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Level 3 Physics, 2016

91526 Demonstrate understanding of electrical systems

2.00 p.m. Tuesday 15 November 2016
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: CHARGING A CAPACITOR

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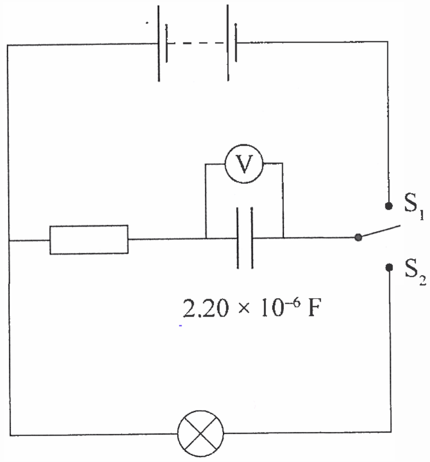
Eleanor sets up a circuit to investigate how capacitors operate. The circuit is shown below. The circuit includes a 2.20×10^{-6} F capacitor and a double pole switch.

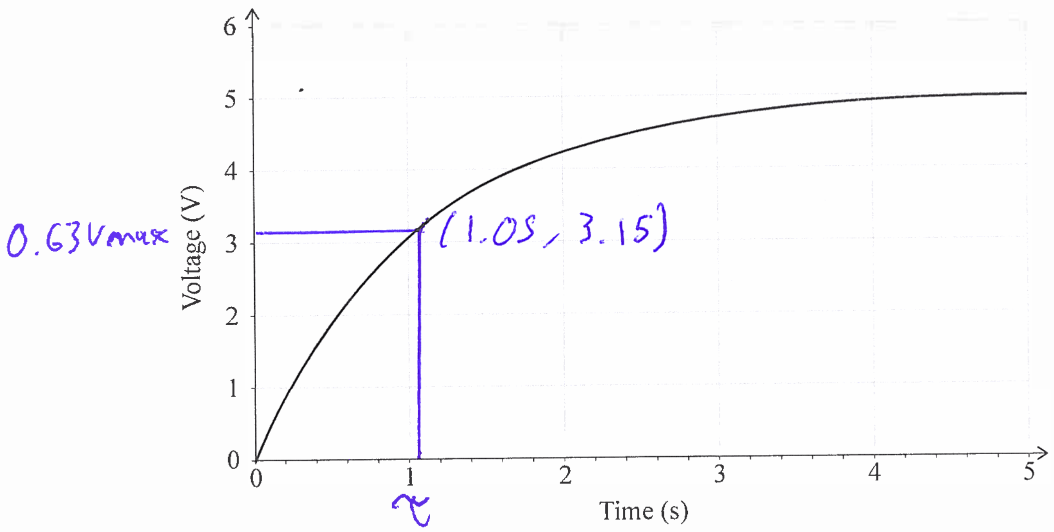


(a) Calculate the maximum charge stored by the capacitor in this circuit.

$Q = CV = 2.2 \times 10^{-6} \times 5 = 1.1 \times 10^{-5}$ C

A

The capacitor is initially uncharged, and the switch is in the position shown. Eleanor moves the switch to S_1 and the capacitor charges up. A graph of the capacitor voltage against time is shown below.



(b) Use the graph to calculate the resistance of the resistor.

Draw lines on the graph to help explain your working.

$0.63 \times 5 = 3.15$, $\tau \approx 1.05$ s

$R = \frac{\tau}{C} = \frac{1.05}{2.2 \times 10^{-6}} = 477000\ \Omega$ (3sf)

N

Causing an electric field between the plates in which ~~charge~~ is stored, because of the positive charges on one plate and the negative charges on the other

(c) Give a comprehensive explanation for the shape of the capacitor voltage graph.

Include the reasons for the starting voltage and the final voltage.

When the switch is initially ~~opened~~, ~~t~~ current cannot flow so there is no voltage across the capacitor. When the switch is closed, electrons will flow onto one of the plates of the capacitor. ~~which causes the electrons to be~~ ~~Electrons~~ Initially, the electrons build up fast as there ~~is a~~ ~~charge~~ is low potential difference between the battery and the electric field between the capacitor plates ~~plates~~. As potential difference decreases, the rate at which the ~~ee~~ electrons flow onto the plate decreases, hence the flattening of the graph. After about 5 time constants, the voltage ~~is~~ of the capacitor is equal to the supply voltage, so there is no potential difference and the voltage of the capacitor ~~charge~~ will not change. ~~[illegible]~~

e

(d) Eleanor connects another 2.20×10^{-6} F capacitor in series with the original capacitor, and repeats the experiment.

Describe and explain how this affects:

- the final voltage across the original capacitor
- the time constant of the circuit.

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} = 1.1 \times 10^{-6}$

The final voltage across the original capacitor decreases ~~due to~~ as the two capacitors in series effectively act as one ~~large~~ capacitor with a smaller capacitance ~~as~~ d ($C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ and d increases). a

Therefore it cannot hold as much charge so ~~can hold~~ will have a lower final voltage.

The time constant will decrease as the capacitance decreases ($\tau = RC$) because it ~~takes~~ takes less time to fully charge a capacitor with lower capacitance.

G

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QUESTION TWO: THE TRANSFORMER

Transformers can be used to increase or decrease the size of an AC voltage. Wei has a transformer that is designed to convert 240 V into 12.0 V.

The secondary coil has 40 turns.

(a) Calculate the number of turns on the primary coil.

$\frac{N_p}{N_s} = \frac{V_p}{V_s}$, $N_p = 40\left(\frac{240}{12}\right)$

$N_p = 800$

A

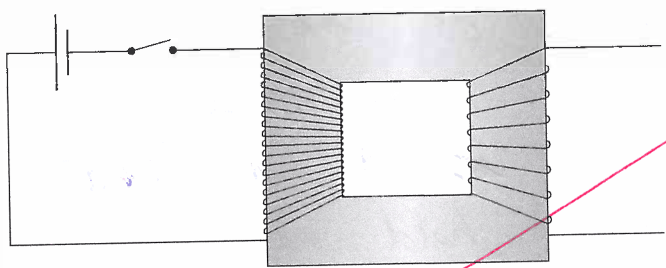
(b) Explain how an alternating voltage across the primary coil creates an alternating current in a light bulb connected to the secondary coil.

The alternating voltage causes an alternating ~~current~~ current which ~~the~~ changes the flux in the primary coil. There will be a back-emf induced in the primary coil to oppose the changing flux. This back-emf in the primary coil ~~changes~~ is changing, so it will induce an alternating current in the secondary coil, which in turn ~~induces~~ causes an alternating current in the bulb.

M

Each coil of a transformer acts as an inductor.

A primary coil is attached to a battery and switch as shown in the diagram below. The switch is closed and then some time later the switch is opened.



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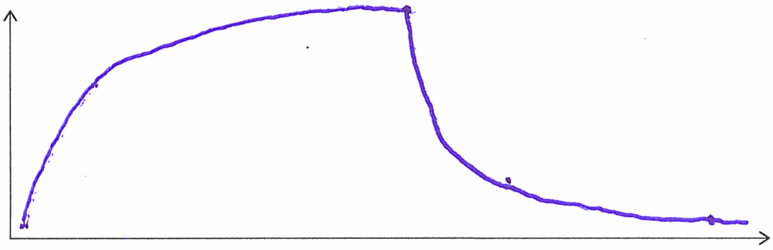
(c) Sketch a graph showing how the current in the coil changes when the switch is closed and then some time later is opened.

Give a comprehensive explanation for the shape of your graph.

current



time

If you need to redraw your response, use the graph on page 8.

When the switch is closed, there is an ~~[illegible]~~ increase in current, which ~~causes~~ causes a changing flux ~~a~~ in the 'inductor' which it will act to oppose by producing a back-emf. The current will still increase to maximum, but at a lesser rate than it would without the inductor, which is ~~why the graph increases but at a lesser rate~~ shown on the graph (it would increase to Imax almost instantaneously without the inductor). ~~It is caused because there a as the current increases, there is less potential difference~~ After the switch is opened, the opening

cont.

e

(d) Calculate the energy stored in the primary coil's magnetic field when the switch has been closed for several seconds.

battery voltage = 6.0 V

resistance of primary coil = 35 Ω

inductance of primary coil = 0.10 H

$E = \frac{1}{2}LI^2 = 0.5 \times 0.1 \times I^2$

$I = \frac{V}{R} = \frac{6}{35} \approx 0.17A$

$E =$ ~~[illegible]~~ $0.5 \times 0.1 \times 0.17^2$

$E = 1.5 \times 10^{-3}$ J (2sf)

M

E8

QUESTION THREE: MEASURING IRON IN SAND

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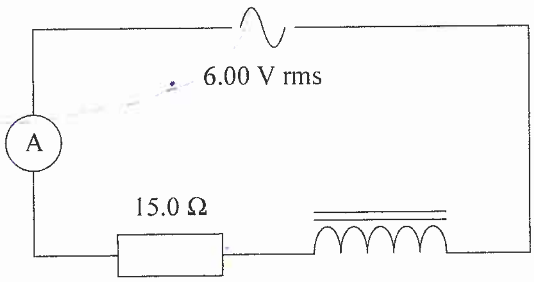
Vivienne wants to measure the amount of iron in iron-sand mixtures collected from different beaches. The diagram below shows the circuit that she uses. The circuit includes a 500-turn coil with a resistance of 15.0 Ω, and an AC supply.

The coil behaves like a resistor and an inductor in series.



The coil has a hollow core that is initially empty. Vivienne adjusts the power supply voltage to 6.00 V rms.

(a) Calculate the instantaneous maximum (peak) voltage across the power supply.

$V_{max} = \sqrt{2}\, V_{RMS} = \sqrt{2} \times 6 = 8.49\text{V}$ (3sf)

a

During testing, Vivienne puts a mixture of iron and sand inside the core of the coil.

(b) State what effect this has on the size of the coil's reactance.

With reference to impedance, explain what happens to the size of the current in the circuit as she adds the mixture of iron and sand.

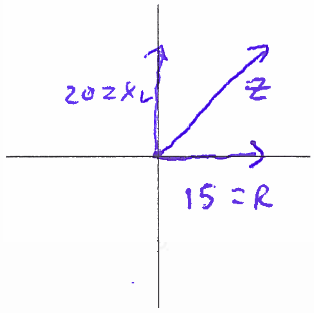
The inductance of the coil increases as the iron contributes to ~~the~~ increasing the flux. This causes reactance ~~impedance~~ to increase ($X_L = \omega L$), which increases the impedance of the circuit. Impedance ~~...~~ acts like ~~resistor~~ resistance in DC, so the size of the current decreases ($I = \frac{V}{Z}$)

M

ASSESSOR'S USE ONLY

(c) When Vivienne sets the frequency of the current to 1.00×10^3 Hz, the inductance of the coil is 3.18×10^{-3} H.

Using a phasor diagram or otherwise, calculate the size of the rms current in the circuit.



$\omega = 2\pi f = 2000\pi$ rads^{-1}

$X_L = \omega L = 2000\pi \times 3.18 \times 10^{-3}$

$X_L = 20.0\ \Omega$ (3sf)

$Z = \sqrt{15^2 + 20^2} = 25\ \Omega$ (from vector)

$I = \frac{V}{Z} = \frac{6}{25} = 0.24$ A

e

(d) Vivenne adds a capacitor in series with the coil, and finds that the current increases.

Explain why the current increases.

The ~~element~~ ~~ca~~ capacitor has ~~impedance~~ reactance ($X_C = \frac{1}{\omega C}$). This ~~impedance~~ reactance is 180° out of phase with the inductor ~~impedance~~ reactance, which ~~acts~~ means that the two ~~impedances~~ reactances 'counteract' each other. This decreases the impedance of the circuit:

Before: $Z = \sqrt{X_L^2 + R^2}$, After: $Z = \sqrt{(X_L - X_C)^2 + R^2}$

M

G8

cont

SPARE DIAGRAMS

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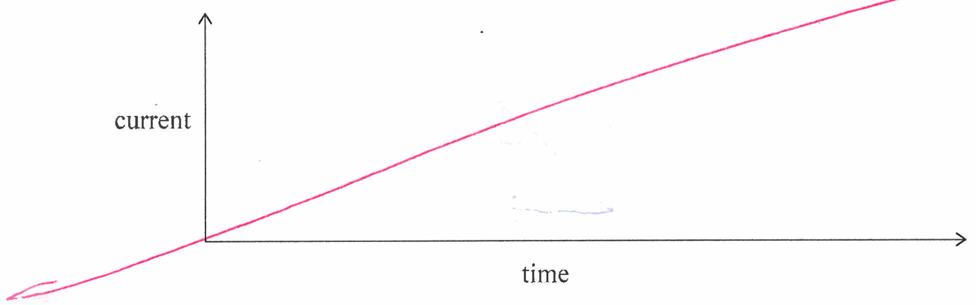
If you need to redraw your response to Question Two (d), use the axes below. Make sure it is clear which answer you want marked.



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

QUESTION NUMBER

2c) acts ~~[illegible]~~ as a very large resistance which causes the flow of current to decrease rapidly. The inductor acts to oppose this change by producing an induced voltage which acts to increase the current. The value of the current ~~[illegible]~~ shrinks to 0 ~~after about 5 time constants~~, but at a slower rate due to the induced voltage opposing the change.

3d) which causes the current to increase ($I = \frac{V}{Z}$).

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