminal voltage.



(c) Mereana is investigating using a capacitor to power her caravan. The capacitor has a capacitance of 90.0 F, and is fully charged by connecting it to a 4.20 V battery. Mereana discharges the capacitor for 2500 s through a 6.00 Ω resistor to model the caravan circuit.

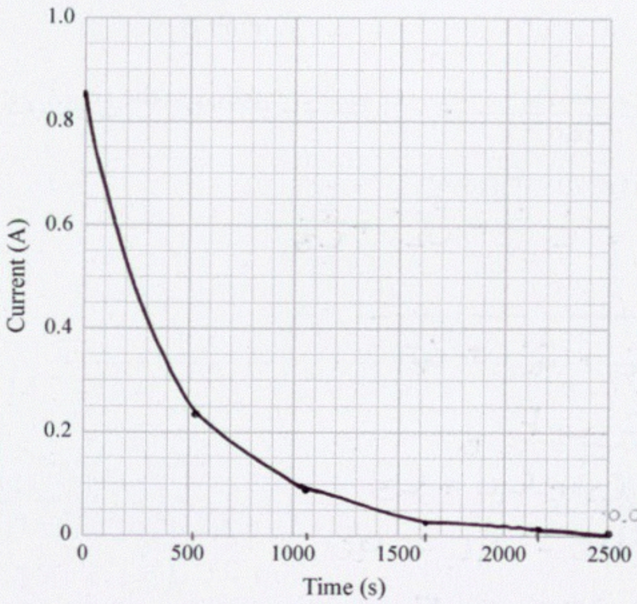


(i) Sketch a graph of current against time for 2500 s after the switch is closed.

Your graph should include the initial current and the final current after one time constant.

Show all calculations clearly.

If you need to redraw your response, use the diagram on page 10.



Space for calculations

$\tau = (6.00\Omega)(90.0)$

$= 540s$

$V = IR$

$I_{max} = \frac{V}{R}$

$= \frac{4.20V}{6.00\Omega}$

$= 0.7A$

τ

1 = 0.259 A

2 = 0.09583

3 = 0.0355

4 = 0.01312

5 = 0.005

$\tau_1 = 540s$

$\tau_2 = 1080s$

$\tau_3 = 1620s$

$\tau_4 = 2160s$

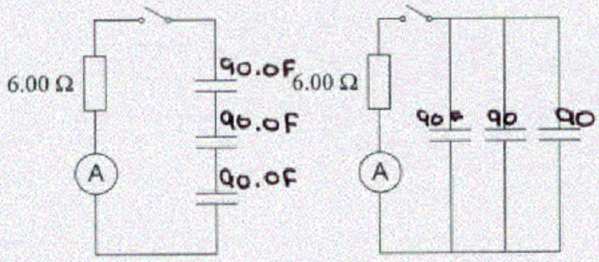
$\tau_5 = 2700s$

(ii) Explain, using physics principles, why the graph has the shape you have drawn.

When Discharging a capacitor the current decreases by a time constant of 63% per time constant. Therefore we achieve an exponential decay curve where we see current decrease by 63% of the previous current value.

04530

(d) Mereana fully charges six 90.0 F capacitors individually with the 4.20 V battery. She connects three of them in series with an ammeter and a 6.00 Ω resistor (Circuit A), and three of them in parallel to an ammeter and a 6.00 Ω resistor (Circuit B), as shown below. Each circuit has its switch closed and the capacitors are discharged.



Circuit A Circuit B

For each circuit, explain how the current varies over time compared to the single capacitor in series with a 6.00 Ω resistor, as in part (c).

You may use calculations to support your answer.

Circuit A: $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

$C_T = \frac{1}{\frac{1}{90} + \frac{1}{90} + \frac{1}{90}}$

$= 30.0\ F$

Circuit B: $C_T = C_1 + C_2 + C_3$

$= 90 + 90 + 90$

$= 270.0\ F$

~~V=IR~~ $Q = CV$, $Q \propto C$, therefore increase in capacitance increases charge. $E = \frac{1}{2}QV$ gives $V = \frac{2E}{Q}$ therefore increasing charge decreases voltage and since $V = IR$ where R is the same for ~~both~~ all circuits, ~~V=IR~~, ~~increasing~~ decreasing voltage decreases current.

Therefore circuit B with the larger capacitance experiences the ~~lo~~ a smaller current than Circuit A.

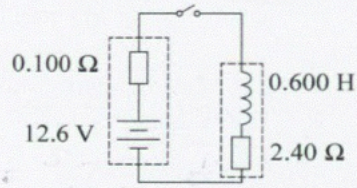
Current experienced by circuits

~~B < A > single capacitor~~

B < single capacitor < A

QUESTION TWO: INDUCTORS

Mereana finds an old coil and connects it to her caravan battery. The corresponding circuit diagram is shown. The coil can be modelled as an inductor with an inductance of 0.600 H, and a resistor with a resistance of 2.40 Ω.



(a) State the size of the induced EMF across the inductor when the switch is first closed.

~~EMF = $I_{max} Z$~~

EMF = 12.6 V

(b) Calculate the size of the induced EMF across the inductor 0.240 s after the switch is closed.

$\varepsilon = -L \frac{\Delta I}{\Delta t}$

$L = 0.6$ H

$t = 0.240$ s

$\varepsilon = (0.6) \times \left(\frac{5.04}{0.240s}\right)$

$I_{max} = \frac{V_{max}}{R} = \frac{12.6V}{2.5\Omega} = 5.04A$

$= 12.6$ V

2.5Ω

(c) When the switch is opened, a small spark is observed where the switch breaks the circuit.

Explain why the small spark is produced.

When the switch is opened ~~this is a ve~~ there is a large change in current over a very small amount of time. ~~This produces a~~ This results in a large change in magnetic flux, where the inductor ~~produces~~ induces a current and change in flux to oppose the switch being opened therefore from $\uparrow\varepsilon = \frac{\uparrow\Delta\phi}{\downarrow\Delta t}$ we get a large induced voltage and from $\uparrow V = \uparrow I R$, for same resistance we see a spark as current increases rapidly. ~~Ha~~

(d) Mereana knows that the maximum amount of energy is stored in an inductor when a steady current is flowing through it. She knows that if she replaces the inductor with the right capacitor, she can store an equal amount of energy.

Calculate the capacitance required to store this energy when the capacitor is fully charged by the 12.6 V battery.

$\frac{1}{2}LI^2 = \frac{1}{2}QV$

$\frac{1}{2}(0.6)(5.04)^2 = \frac{1}{2}(12.6)Q$

$\frac{7.62048}{\frac{1}{2}(12.6)} = \frac{\frac{1}{2}(12.6)Q}{\frac{1}{2}(12.6)}$

$1.2096 = Q$

$Q = CV$

$C = \frac{Q}{V}$

$= \frac{1.2096 J}{12.6 V}$

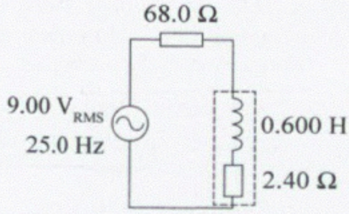
$= 0.096 C$

$V = 12.6 V$

$L = 0.6 H$

$I = 5.04 A$

QUESTION THREE: AC INDUCTORS AND CAPACITORS



Mereana takes the coil back to school, and connects it to a variable frequency AC supply. The 0.600 H coil (modelled as an ideal inductor and a resistor) is now connected in series with a 68.0 Ω resistor to the supply, set to 25.0 Hz and 9.00 V_{RMS} as shown.

(a) Show that the reactance of the inductor is 94.2 Ω.

$X_L = \omega L$

$= (2\pi \times 25.0 Hz)(0.6)$

$= 94.2477$

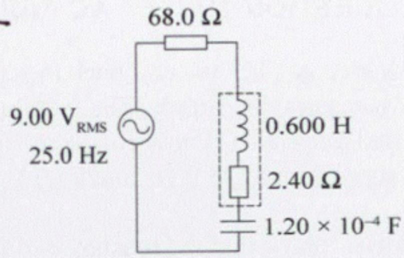
$= 94.2\ \Omega$

(b) Mereana notices that she can insert an iron nail inside the coil.

Explain what effect this would have on the RMS voltage across the 68.0 Ω resistor.

Inserting an iron nail would increase the magnetic flux thus decreasing the current through the circuit. Since $\downarrow V = \downarrow I R$, $V \propto I$ so decreasing current would decrease the voltage RMS across the resistor.

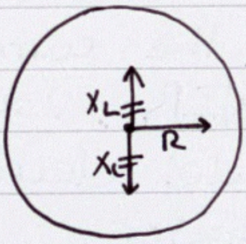
(c) The nail is then removed from the coil and a 1.20×10^{-4} F capacitor is added to the circuit in series with the coil and the 68.0 Ω resistor. Mereana reduces the frequency and notices that the voltage across the 68.0 Ω resistor increases and reaches a maximum value at a particular frequency.



Explain why the voltage across the 68.0 Ω resistor reaches a maximum value at one particular frequency.

No calculations are required.

V=IR therefore if V is a maximum then I must also be a maximum. This happens at resonance when Z is a minimum because R=Z as $X_L = X_C$.



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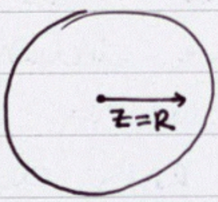

(d) The supply frequency of the circuit in part (c) is then further reduced.

Calculate the RMS current in the circuit when the frequency of the supply is 16.0 Hz.

A phasor diagram may assist your answer.

If you need to redraw your response, use the box on page 10.

Merit

Subject: L3 Physics

Standard: 91526

Total score: 16

Q	Grade score	Marker commentary
One	5	(b) The candidate has explained why the terminal voltage will decrease. (c) The initial current, time constant and current after one time current have been calculated correctly, but the candidate has incorrectly plotted the graph starting at 0.825 A. (d) The candidate has correctly calculated the total capacitance for both circuits, but has not explained how the current varies over time, or how the size of the initial current compares for each circuit.
Two	6	(b) The candidate has not realised that the time given is the time constant of the circuit, and has therefore approached answering this question incorrectly. (c) The large, induced voltage due to a large change in current and change in flux in a small time has been explained but the candidate has not discussed why the time is small or that the voltage can be larger than the supply voltage.
Three	5	(b) The candidate has not explained why the increase in flux causes the current to decrease, or that because the inductor voltage increases the voltage across the resistor decreases. (c) All the requirements for excellence have been stated, especially that the circuit is at resonance and what happens when $X_L = X_C$.