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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.

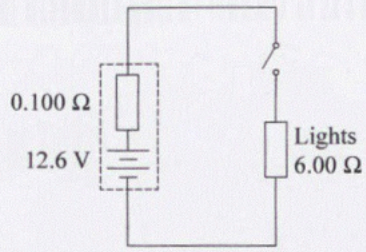
Do not write in the margins. This area will be cut off when the booklet is marked.

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

Excellence

TOTAL 21

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.

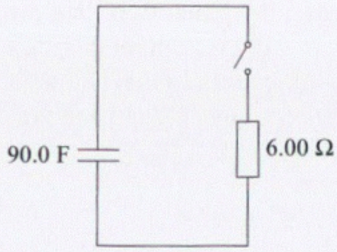
$V = \mathcal{E} - Ir$
$= 12.6 - 2.07 \times 0.1$
$= 12.4\text{V}$ (3 s.f.)

(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 the internal resistance increases, when any amount of current is drawn from the battery, its terminal voltage would be less compared to before because the internal resistance would acquire a relatively larger ~~amount~~ proportion of the EMF, providing a decreased leftover voltage ~~amon~~ amount for other components.
$V = \mathcal{E} - Ir$.

(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.

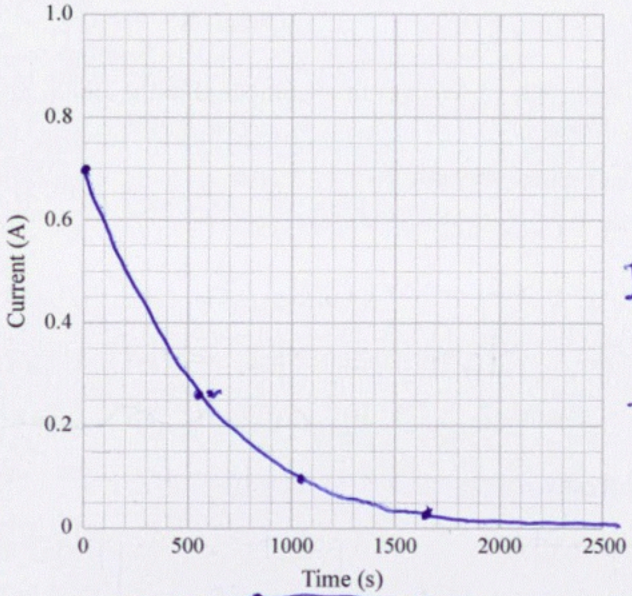


(i) Sketch a graph of current against time for 2500 s after the switch is closed.

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

$\tau = RC = 6 \times 90 = 540\,s$

$I_{max} = \frac{V}{R} = \frac{4.2}{6} = 0.7$

$\therefore I = I_{max} \times e^{-\frac{t}{\tau}}$

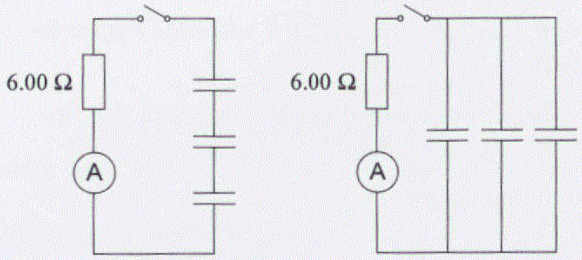
$I = 0.7e^{-\frac{t}{\tau}}$

$\therefore$ when $t = 0\tau$, $I = 0.7$

t	1τ (540s)	2τ (1080s)	3τ (1640s)
I	~~0.7~~ 0.258A	0.0947A	0.0349A

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

(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).

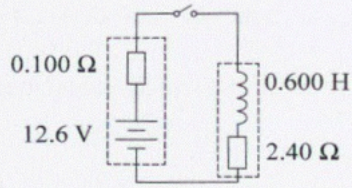
You may use calculations to support your answer.

Each capacitor in circuits A and B is connected such that each one ~~sup~~ individually supplies voltage of 4.2V at the start. So, the total voltage of circuit A is 3×4.2 = 12.6V ~~(3 capacitors~~ whereas the total voltage of circuit B is 4.2V because when ~~capacitor~~ 3 capacitors supply the same voltage in parallel, ~~the~~ the effective voltage is ~~4.2V at the start.~~ equal to that of one capacitor. So, initially, the current flowing through ~~the cir~~ circuit A is greater than the current flowing through circuit B while the ~~curre~~ initial current flowing through circuit B is equal to that of ~~sig~~ the circuit with the single capacitor in series with a 6Ω resistor from part (c). However, the net effective capacitance of each circuit is different because of how capacitors are connected.

Continued on extra paper...

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.

~~ε V_{max} = I~~ The inductor completely opposes the EMF of the battery when the switch is first closed. So, its ~~size is~~ induced EMF is 12.6V.

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

$\tau = \frac{L}{R} = \frac{0.6}{2.5} = 0.24s$ So, $t = 1\tau$

$\therefore V = V_{max} \times e^{-\frac{t}{\tau}}$

$= 12.6 \times e^{-1}$

$= 4.64V$ (3s.f.)

(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, the ~~volt~~ source voltage suddenly becomes 0V. So, the current starts to decrease at a rapid rate. $\varepsilon = -L\frac{\Delta I}{\Delta t}$. ~~So~~ Since Δt is extremely small, ~~the~~ an extremely high voltage gets induced across the inductor as it ~~&~~ opposes the decrease in current to keep it flowing. Hence, current flows through the circuit, ~~accumulating at the 2 ends of of the open circuit.~~ causing charge to accumulate at the 2 ends of the circuit. ~~then~~ ~~on~~ When enough charge is accumulated, they acquire enough electric potential energy to suddenly jump on to the other side with a spark (caused by the electric potential energy difference).

(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.

$I = \frac{V}{R} = \frac{12.6}{2.5} = 5.04 A$

$\therefore E_L = \frac{1}{2} L I^2 = \frac{1}{2} \times 0.6 \times 5.04^2$

$= 7.62048 J$

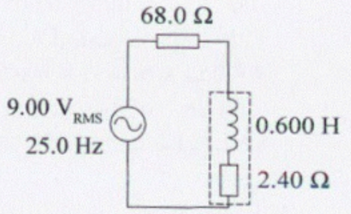
$E_L = E_C = \frac{1}{2} C V^2$

$\therefore C = \frac{2E_L}{V^2}$

$= \frac{2(7.62048)}{12.6^2}$

$=$ ~~0.096F~~ 0.096F

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.

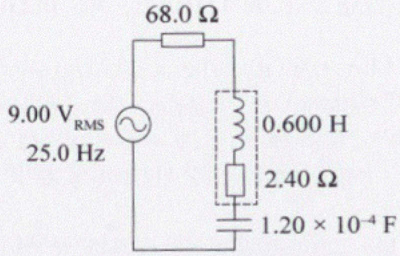
$X_L = 2\pi f L = 2\pi \times 25 \times 0.6$
$= 94.2\,\Omega$ (3s.f.)

(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 inside the coil causes ~~its~~ the inductance of the inductor to increase since now it has better magnetic strength. Hence the reactance of the inductor would increase. This causes the impedance of the circuit, $Z = \sqrt{X_L^2 + R^2}$, to increase. ~~Hence,~~ Now that there's greater opposition to the same current flow (i.e. greater impedance), the ~~voltage~~ current flowing through the circuit decreases at every point in time (given the source voltage is constant): $I = \frac{V}{Z}$. Thus, similarly, the voltage across the resistor decreases at every point in time since $V = IR$. So, the RMS voltage across the 68Ω resistor decreases.

(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.

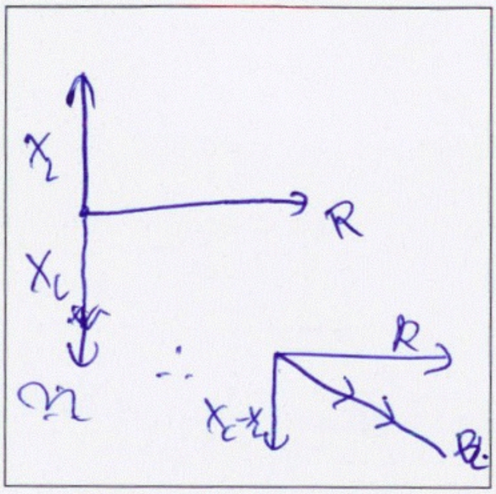
No calculations are required.

At that frequency, the reactance of the capacitor, $X_C = \frac{1}{2\pi f C}$ is equal to ~~that of~~ the reactance of the inductor, $X_L = 2\pi f L$. Because the capacitor and ~~reac~~ inductor voltages are 180° out of phase, their reactances completely cancel out, resulting in the minimum impedance in the circuit: $Z = \sqrt{R^2 + (X_L - X_C)^2}$. This frequency is called the resonance frequency. Since there is minimum impedance at resonance, the current flowing ~~the~~ through the circuit is at max. Since $V = IR$, the voltage across the 68 Ω resistor reaches its maximum value.

(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.

$X_L = 2\pi f L = 2\pi(16)(0.6) = 60.32\,\Omega$

$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(16)(1.2\times10^{-4})} = 82.89\,\Omega$

$R = 68 + 2.4 = 70.4\,\Omega$

$\therefore Z = \sqrt{R^2 + (X_C - X_L)^2}$

$= \sqrt{70.4^2 + (82.89 - 60.32)^2}$

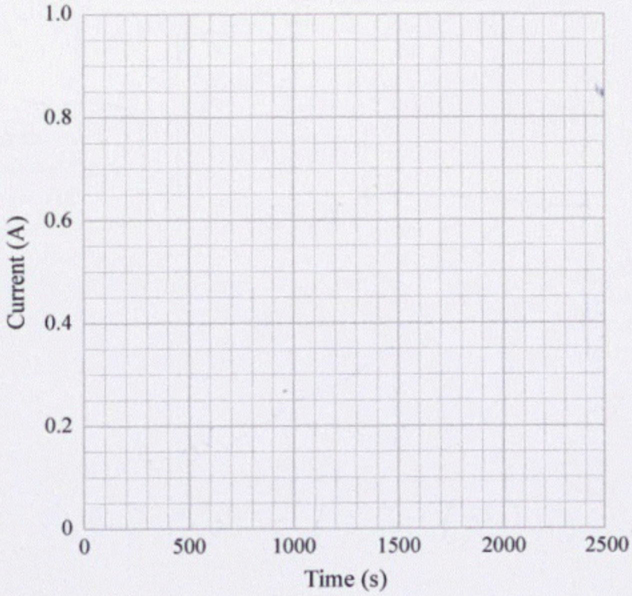
$= 73.93\,\Omega$

$\therefore I_{RMS} = \frac{V_{RMS}}{Z} = \frac{9}{73.93}$

$= 0.122\text{ A}$

SPARE DIAGRAMS

If you need to redraw your response to Question One (c), use the diagram below. Make sure it is clear which answer you want marked.



Space for calculations

If you need to redraw your response to Question Three (d), use the box below. Make sure it is clear which answer you want marked.

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

1(d) Circuit A:

$$C = \frac{1}{\frac{1}{90} \times 3} = 30F$$

Circuit B:

$$C = C_1 + C_2 + C_3 = 90 \times 3 = 180F$$

Part (c) Circuit:

$$C = 90F.$$

So, ~~resp~~ the time constant of circuit B is greater than that of ~~circuit B~~ part (c) circuit, which is greater than that of circuit A. This is because $\tau = RC$ and the resistance of each circuit is the same. So, ~~the~~ even though circuits B and part (c) circuit have the same initial current (I_{max}), the current in circuit B decreases at a ~~faster~~ slower rate and takes approximately $\frac{180}{90} = 2$ times longer to die off.

$$I = I_{max} e^{\frac{-t}{RC}}$$

Circuit A has a greater initial current than ~~of~~ the part (c) circuit. Yet, because its time constantk is ~~h~~ one third of part (c) circuit, it dies of relatively faster (because the rate is high). Hence, the part (c) circuit's ~~wor~~ current would take 3 times longer to die off compared to circuit A.

Excellence

Subject: L3 Physics

Standard: 91526

Total score: 21

Q	Grade score	Marker commentary
One	7	(b) The candidate has explained why the terminal voltage will decrease. (c) A graph has been correctly drawn showing the initial current and the current after one time constant, but the candidate has not explained why the graph has the shape they have drawn. (d) The candidate has correctly compared the total capacitance, time constants, and how current varies for the circuits. The candidate has also compared the size of the original current in each circuit.
Two	7	(b) The candidate has calculated the time constant using the total resistance, and then identified that this is equivalent to the time given. As a result, the emf of the inductor has been correctly calculated. (c) A large, induced voltage due to a large change in current in a small time has been explained, but there is no mention of a change in flux. The candidate has not discussed why the time is small or that the voltage can be larger than the supply voltage.
Three	7	(b) Correct answer explaining why the impedance increases and the current decreases, and how this relates to the resistor voltage increasing. (c) The frequency has been identified as being the resonant frequency. The candidate has explained why X_L and X_C cancel, why the impedance is minimum and the current maximum but has omitted to state that the resistance is equal to the impedance. (d) The candidate has correctly calculated the impedance by using the total resistance of the circuit and the differences in the reactance of the capacitor and inductor. The correct current has been calculated using the rms voltage and impedance.