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

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NZQA

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Physics 2023

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 any cross-hatched area (DO NOT WRITE IN THIS AREA). 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

24

QUESTION ONE: CAPACITORS

Kate is learning about capacitors. She investigates a capacitor found in a camera. The capacitor is labelled 185 nF (1.85×10^{-7} F).

(a) The camera also contains a 1.50 V ("AA") battery.

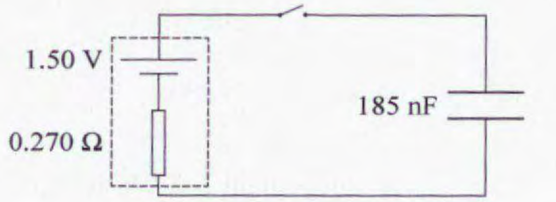
Show that the energy stored by the capacitor, when it is fully charged by connecting it to the battery, is 2.08×10^{-7} J.

$E = \frac{1}{2}CV^2 \quad = 0.5 \times 1.85 \times 10^{-7} \times 1.5^2$

$= 2.08125 \times 10^{-7}$

$\approx 2.08 \times 10^{-7}$ J

(b) The diagram below shows the circuit used to charge the capacitor. The battery has an internal resistance of 0.270 Ω. Assume the rest of the circuit has no resistance.



Sketch a curve by plotting at least four points on the grid opposite to show how the charge on the capacitor plates varies with time, once the switch is closed.

Your answer should indicate:

- the time constant for charging the capacitor
- the maximum charge that will be stored on the capacitor plates.

Show all calculations clearly.

$\tau = RC = 0.27 \times 1.85 \times 10^{-7} = 4.995 \times 10^{-8} \approx 5 \times 10^{-8}$ s

$Q = \frac{\cancel{2.08 \times 10^{-7}}}{\cancel{0.5 \times 1.5}} = 1.5 \times 1.85 \times 10^{-7}$

$= 2.775 \times 10^{-7}$ or 27.75×10^{-8} C max

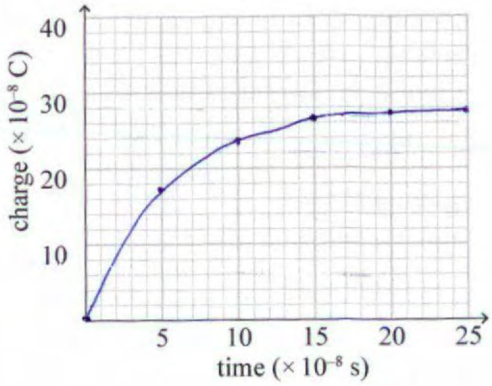
At T_1, $27.75 \times (1 - e^{-1}) = 17.54 \times 10^{-8}$ C

T_2, $27.75 \times (1 - e^{-2}) = 23.99 \times 10^{-8}$ C

T_3, $27.75 \times (1 - e^{-3}) = 26.37 \times 10^{-8}$ C

T_4, $27.75 \times (1 - e^{-4}) = 27.24 \times 10^{-8}$ C

T_5 $27.75 \times (1 - e^{-5}) = 27.56 \times 10^{-8}$ C



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

(c) Although the capacitor plates are rolled up, they act like two metal rectangles measuring 3.2×10^{-2} m × 1.83 m, with dielectric material in between.

If the dielectric material in the capacitor has a relative permittivity of 2.10, calculate the distance between the metal rectangles.

$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ $\quad d = \frac{2.1 \times 8.85 \times 10^{-12} \times 0.05856}{1.85 \times 10^{-7}}$

$= \frac{1.09 \times 10^{-12}}{1.85 \times 10^{-7}} = 5.88 \times 10^{-6}$ m

$A = 0.05856 \text{ m}^2$

(d) The charged capacitor can be discharged through a lamp by pressing a switch. In the camera, the lamp flashes when a picture is taken.

Kate fully charges the capacitor with the 1.5 V battery, but when the bulb is connected, it barely glows. Inside the camera she finds wiring that allows the capacitor to be charged to 200 V.

Explain how this arrangement allows for a much more powerful flash.

In your answer you should show:

- how the energy stored in a fully-charged capacitor at 200 V compares with 1.5 V
- how the higher voltage increases the initial current from the capacitor when it is connected to the bulb
- how the brightness of the flash will be affected by the higher voltage.

At 1.5V, only 2.08×10^{-7} J, at 200 V, $E = \frac{1}{2}CV^2$
$= 3.7 \times 10^{-3}$ J,

about 18000x more energy stored at 200 V, as increasing voltage has a sq relationship with energy in electric field. Since $\tau = RC$ and resistance of lamp and capacitance constant, time constant is also the same. Since $Q = CV$ and V is much larger, amount of charge stored increases, and the time taken to discharge this larger energy / amount of charges is the same. Thus there is a large increase in initial current from capacitor. $P = VI$, and I increases and V increases for 200V capacitor, so power of lamp increases which makes the flash brighter for the same lamp, compared to 1.5 V capacitor.

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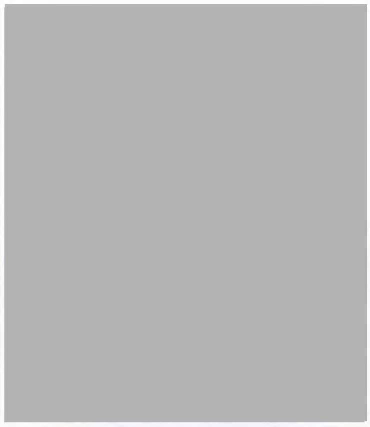
The assessment continues on the following page.

QUESTION TWO : TRANSFORMERS AND INDUCTORS



Source: www.findel-international.com/product/science/physics/electricity-and-electromagnetism/dissectible-transformer/e8h26564

Kate's school has a demonstration transformer, pictured alongside. She connects the 12 000-turn primary coil (red in the picture) to the mains supply (240 V rms).

(a) She connects an AC voltmeter to the blue coil.

Calculate the rms voltage she would measure from the 600-turn secondary coil.

$\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $\quad \frac{12000}{600} = \frac{240}{V_s}$

$V_s = 12\ V_{Rms}$

(b) The two coils are held by a ring of laminated soft iron, which runs through the core of each coil.

Explain why:

- an AC voltage in the red coil produces an AC voltage in the blue (secondary) coil
- the coils are wrapped around an iron ring.

An AC voltage in the red coil means there is changing current, causing changing magnetic flux in the red coil. The iron ring efficiently allows this changing magnetic flux of primary coil to also be experienced by the secondary coil. Thus there is induced voltage in secondary coil due to changing magnetic flux, but will be in the ratio of turns in the coil of primary and secondary coils. The AC voltage is now induced in secondary coil, due to the coil experiencing a changing magnetic flux, due to the iron ring and AC voltage and changing flux of primary coil.

(c) Kate connects the 12 000-turn primary coil in a circuit with a 12 V battery (DC) and a 12 V car headlamp bulb. (The cores of the coils are still linked with iron.)

Explain why the headlamp bulb only comes on after a slight delay.

The coil acts as an inductor, so when the switch is on, there is a significant change in current, and since inductors have an induced voltage from the changing current and flux, produce an opposing voltage to decrease the change in current. There will be no current initially in circuit due to the back EMF of inductor, but as the change in current decreases, $\mathcal{E} = -L\frac{\Delta I}{\Delta t}$, back EMF decreases as induced voltage decreases, so current ~~gradually~~ increases in circuit allowing it to turn on the head lamp bulb in circuit, after a delay.

(d) The power station that supplies Kate's area generates 50 kW of power. The transmission line near Kate's house carries 50 kW of power to an industrial user. The voltage across the transmission line is 220 kV. The resistance of the transmission line is 4.00 Ω for every kilometre.

Calculate the power lost as heat energy across a distance of 300 km.

Comment whether this amount calculated is significant compared to a situation where the voltage is not stepped up to 220 kV, but is transmitted at 25 kV.

Resistance total = $4 \times 300 = 1200\ \Omega$

$\frac{50 \times 10^3\ \text{W}}{220 \times 10^3\ \text{V}} = \frac{5}{22}$ Amps in line.

V of line $= \frac{5}{22} \times 1200 = 272.7 \approx 273$ V lost.

Power lost $= 273 \times \frac{5}{22} = 61.98 \approx 61.9$ W lost.

If 25kV, current is 2 Amps, and power lost $= I^2R$

$= 2^2 \times 1200 = 4800$ W lost.

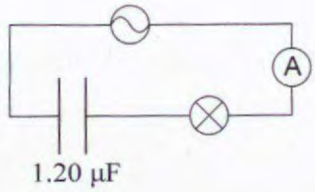
At 220 kV, only $\frac{61.9}{50 \times 10^3}$ W or 0.12 % lost, but

at 25 kV, $\frac{4800}{50 \times 10^3}$ W or 9.6 % energy lost, so amount is

less significant at 220 kV.

QUESTION THREE: ALTERNATING CURRENT (AC)

Kate builds a circuit with a signal generator set at 200 Hz, an AC ammeter, a lamp (15.0 Ω), and a capacitor (1.20 μF) in series.



(a) Show that the capacitive reactance (X_c) is 663 Ω, and hence determine the impedance of the circuit.

$X_c = \frac{1}{\omega c} = \frac{1}{200 \times 2\pi \times 1.2 \times 10^{-6}} = 663.14 \simeq 663\ \Omega$

$Z = \sqrt{663^2 + 15^2} = 663.32 \simeq 663\ \Omega$ impedance.

(b) Kate increases the frequency of the signal generator from 200 Hz to 20 kHz, and then to 200 kHz.

Give an in-depth explanation of what Kate will observe in the circuit at each frequency compared to her observation in part (a).

In your answer consider the effect of changing the frequency on:

- the impedance of the circuit
- the rms current
- the brightness of the lamp.

Since X_c (reactance of capacitor) $= \frac{1}{\omega C}$, so as frequency increases, ω ↗, and X_c decreases as it is inversely proportional. As resistance of lamp is the same $Z = \sqrt{X_c^2 + R^2}$ will decrease, so impedance decreases. $V = IZ$, so for the same generator voltage, $current_{RMS}$ increases. As $current_{RMS}$ increases in circuit, $P = I^2R$ of lamp, so the power and voltage ($V = IR$) of same resistance lamp increases, and it gets brighter. Thus as she increases from 200, to 20 kHz to 200 kHz, the capacitive reactance decreases, RMS current increases, and the bulb glow brighter and brighter.

Kate adds a 0.200 H inductor in series with the capacitor.

(c) While the signal generator is set at 2000 Hz, the lamp is off, but as she slowly decreases its frequency, the lamp suddenly glows brightly, but then goes off at lower frequencies.

Calculate the frequency at which the bulb glows brightest.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.2 \times 1.2 \times 10^{-6}}}$$

$$= 324.8$$

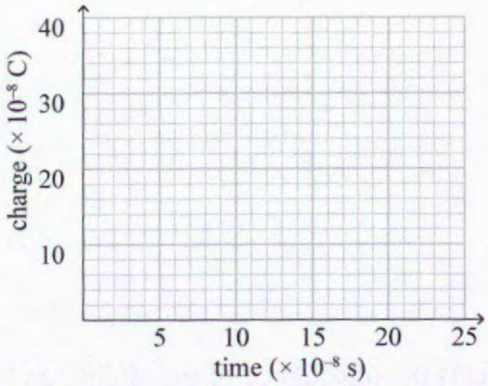
$$\approx 325 \text{ Hz}$$ will be brightest.

(d) Explain how the inductor affects the impedance of the circuit, and why there is one frequency at which the impedance equals the resistance of the circuit (15.0 Ω), causing the lamp to glow brightly.

In an AC circuit, the inductor provides an induced voltage, but in an opposite direction to the voltage of the capacitor. This means ~~they~~ the sum of their voltages $V_L \pm V_C$, or sum of their reactances $X_L \pm X_C$ provides the vector to calculate total impedance. At the resonant frequency 325 Hz, the reactances of the capacitor and inductor are exactly equal and opposite $X_C = X_L$, $\frac{1}{\omega C} = \omega L$, and so the vector for impedance is only the resistance of the resistor (15 Ω). Thus since $V = IZ$ ~~$V = IR$~~, ~~and~~ for ~~[illegible]~~ a smaller impedance, current is increased, and (impedance)/resistance is smallest at 15 Ω, so current is maximum. Thus lamp has maximum current for power, larger voltage, $P = IV$, so as current and V increase, power and brightness increases, at a maximum when $Z = R$, and $f_{generator} = f_{resonance}$.

SPARE DIAGRAM

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



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

QUESTION NUMBER

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

QUESTION NUMBER

91526

<table>
<tr><td>Standard</td><td>91526</td><td></td><td></td><td>Total score</td><td>24</td></tr>
<tr><td>Q</td><td>Grade score</td><td colspan="4">Marker commentary</td></tr>
<tr><td>1</td><td>E8</td><td colspan="4">b) The time constant and the charge at different times have been calculated and plotted to show an accurate curve of charge versus time.
d) All three bullet points have been answered in detail:
the energy at 200V has been calculated and compared to the energy at 1.5V
an explanation of why the current increases
a link between the brightness of the light bulb and the power.</td></tr>
<tr><td>2</td><td>E8</td><td colspan="4">b) The candidate has correctly explained how a voltage is induced in the blue coil of the transformer (and has NOT referred to an induced current).
d) There are calculations to show the power lost in transmission wires and a justification why the voltage should be stepped up during transmission.</td></tr>
<tr><td>3</td><td>E8</td><td colspan="4">b) There is a discussion explaining how and why the impedance, current and brightness of the lamp changes as the frequency increases from 20Hz to 20kHz and then to 200kHz.
d) The candidate has given a detailed discussion about resonance and how the reactance of the inductor affects the impedance, current and brightness of the lamp at resonance.</td></tr>
</table>