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SUPERVISOR'S USE ONLY

Level 3 Physics, 2015

91526 Demonstrate understanding of electrical systems

9.30 a.m. Friday 20 November 2015
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.

Not Achieved

TOTAL 4

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QUESTION ONE: AC CIRCUITS

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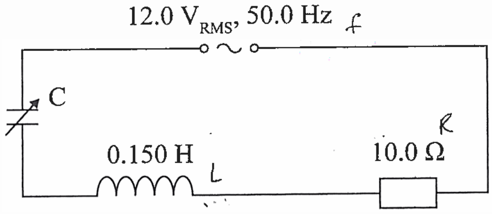
An AC circuit has a variable capacitor, an inductor, and a resistor in series, as shown below.



(a) Calculate the angular frequency of the supply.

$\omega = 2\pi f.$

~~$f = 2\pi / \omega$~~

na

(b) Show that the reactance of the inductor is 47.1 Ω.

$X_L = 2\pi f L$

$= 2\pi . 50.0 \cdot 0.150$

$= 47.123 = 47.1\ \Omega$

a

Correct working

(c) When the variable capacitor has a value of 1.00×10^{-6} F, the voltage across the capacitor is measured as 20.9 V_{RMS} and the current flowing in the circuit is measured as 0.656 A_{RMS}.

Calculate the voltages across the inductor and the resistor, and draw labelled phasors showing the voltages across the capacitor, the inductor, and the resistor.

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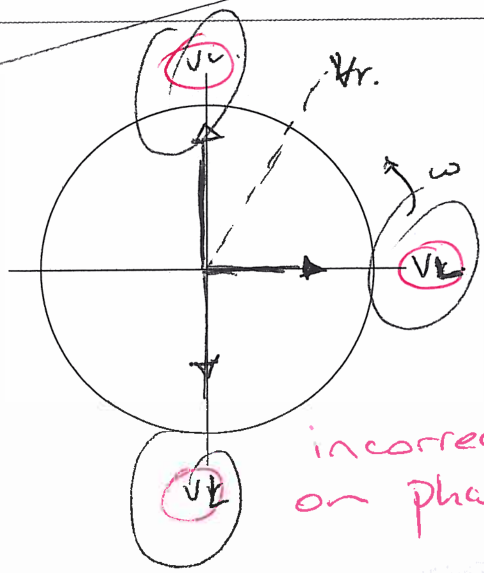

incorrect labels on phasers

(d) The variable capacitor is adjusted so that the circuit is now at resonance.

Explain, using physical principles, why the current is now a maximum, and calculate the value of the current in the circuit at resonance.

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$X_L = X_C$ at resonance.

$47.1 = \frac{1}{2\pi f C}$

$V = IR$

$C = \frac{47.1}{2\pi f}$

$I = \frac{V}{R} = \frac{20.9}{47.1}$

$C = \frac{47.1}{2\pi 50} = C = 0.15$ coulombs.

$= 0.4437$

$= 0.44$ A.

$I_{max} = \sqrt{2}\, I_{rms}$.

$= \sqrt{2} \times 0.44$

$= 0.627$ A.

~~capaci~~ reactance of the capacitor and inductor are equal at resonance. The current is now a maximum because as the voltage across the capacitor decreased due to the reactance of the capacitor. the current was able to build up. hence reaching maximum (I_{max}).

a

- has identified that $X_L = X_C$ at resonance
- no idea that $Z = R$ & is minimum ∴ I is maximum.
- incorrect calculation for I

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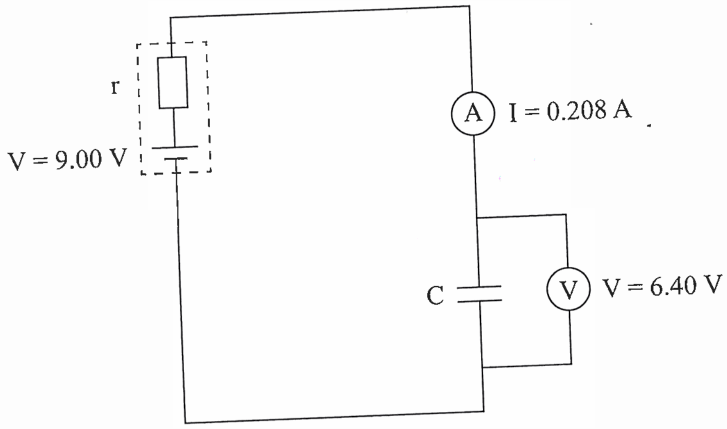
QUESTION TWO: CAPACITORS

Dielectric constant of air = 1.00

Permittivity of free space = 8.85×10^{-12} F m^{-1}

A 9.00 V cell is being used to charge a capacitor, as shown below.



(a) At one point during the charging, the capacitor has a voltage of 6.40 V, and the current flowing in the circuit is 0.208 A.

Show that the internal resistance, r, of the cell is 12.5 Ω.

$V = IR$. $R = 6.40 / 0.208 = 30.76$

$R = \frac{V}{I}$ $R = 9.00 / 0.208 = 43.26$

$R_{tot} =$ $43.76 - 30.26 = 12.5\,\Omega$

a

(b) The capacitor has air between its plates, and a plate separation of 2.26×10^{-4} m.

If the capacitor has a capacitance of 2.75×10^{-9} F, what is the overlap area of the plates?

$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ $\Rightarrow \frac{Cd}{\varepsilon_0 \varepsilon_r} = A$.

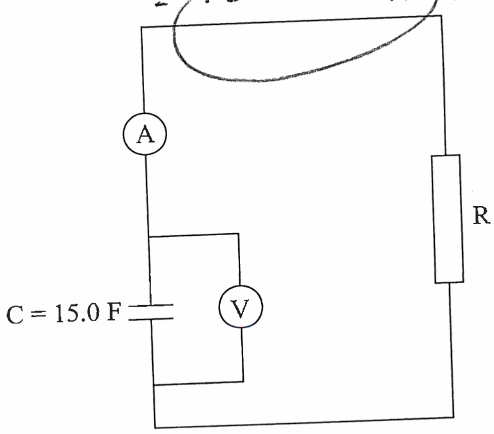
$Cd = \varepsilon_0 \varepsilon_r A$ $\frac{2.75 \times 10^{-9} \times 2.26 \times 10^{-4}}{8.85 \times 10^{-12}} = A = 1374931.233$

$= 13.7 \times 10^{5}\ m^2$

na

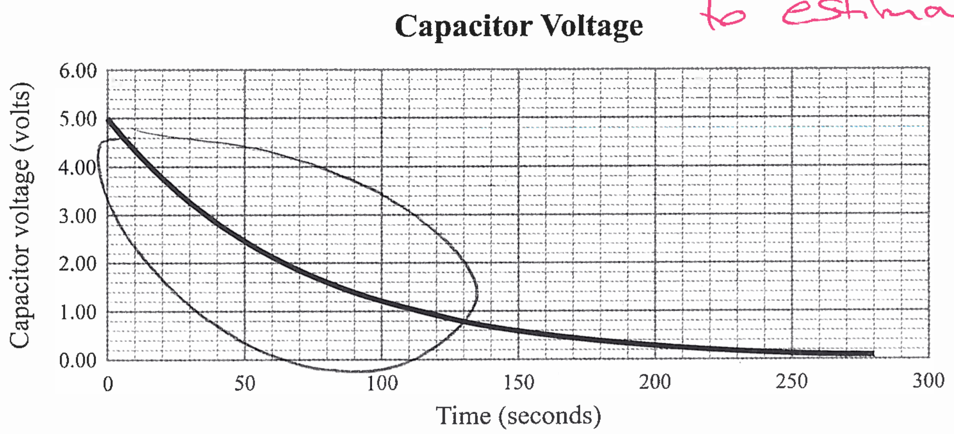
(c) Recently in the news, a teenager claimed to have developed a super capacitor as a way of rapidly charging a cell phone within 5 minutes. The actual circuit in a cell-phone charger is complicated, but the use of a capacitor to supply the energy to the charging unit can be modelled using a simple circuit.

In the circuit shown, a capacitor with capacitance 15.0 F has already been charged to 5.00 V, and is now discharged through a resistor, R, which represents the charging unit.



Use the graph to show that the resistor is 4.50 Ω, and calculate the maximum current in the circuit.

Graph not used to estimate τ



$V = I\cancel{R}$

$5.00 = I \times 4.50$ $\qquad I_{max} = \sqrt{2} \times (1.11)$ na

$I = 1.11 A$ $\qquad = 1.57$ ~~...~~ A.

(d) One particular cell phone requires about 6×10^5 joules of energy to fully charge. A super capacitor of 400 F could be used to charge a cell phone that requires 5 V with a resistance of 4.5 Ω.

Use calculations to decide whether this capacitor would fully charge the cell phone within 5 minutes.

In your answer you should:

- calculate the time taken for the capacitor to become effectively discharged
- discuss whether the capacitor will release its energy within 5 minutes
- calculate the energy released by the capacitor when discharging through the resistor
- compare the energy released by the capacitor with the energy that would be required to fully charge a cell phone.

$\tau = RC$ $\qquad Q = CV = 400 \times 5$

$= 4.5 \times 400$ $\qquad = 2000 J.$ a

$= 1800 s.$ Correct working for τ

$= 30$ mins. for discharge.

within 5 mins it would only release 1/6 of its total energy.

$\Delta E = Vq = 6 \times 10^5 \times 5$

$= 3000000 = 3.0 \times 10^6 J.$

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QUESTION THREE: ELECTROMAGNETIC INDUCTION

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There are a number of techniques used to detect cars and bicycles waiting at traffic lights. The most common technique is the inductive loop circuit.

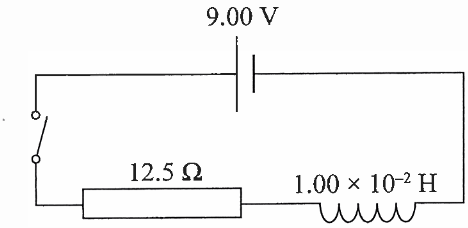
(a) State how an inductor stores energy.

by causing a buildup of voltage to the oppose to create charge.

incorrect answer

na

(b) One type of inductor loop circuit is shown below. This circuit contains a 9.00 V battery, with an inductor of 1.00×10^{-2} H, and a total resistance of 12.5 Ω in the circuit.



Soon after closing the switch, the current is 0.260 A.

Find the voltage across the resistor and the voltage across the inductor, and therefore calculate the rate of change of current.

$V = IR$

$= 0.260 \times 12.5$

$= 3.25V$

$V = I X_L$

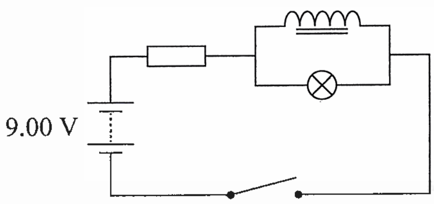
$= 2.6 \times 10^{-3} V$

Correct V_R but incorrect V_L

na

The rate of change of current has increased 100% ; between the resistor an inductor.

(c) A different inductive loop circuit is constructed, as shown below.



When the switch is closed, the bulb is bright and then gets dimmer.

Explain, in terms of current, why the inductor makes the circuit behave this way.

according to Lenz Law the change must be opposed by an opposite change the voltage buildup is met by the magnetic flux causing all the voltage to go in the direction of the supply voltage (opposite direction).

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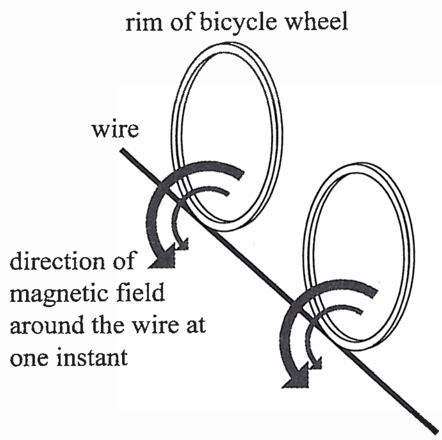
(d) Inductive loops at traffic lights can be adjusted to detect bicycles with metal rims. Below is a simplified diagram of a bike waiting for the traffic lights to change.



The inductive loop circuit uses Faraday's law to detect changes in the inductance when a bicycle is above the circuit. The high-frequency, alternating current induces a magnetic field in the metal bicycle rim. The magnetic field induced in the bicycle rim reduces the overall magnetic field. The inductance of the circuit is reduced, and this is detected by the traffic lights.

Explain the underlying physical concepts used in this situation.

In your answer you should:

- describe the nature of the magnetic field that is created by the alternating current in the wire
- explain why a high-frequency alternating current is needed to induce a significant magnetic field in the rims of the bicycle wheels
- explain why the induced magnetic field in the rims of the bicycle wheels is in the opposite direction to the magnetic field around the wire.

the magnetic field moves from north to south.
because the rim of the bicycle wheel is small (less surface area) more range (stronger magnetic field) is needed for the bicycles to be detected by the lights. The opposing force of the bicycle magnetic field to the magnetic field of the wire is what allows it to be detected. If it were in the same direction the magnetic force would simply be amplified. The traffic light detect the the disturbance in magnetic field therefore alerting them to the presence of the bicycle.

na

No

no understanding of induced current