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NZQA
NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

Level 3 Physics, 2014

91526 Demonstrate understanding of electrical systems

2.00 pm Tuesday 25 November 2014
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 SI unit, to an appropriate number of significant figures.

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 2–8 in the correct order and that none of these pages is blank.

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

Excellence

TOTAL 24

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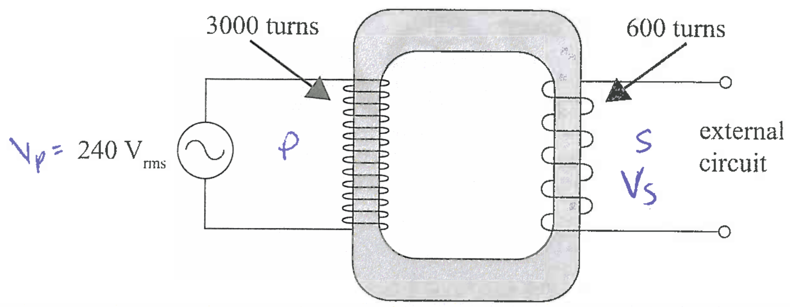
QUESTION ONE: AC

The ideal transformer shown below has 3000 turns in its primary coil, and 600 turns in the secondary coil. A 240 V_{rms} AC power supply is connected across the primary coil. The secondary coil is connected to an external circuit.



(a) (i) Calculate the rms voltage across the external circuit.

$\frac{N_P}{N_S} = \frac{V_P}{V_S}$ $\qquad V_S = \frac{240}{(3000/600)}$

$\frac{3000}{600} = \frac{240}{V_S}$ $\qquad = 48.0\ V$ (2sf).

a

(ii) Calculate the peak voltage across the external circuit.

$V_{peak} = \cancel{V_{rms}}\ \sqrt{2} \times V_{rms}$ $\qquad V_{peak} = 68.0\ V$ (2sf).

$= \sqrt{2} \times 48$

$= 67.88\ V$.

a

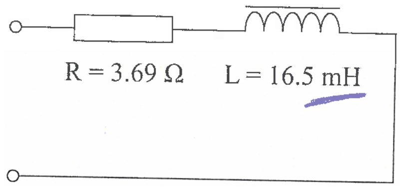
(b) Explain why rms values are often used to describe AC voltages.

RMS voltages are used as in an AC circuit the voltage constantly changes. The RMS value indicated in the AC circuit the ~~V~~ voltage which would give the same power output as the ~~wom~~ equivalent DC circuit. (with the peak voltage of the supply in the ~~a~~ DC circuit). In this sense the rms voltage gives an 'average' voltage & power output for the AC circuit.

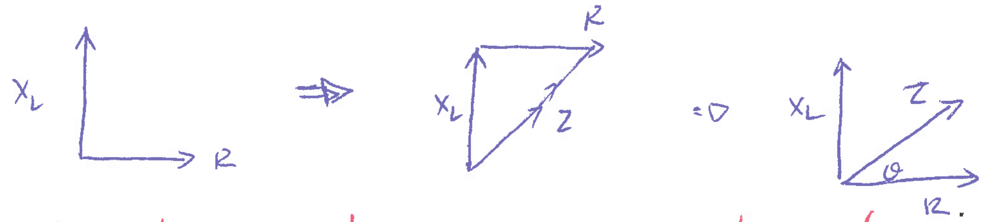
a

Correct explanation

(c) The external circuit consists of a resistor and an inductor as shown.
The frequency of the power supply is 50.0 Hz.



By drawing a phasor diagram, show how the impedance of the external circuit can be calculated.



Correct phasor diagram, explanation & calculation

The impedance can be calculated by vectorially adding inductor impedance and resistance X_L and R in the circuit, as they are out of phase due to changing voltage & current.

Hence as X_L leads the circuit resistance R by 90° or ¼T, Z is the sum of these vectors. Hence $Z = \sqrt{X_L^2 + R^2}$

where $X_L = 2\pi f L$ and $R = 3.69\,\Omega$.

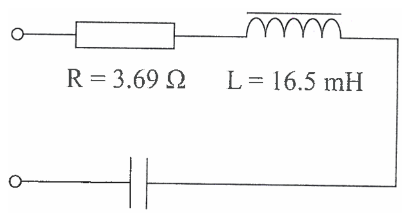
$X_L = 2\pi \times 50 \times 16.5 \times 10^{-3}$
$= 5.18\,\Omega$

$\therefore Z = \sqrt{5.18^2 + 3.69^2} = 6.36\,\Omega$.

∴ Z will lead R by θ, and is in phase with neither X_L or R.

M

(d) A capacitor is added to the external circuit, causing the circuit to be at resonance.



At resonance $X_C = X_L$.

At resonance $V_C \mp V_L = 0$.
∴ $V_{\text{supply}} = V_R$

Determine the rms voltage across the capacitor.

$\frac{1}{2\pi f C} = 2\pi f L$

$\frac{1}{2\pi \times 50 C} = 2 \times \pi \times 50 \times 16 \times 10^{-3}$

$= 5.18362787\,\Omega = X_C$

$100\pi C = 0.192915$

$C = 6.1406 \times 10^{-4}$ F.

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

$X_C - X_L = 0$.

$Z = R$
$= 3.69\,\Omega$.

$\therefore V_C = V_L$.

$I_{rms} = V_{rms}/Z = 48/3.69 \approx 13.008$ A.

$V_C = I X_C$
$= 13.008 \times 5.18362787$
≈ 67.43 V

$V_C = 67.4\ V_{rms}$. (3sf).

E

E8

QUESTION TWO: BATTERIES

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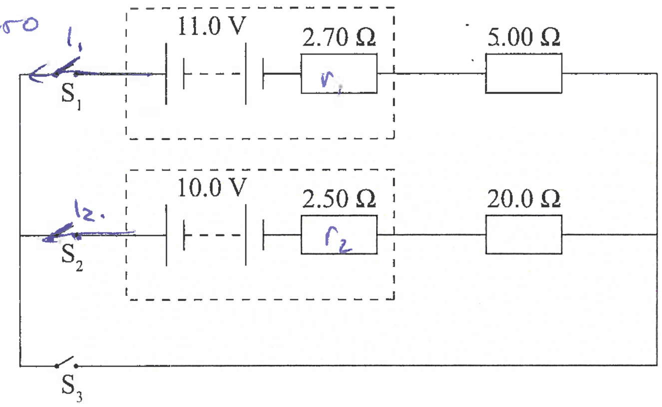
$R_T = 2.70 + 5.00 + 20 + 2.50$



The circuit diagram shows two batteries connected into a circuit. The internal resistance, r_1, of the 11.0 V battery is 2.70 Ω, and the internal resistance, r_2, of the 10.0 V battery is 2.50 Ω.

(a) Switches S_1 and S_2 are closed and switch S_3 is left open.

Show that the current in the circuit is 0.0331 A.

Opposing voltages = 11 − 10 → V_{Total} = 1.0 V.

Total resistance in circuit = 5.0 + 2.70 + 20.0 + 2.50 = 30.2 Ω

$V_C = IR_T$

$I = 1/30.2$

$= 0.03311258278$ A.

$= 0.0331$ A (3 sf).

Correct calculation

(b) In which direction will the current be flowing through switch S_1?

Explain your answer.

The current produced by the ~~will flow ant~~ 11 V battery will flow anti clockwise through the switch S_1 and will be opposed by the current from the 10 V battery flowing clockwise through S_2. However, as the remaining voltage from the opposing 11 V and 10 V sources is 1 V anticlockwise, the current will also flow in this direction hence the current will flow anticlockwise through the switch S_1 (to the left)

correct direction & reason

21 7.2 + 5

(c) Switch S_3 is now closed so all three switches are closed.

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Show, using Kirchhoff's laws, that the current through switch S_3 is 1.87 A.

~~Sum of the voltages around outer loop = 0~~

~~$\therefore 11 - 2.70 I_1 - 5 \times I_1 = 0$~~

~~$11 = 7.7 I_1$~~

~~current in to S_3 junction = $I_1 + I_2$.~~

~~$I_1 + I_2 = 0.0331$ A.~~

~~$\therefore I_1 = 0.0331 + I_2$.~~

~~$\therefore 11 - 2.7(0.0331 + I_2) - 5(0.0331 + I_2) = 0$~~

V outer loop

$11 - (2.7)I_1 - 5 \times I_1 = 0$

$11 = 7.7 I_1$

V inner loop

$10 - (2.50 \times I_2) - (20 \times I_2) = 0$

$10 = 22.5 I_2$

$I_1 = \frac{11}{7.7} = 1.42857$ A.

$I_2 = \frac{10}{22.5} = 0.4444$ A.

$I_{S_3} = I_1 + I_2 = 0.4444 + 1.42857$

$= 1.873$

$I_{S_3} = 1.87$ A (3sf)

correct working

M

(d) Switch S_1 is now opened, leaving switches S_2 and S_3 closed. After this circuit has been operating for some time, the 10.0 V battery starts to go flat. A student suspects that this is caused by an increase in the internal resistance.

Explain what effect a changing internal resistance has on the power delivered to the 20.0 Ω resistor.

A full answer will include some sample calculations.

Internal resistance is caused by a resistance in the chemical reactions occurring in the battery, causing energy to be lost by charge passing through the battery and hence reducing the voltage and current provided to the external circuit (as $V = IR$ and $R_{circuit}$ is constant). Because both the voltage and current delivered to the circuit decrease when the internal resistance is higher, this results in a smaller power through the 20 Ω resistor, which receives the full remaining current and voltage. ($P = VI$) ∴ if both V and I decrease, P will decrease.

e

e.g. INCREASED internal resistance of 3 Ω

$I_{circuit} = 10/(3.0 + 20)$

$= 0.43$ A.

$\therefore V_{circuit} = EMF - (0.44 \times 3.0)$

$= 8.70$ V.

$I_{circuit} = 8.70 / 20$

$= 0.43$ A.

$P = 8.67 \times 0.43$

$= 3.77$ W. (3sf).

NORMAL IR of 2.5 Ω.

$I = 10/(2.5 + 20)$

$= 0.44$ A.

$V_C = EMF - (0.44 \times 2.5)$

$= 8.9$.

$I_C = 8.9 / 20$

$= 0.45$ A.

$P = 8.9 \times 0.45$

$= 3.96$ W (3sf).

emf constant

V_o, I & P decreases

E8

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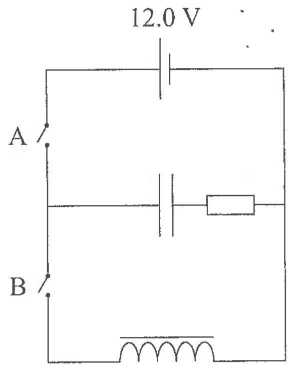
QUESTION THREE: ENERGY



(a) In the circuit above, switch B is kept open and switch A is closed, allowing charge to flow onto the plates of the capacitor.

Explain why the voltage of the capacitor rises to the voltage of the battery.

As time passes, charge builds on the capacitor plates as current flows through the circuit and is unable to flow through the capacitor. This results in charge being held on the capacitor plates as one side where charge builds becomes positively charged and (due to attraction of opposite charges) the other side becomes negatively charged. Charge becomes stored here due to this attraction,

M

(b) When the capacitor in the circuit above is fully charged, it carries a charge of 8.60×10^{-3} C.

Calculate the energy stored in the capacitor when it is fully charged.

$E = \frac{1}{2} QV$ $\quad$ $E = 0.052$ J (3sf)

$= \frac{1}{2}\, 8.6 \times 10^{-3} \times 12$ $\quad$ Correct calculation $\quad$ A

$= 0.0516$ J.

(cont. part a)

and reduces the amount of charge and energy the charge has and prevents it from passing around the circuit. The voltage of the capacitor therefore opposes the voltage of the supply and cannot exceed the supply voltage due to Kirchoffs law (voltage around a loop sums to 0) and the capacitor holds all charge in the circuit on its plates when $V_c = V_s$. A

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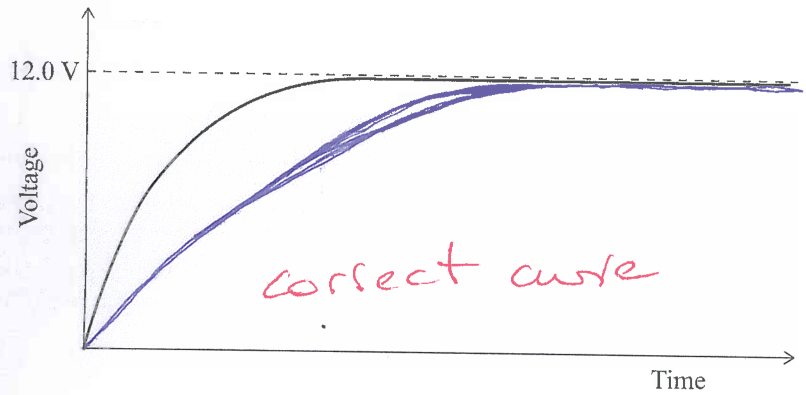
(c) The graph below shows the relationship between voltage and time as the capacitor charges.



shape same curve but longer time to reach maximum voltage. → larger time constant $\tau = RC$.

a

Sketch another curve on the graph to show the effect of an increased resistance on the charging of the capacitor.

Now switch A is opened and switch B is closed. The current changes with time.

(d) Explain the effect that inductors have on currents that change with time.

A changing current through an inductor coil creates ~~an opposing~~ changing magnetic flux through the coil. This results in an induced voltage which acts to oppose the change in current and flux through the coil. The size of this induced voltage is directly proportional to the rate at which the current is changing. When switch B is first closed there is an increasing current through the coil from the supply voltage, producing an opposing induced inductor voltage through the inductor which opposes the $\Delta I / \Delta t$ and therefore opposes the supply voltage. (no reference to increasing the time it takes)

m

(e) Discuss how energy is stored in the capacitor and inductor at the instant switch B is closed, and then while the capacitor is discharging.

When switch B is closed → and the capacitor discharges the stored energy in the capacitor is released - it does not store more energy. This energy is released as electrical energy as charge flows off the capacitor plates. This increases the current flowing through the inductor creating a changing magnetic flux through the coil which in turn allows energy to be stored in the magnetic field in the coil as the induced voltage in the coil opposes the ~~[illegible]~~ changing current through the coil.

When switch B is closed there is a lot of energy stored due to the extremely high induced voltage in the coil (without V supply V induced can be huge → no Kirchoffs law).

In the capacitor electrical potential energy is stored in the electric field between the plates (this decreases as it charges) and in the inductor the energy is stored in the magnetic field caused by an ~~increasing~~ changing current, as electrical potential energy → which created a magnetic flux.

e

E8