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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.

Excellence

TOTAL 23

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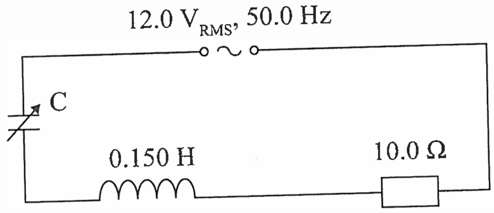
QUESTION ONE: AC CIRCUITS

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.

$\omega = 2\pi f$ $\omega = 2\pi \times 50 = 314.16$ rad s^{-1}

a

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

$X_L = \omega L$ $X_L = 314.16 \times 0.150 = 47.1\ \Omega$

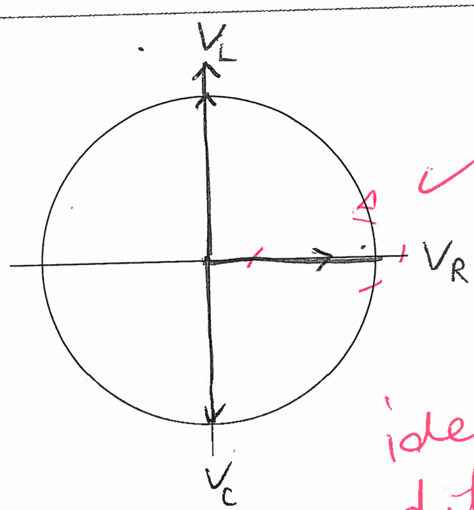
a

(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.

$V = IZ$ $V_L = 0.656 \times 47.1 = 30.89 \approx 31\ V_{rms}$

$V = IR$ $V_R = 0.656 \times 10 = 6.56\ V_{rms}$



e

identified different sizes

(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.

When $f = f_0$, $X_C = X_L$ and I is at a maximum because resistance is at a minimum. Resonance occurs when the frequency going through an LCR circuit is $\frac{1}{2\pi\sqrt{LC}}$, and the frequency of the alternating current matches the resonant frequency of the circuit.

~~$X_C = 47.1$~~

$X_C = 47.1 = \frac{1}{\omega C} = \frac{1}{314.2C}$

$C = 6.76 \times 10^{-5}$ F

$Z_{total} = \sqrt{(X_C - X_L)^2 + R^2}$

$= 10\ \Omega$

Has identified that $X_L = X_C$ and $Z = R$

$V = IZ$

$12 = I10$

$I = 1.2$ A_{rms}

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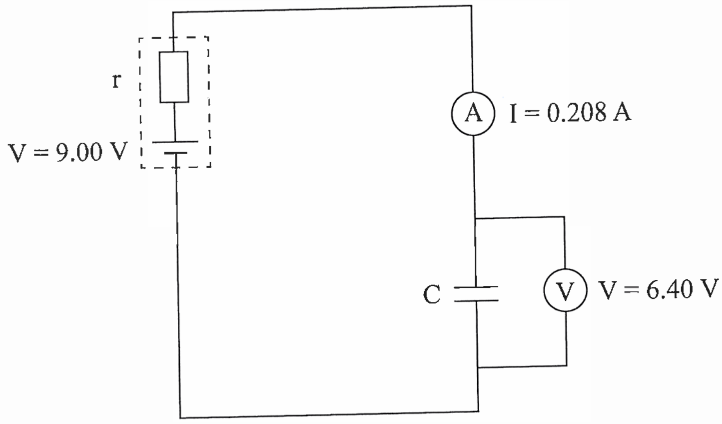
QUESTION TWO: CAPACITORS

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.

~~$\mathcal{E} =$~~ $V = IR$ $2.6 = 0.208 \times R$

For 'show that' $R = 12.5$ internal Ω

$\mathcal{E} = V - Ir$ is required for Merit.

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?

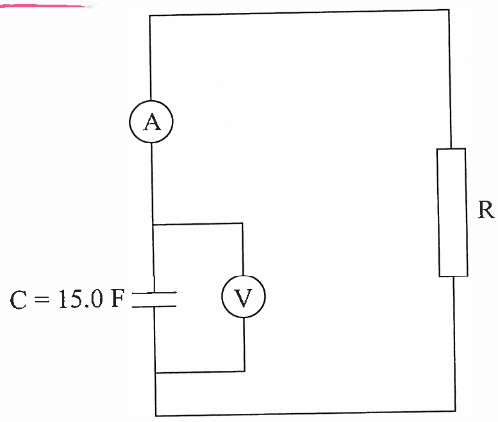
$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ $2.75 \times 10^{-9} = \frac{8.85 \times 10^{-12} \times 1 \times A}{2.26 \times 10^{-4}}$

$A = 0.070$ m^2

a

(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.



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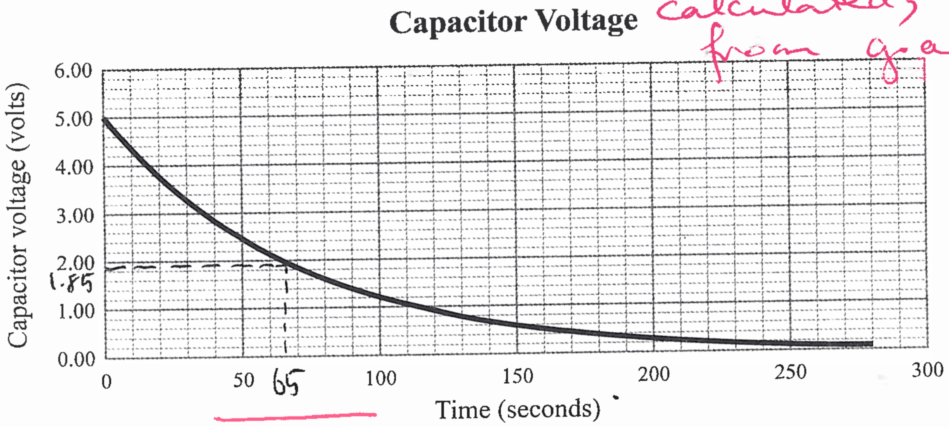
Use the graph to show that the resistor is 4.50 Ω, and calculate the maximum current in the circuit.

Decrease in Voltage calculated, τ estimated from graph & R & I calculated.



~~V=IR~~ τ = RC ~~τ = 5 × 0.37~~

~~5 =~~ ~~τ~~ ~~= 1.85~~

V × 0.37 = 5 × 0.37 = 1.85

τ = 65 seconds 65 = R × 15 R = 4.33 ≈ 4.5 Ω

~~65 = R × 2.75 × 10^-9~~ ~~R =~~ V = IR

I = 1.11 Amps

e

(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.

Time taken for full discharge = 5τ ~~= 5.45 secs~~

τ = RC = 4.5 × 400 = 1800 seconds ≈ 30 minutes

5 × 30 = * 15 hours. No, the capacitor will not discharge in five minutes. Q = CV = 400 × 5 = 2000 C

E = ½ 2000 × 5 = 5000 J through resistor.

$\frac{5000}{600000}$ = 0.00833 % of total to charge phone.

e

* Student has made a minor calculation error but has shown understanding of time to fully discharge & compared energy

E8

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QUESTION THREE: ELECTROMAGNETIC INDUCTION

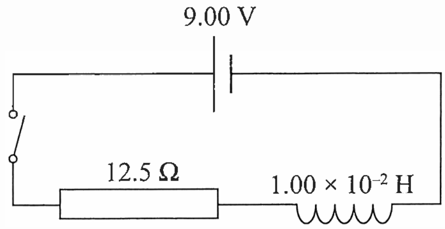
There are a number of techniques used to detect cars and bicycles waiting at traffic lights. The most common technique is the inductive loop circuit.

(a) State how an inductor stores energy.

In the magnetic field surrounding the wire.

a

(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.

$V = IR$ $\quad V = 0.260 \times 12.5 = 3.25$ V (resistor)

$9 - 3.25 = 5.75$ V_L

max current $I = \frac{9}{12.5} = 0.72$

$\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\quad -5.75 = -1 \times 10^{-2}\left(\frac{0.46}{t}\right)$

$t = 8 \times 10^{-4}$ s

$\therefore$ Δ is ~~0.46 Amps per~~ 575 Amps pers second

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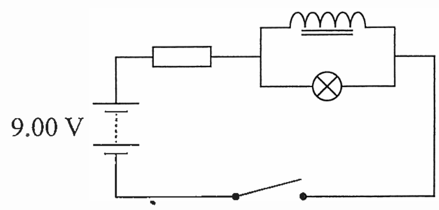
(c) A different inductive loop circuit is constructed, as shown below.



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.

Brightness ∝ P $\quad P = IV$. The inductor creates a massive potential difference that opposes the current. Thus, when the switch is first closed, more current flows through the bulb. As the pd of the inductor decreases, current across it increases and current across the bulb decreases.

e

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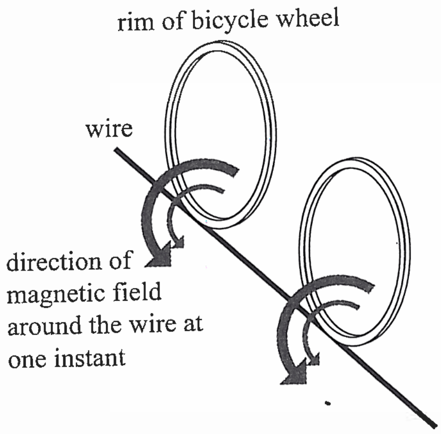
(d) Inductive loops at traffic lights can be adjusted to detect bicycles with metal rims. Below is a simplified diagram of a bike waiting for the traffic lights to change.



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.

Relative motion of charge to a conductor creates a magnetic field that opposes the current that created it. It exist around a wire in a cylinder with the direction aligning with the right hand rule (clockwise or anticlockwise relative to direction of current). A high frequency is needed as ~~$\varepsilon \propto \Delta\Theta$~~ $\varepsilon = \frac{\Delta\Phi}{\Delta t}$. ~~The induced voltage will stay the same~~ thus, the change in the magnetic field will be higher to maintain the same induced voltage, or the induced voltage will increase to maintain the

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

QUESTION NUMBER

~~#~~ same change in magnetic field. Both of these could be needed, as a higher induced voltage means a more significant change in inductance as the resulting field in the bike rims will be stronger. Alternatively, a greater Δmagnetic flux would be needed as $\Delta\phi = BA$, and a magnetic field with a large area could be needed to reach the rims of the bicycle, if the wire is not on the surface of the tarmac. The induced magnetic field in the rims are in the opposite direction because any relative motion of charge (the current in the wire) ~~induced~~ induces a magnetic field to a conductor (rims) that opposes the current that created it. Thus, energy is conserved, as the net magnetic field is reduced because more energy is now stored in the magnetic fields of the system.

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