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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.

Merit

TOTAL 17

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QUESTION ONE: AC CIRCUITS

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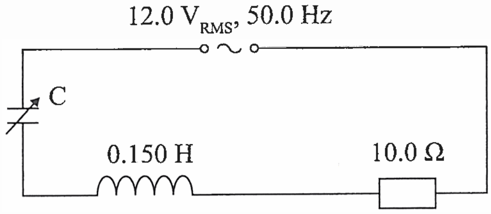
An AC circuit has a variable capacitor, an inductor, and a resistor in series, as shown below.



(a) Calculate the angular frequency of the supply.

$\omega = 2\pi f$

$= 2 \times 3.14 \times 50.0$

$= 314$ ~~rad s⁻¹~~ Hz

a

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

$X_L = 2\pi f L$

$= 2 \times 3.14 \times 50 \times 0.150$

$= 47.1\ \Omega$

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}.

✓ R1

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

~~$V_{resistor} = 10 \times 0.$~~

$V_{Resistor} = R \times I$

$= 10 \times 0.656$

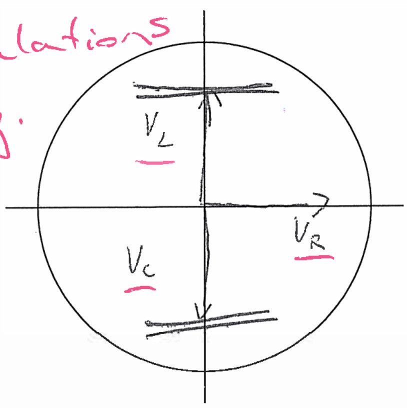
$= 6.56\ V$

$V_{inductor} = R \times I$

$= 47.1 \times 0.656 = 30.9\ V$

m

Correct calculations & phasor diag. but sizes incorrect.



(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.

At resonance, $X_L = X_C$ and they cancel each other out. Hence the impedence of circuit is only gotten from the resistor and it is at minimum. Because ~~the Impedence is minimum~~ current flows at maximum.

$I_{resonance} = \cancel{\sqrt{2}\, I_{rms}}\ \frac{V}{R}$

$= \cancel{\sqrt{2}}\ \frac{12}{10}$

$= 1.2A$

Understanding that current is max because Z is minimum due to X_L & X_C cancelled out.

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e

E7

QUESTION TWO: CAPACITORS

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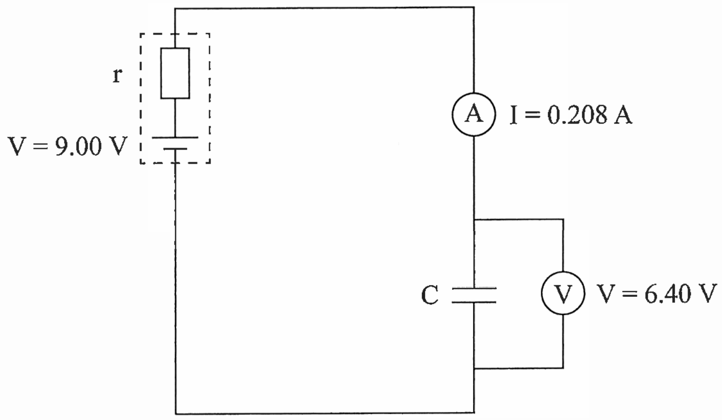
Dielectric constant of air = 1.00

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.



$V = \varepsilon - ir$

$6.4 = 9 - 0.208r$

(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.

$V = \varepsilon - ir$

$6.4 = 9 - 0.208r$

$r = 12.5\ \Omega$

M

(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?

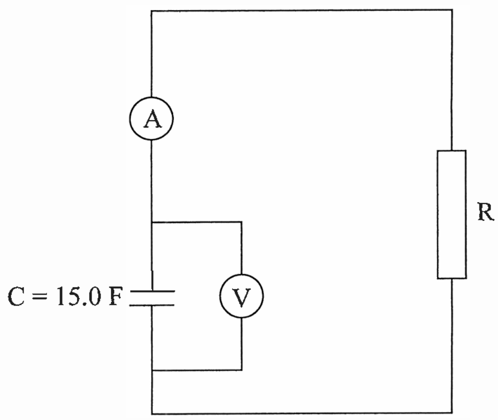
$C = \frac{\varepsilon_0 A}{d}$

$2.75\times10^{-4} = \frac{8.85\times10^{-12} A}{2.26\times10^{-4}}$

$A = 0.0702\ m^2$

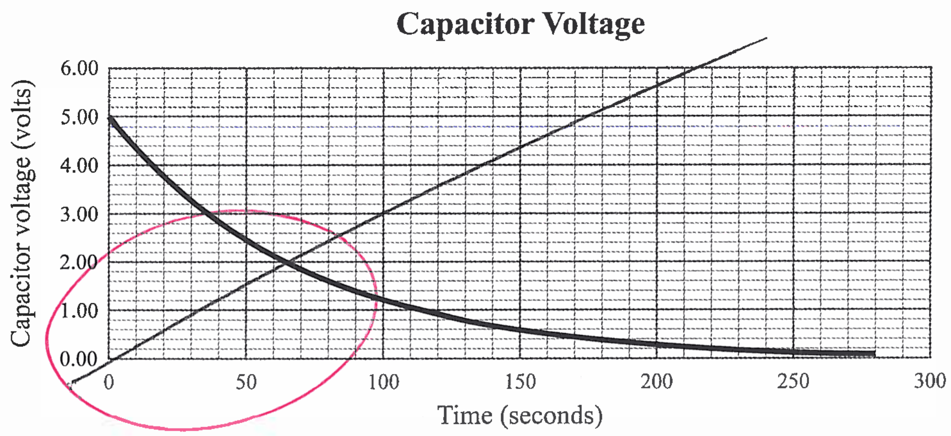
R

(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.



$V = IR$

~~the~~ time constant voltage = 37% × 5.00 = 1.85 V

$R = \frac{68}{15} = 4.50\ \Omega$

$\tau =$ ~~70s~~ 68 s

$I_{max} = \frac{5}{4.50} = 1.1\ A$

$\tau = RC$

m

(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 discharge = ~~270s~~

$E = \frac{1}{2}CV^2$

$= \frac{1}{2} \times 400 \times 5^2$

$= 5000\ J$

Has not calculated the time taken to fully discharge correctly, this is also required for 'e'

The capacitor will release its energy with 5 minutes because it only takes 270 s (4.5 min) for it to fully discharge. The energy released by capacitor will not be able to fully charge a cell phone, as it is too small.

m

m6

QUESTION THREE: ELECTROMAGNETIC INDUCTION

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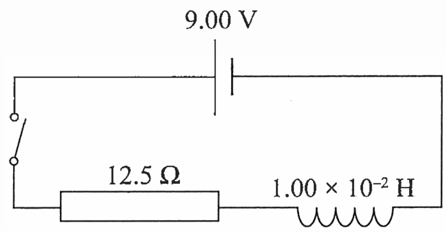
There are a number of techniques used to detect cars and bicycles waiting at traffic lights. The most common technique is the inductive loop circuit.

(a) State how an inductor stores energy.

The steady current causes a magnetic field throughout the coil where energy can be stored.

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.

$V = IR$

$V_{Resistor} = 0.206 \times 12.5$

$= 2.575 V$

$V_{inductor} = 9.00 - 2.575$

$= 6.425 V$

$\varepsilon = -L \frac{\Delta I}{\Delta t}$

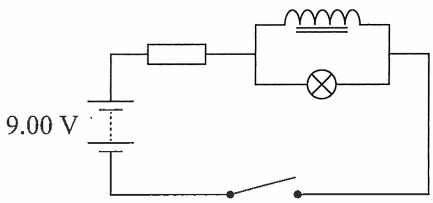
$6.425 = -1.00 \times 10^{-2} \frac{\Delta I}{\Delta t}$

$\frac{\Delta I}{\Delta t} = 643 \ A s^{-1}$

minor calculation error

M

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



Correct idea that inductor produces induced voltage due to $\Delta\phi$

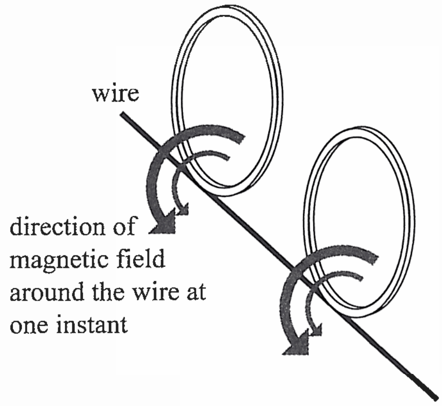
When the switch is closed, the bulb is bright and then gets dimmer.

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

When current flow into conductor this causes a change in magnetic flux creating an induced voltage (Faraday's Law). An induced current is produced which opposses the incoming current (Lenz's Law). This prevents current from flowing to the bulb and hence it gets dimmer.

a

(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.

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A4