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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.

Achievement

TOTAL 10

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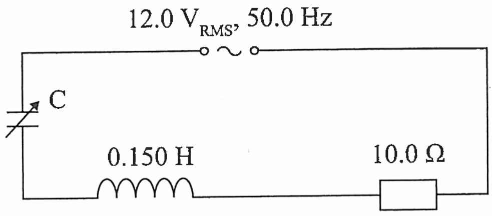
QUESTION ONE: AC CIRCUITS

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.

$\omega = 2\pi f$

$= 2\pi \times 50.0\text{Hz}$

$= 314 \text{ rads}^{-1}$

a

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

$X_L = \omega L$

$= 314 \times 0.150$

$= 47.1\ \Omega$ (3sf)

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}.

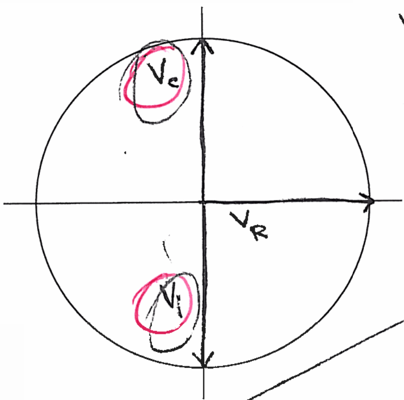
Calculate the voltages across the inductor and the resistor, and draw labelled phasors showing the voltages across the capacitor, the inductor, and the resistor.

$V_{max} = \sqrt{2} \times V_{rms}$

$= \sqrt{2} \times 20.9 = 29.56 \sim 29.6\text{V}$

na

incorrect labels on phasors



V_c = capacitor
V_R = resistor
V_i = inductor

(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.

$I_{max} = \sqrt{2}\, I_{rms} \rightarrow \sqrt{2} \times 0.656A = 0.928A$ (3sf)

When ~~the~~ the ~~ca~~ capacitor discharges the current is ~~at~~ its maximum as electrical potential energy is released. There is less charge being stored (less repulsive forces between electrons).

~~If~~ Increasing the amount of charge that can be stored on a capacitor decreases current, thus if the amount of charge that can be stored decreases, current increases.

no mention of resonance or what happens at resonance

na

N2

QUESTION TWO: CAPACITORS

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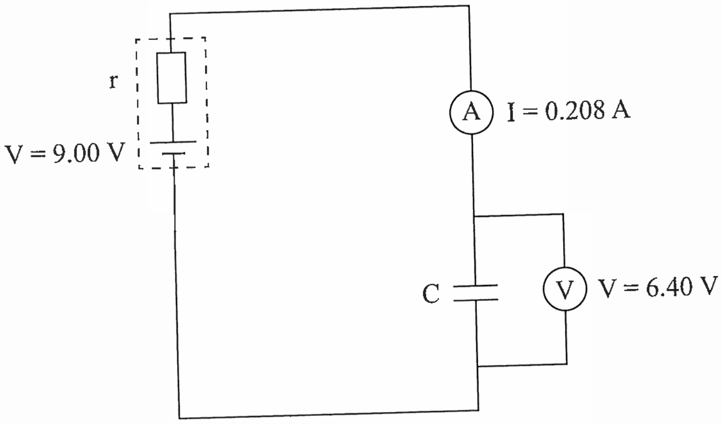
Dielectric constant of air = 1.00

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.



$V = IR$

(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.

~~Vaha~~ $V = IR \rightarrow I = \frac{V}{R}$

$(9 - 6.4) \div 0.208$ correct working m

$= 12.5\,\Omega$

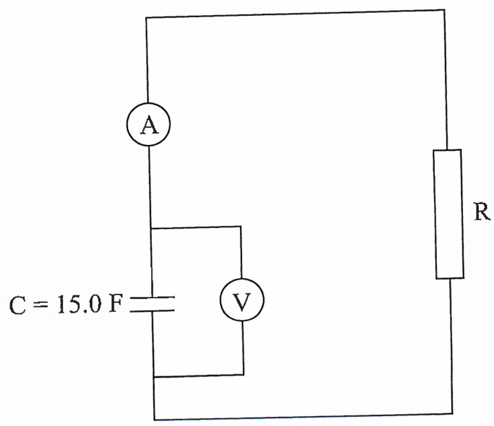
(b) The capacitor has air between its plates, and a plate separation of 2.26×10^{-4} m.

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

$A = \frac{Cd}{\varepsilon_0 \varepsilon_r} = \frac{(2.75\times10^{-9}) \times (2.26\times10^{-4})}{(1.00 \times 8.85\times10^{-12})}$

$= 7.02 \times 10^{-26}$ m^2 is the area of overlap 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.

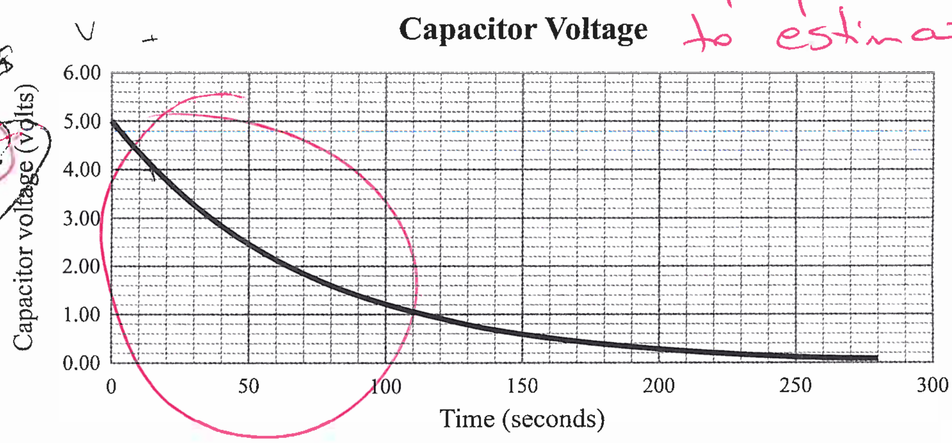
r , V , C

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

① 5×0.37 = 1.85

② 1.85×0.37 = 0.6845



na

$I = \frac{V}{R} = \frac{5.0}{4.5} = 1.11A$ is the max current

Capacitor voltage decreases as it discharges.

$\tau = RC \rightarrow R = \frac{\tau}{C}$ $\frac{0.6845}{15} = 0.0456\,\Omega$

$V = IR$

(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.

~~$E = \frac{1}{2}QV$ Q $\frac{1}{2}Q = \frac{E}{V} = \frac{6.0\times10^5}{5} = 1.2\times10^5 C$~~

$Q = CV = 400 \times 5 = 2000$

$E = \frac{1}{2}QV = \frac{1}{2} \times 2000 \times 5$

$= 5000J \sim 5.0\times10^3 J$

has calculated & compared energies but not discussed total time to discharge

M

$\tau = RC = 4.5 \times 400 = 1800s = 30 minutes$

Energy released by the capacitor would not be enough to fully charge a phone as the energy released by capacitor is $5.0\times10^3 J$ and the energy required is $6\times10^5 J$. One time constant (time it takes for voltage

M5

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QUESTION THREE: ELECTROMAGNETIC INDUCTION

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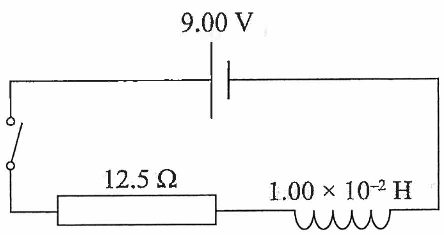
There are a number of techniques used to detect cars and bicycles waiting at traffic lights. The most common technique is the inductive loop circuit.

(a) State how an inductor stores energy.

Inductor store energy within a magnetic field.

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.



L V R I

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.

voltage of resistor
$V = IR$
$= 0.260 \times 12.5$
$= 3.25V$

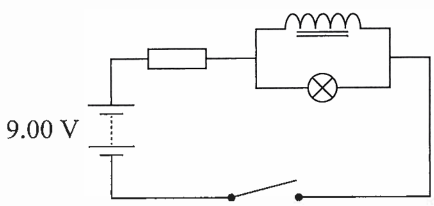
~~L = V/IR~~
~~V = L·I·R~~
~~= (1.00×10⁻²)(3.25)~~
~~= 3.26V~~

Voltage of inductor
$9 - 3.25$
$= 5.75V$

has not calculated $\frac{\Delta I}{\Delta t}$

N2

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



no mention of induced voltage

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.

NA

The current in the circuit decreases due to the resistance of the inductor (lags charge). Charge is stored as magnetic electrical potential within the magnetic field created by the inductor – storing charge increases the ~~rep~~ repulsive forces of the electrons which oppose the flow of current.

(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.

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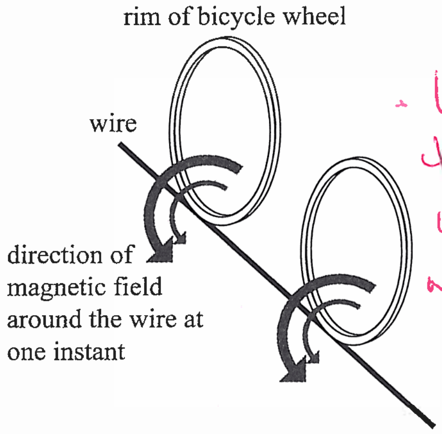

· has mentioned that frequency will affect the magnetic flux

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.

Faraday's Law states that an induced current in a magnetic field creates a force. As the bike is moving it cuts the magnetic field lines – as it is an alternating current the direction of the current changes as the bicycle wheels cut the field lines. The ~~opposing~~ induced current produced opposes change and thus opposes the current of the magnetic field. $\varepsilon = -L\frac{\Delta I}{\Delta t}$ For the alternating current produced by the ~~current~~ bicycle to create a significant ~~magnetic flux the time~~ it takes ~~...~~ 'cutting' the ~~flux (time taken for the changing~~ flux) must ~~be decreased~~ $f = \frac{1}{T}$ as time is decreased the frequency is increased as frequency is inversely proportional to time

a

A3