Circuits

13. A student is investigating the charging and discharging of a capacitor. The circuit used is shown in Figure 13A.
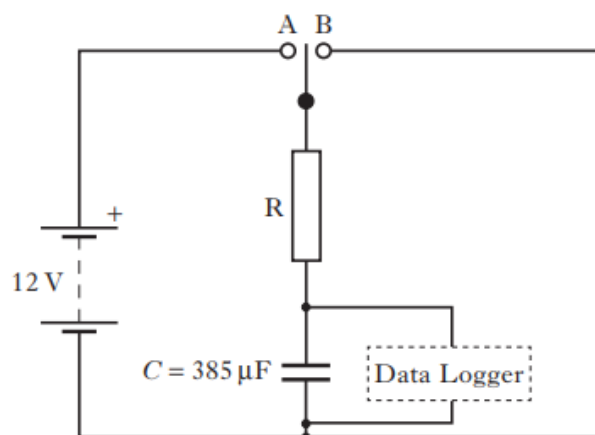
Marks

Figure 13A

With the switch in position A, the capacitor charges. To discharge the capacitor, the switch is moved to position B. The data logger monitors the voltage across the capacitor.

The graph in Figure 13B shows how the voltage across the capacitor changes during discharge.
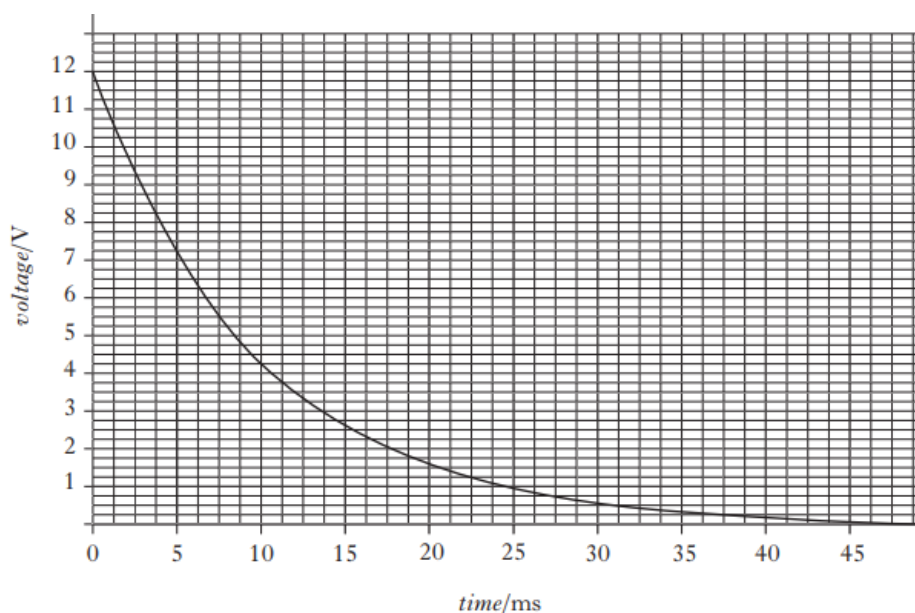

Figure 13B

    (a) Determine the time constant from the graph.   2

    (b) Calculate the resistance of resistor R.   2

    (4)

14. A 0·40 H inductor of negligible resistance is connected in a circuit as shown in Figure 14. Switch S is initially open.

9·0 V
+ −
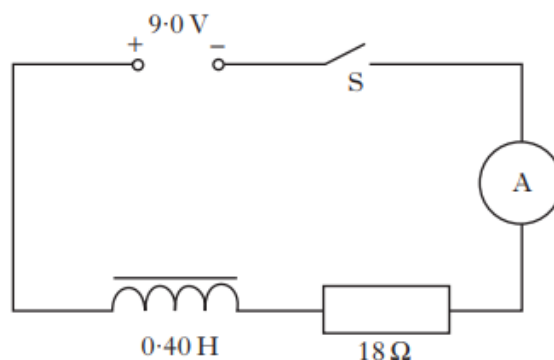S

A

0·40 H   18 Ω

Figure 14

(a) (i) Sketch a graph of current against time after the switch S is closed. Numerical values are required on the current axis. **2**

　　(ii) Explain fully the shape of the graph. **2**

(b) Calculate the initial rate of change of current when switch S is closed. **2**

(6)

15. A student sets up an LC circuit, as shown in Figure 15A.

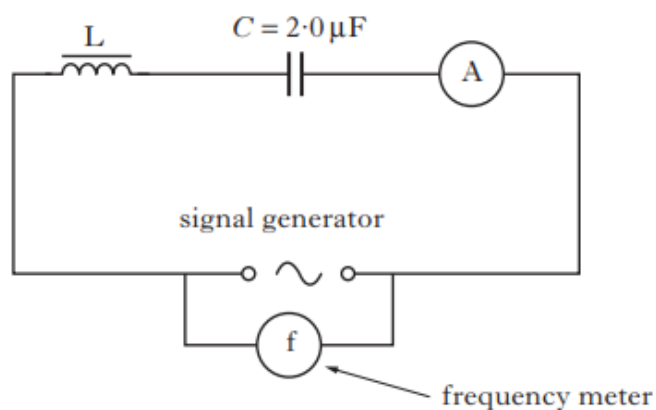L $C = 2·0\,\mu F$

A

signal generator

f

frequency meter

Figure 15A

Maximum current occurs at the resonant frequency f_0. Resonance occurs when the capacitive reactance equals the inductive reactance. The student varies the supply frequency and records the corresponding current. A graph of current against frequency is shown in Figure 15B.
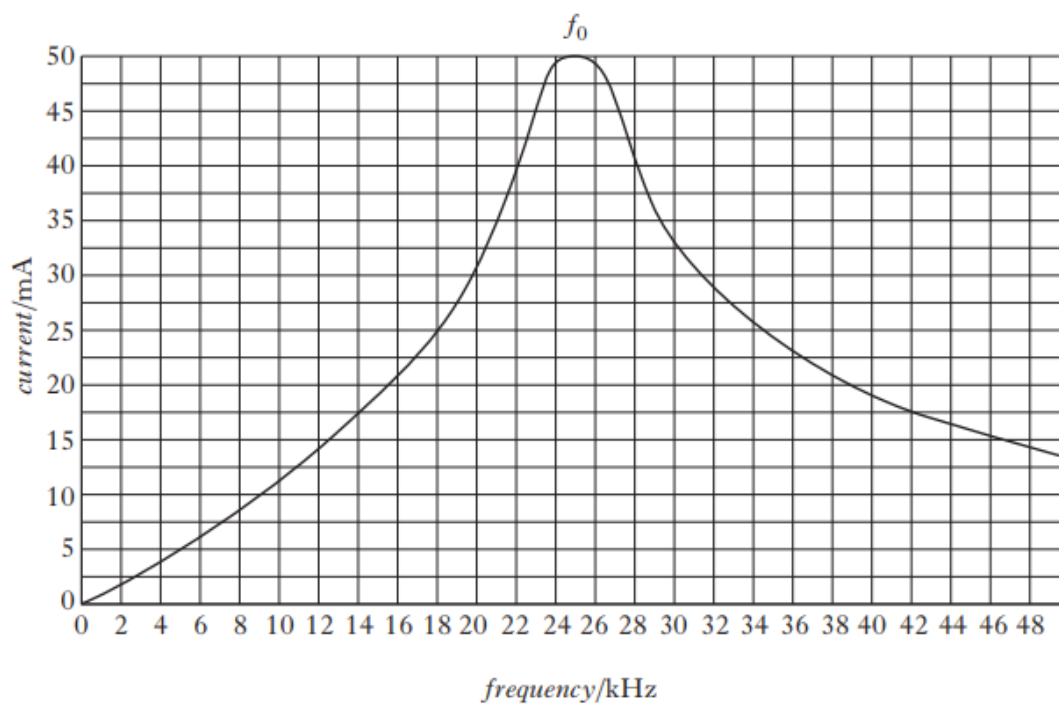
f_0

Figure 15B

15. **(continued)**

(a) Show that the resonant frequency f_0 is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}.}$$

    1

(b) The capacitance of C is $2 \cdot 0 \, \mu F$. Calculate the inductance of L.

    2

(c) The student wants to change the design of this circuit in order to double the resonant frequency. Describe, in detail, a change the student could make to achieve this.

    2

    (5)

Mark.

13. An inductor of inductance 4·0 H with negligible resistance is connected in series with a 48 Ω resistor shown in Figure 13A.
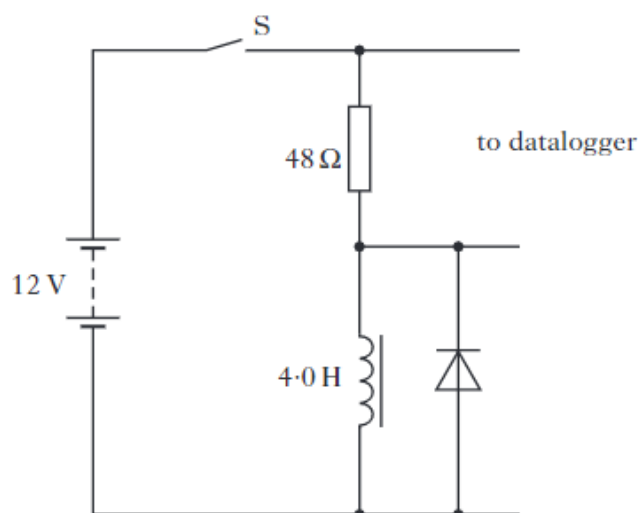

Figure 13A

The datalogger is set to display a graph of current against time.

(a) Sketch the graph obtained from the time the switch S is closed until the current reaches a maximum. Numerical values are required on the current axis only.

2

(b) Calculate the initial rate of change of current in the 4·0 H inductor.

2

(c) The 4·0 H inductor is now connected in the circuit shown in Figure 13B.
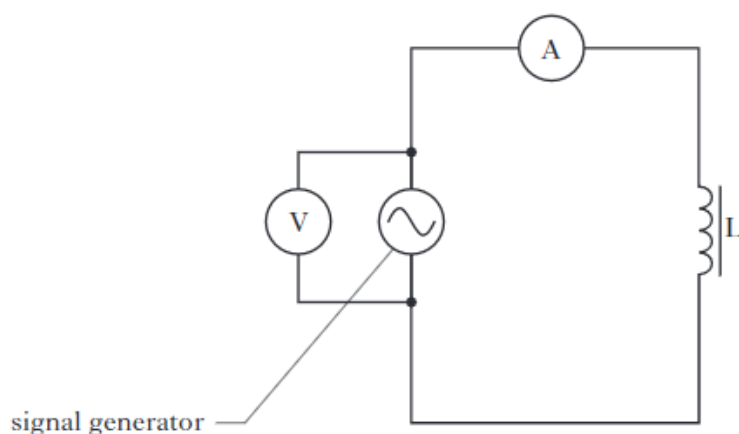

Figure 13B

The output voltage of the signal generator is set at 6·0 V. The reading in the ammeter is 5·0 mA.

Calculate the output frequency of the signal generator.

3

(7)

12. (a) A student investigates how the current in an inductor varies with the frequency of a voltage supply.

   (i) Draw a suitable labelled circuit diagram of the apparatus required to carry out the investigation.   **2**

   (ii) The student collects the following data.

Frequency/Hz	40	60	80	100	120
Current/mA	148	101	76·0	58·2	50·0

Determine the relationship between the supply frequency and current for this inductor.   **2**

(b) An inductor of inductance 3·0 H and negligible resistance is connected in a circuit with a 12 Ω resistor and supply voltage V_s as shown in Figure 12A.
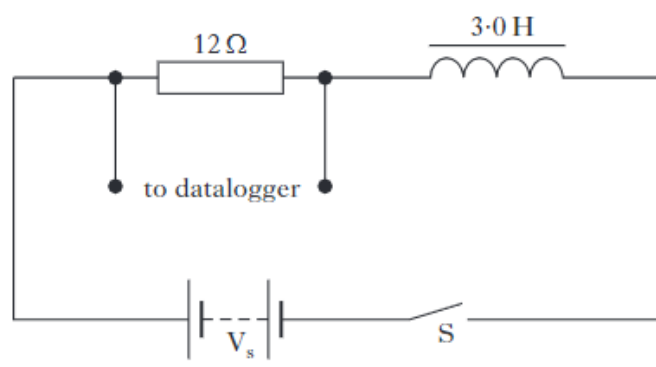

Figure 12A

The datalogger is set to calculate the back emf across the inductor.

Switch S is initially open.

Switch S is now closed. Figure 12B shows how the back emf across the inductor varies from the instant the switch is closed.
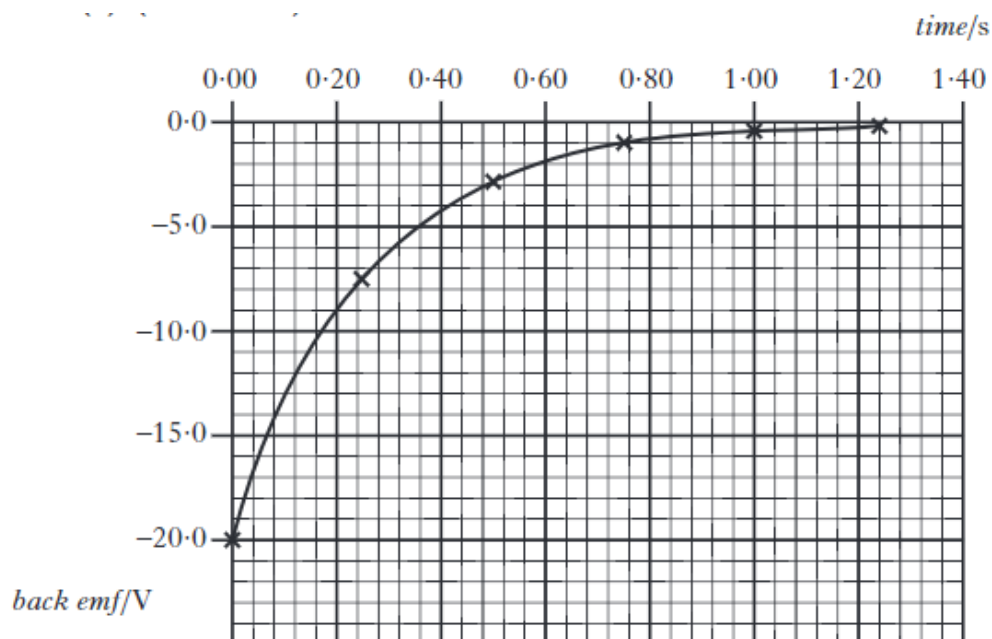
Figure 12B

(i) Determine the voltage across the resistor at $t = 0.20$ s. **2**

(ii) Calculate the rate of change of current in the circuit at $t = 0.40$ s. **2**

(iii) State why the magnitude of the back emf is greatest at $t = 0$. **1**

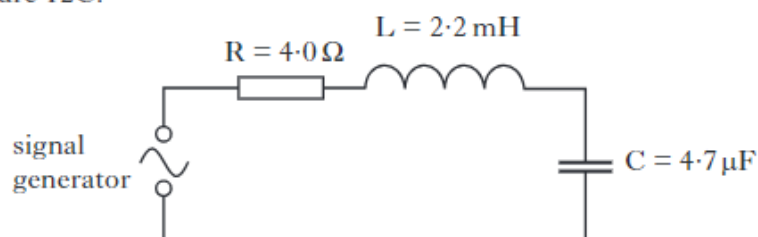(c) A tuned circuit consisting of an inductor, capacitor and resistor is shown in Figure 12C.

Figure 12C

The impedance Z, measured in ohms, of the circuit is given by the relationship

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

where the symbols have their usual meanings.

(i) At a particular frequency f_0, the impedance of the circuit is a minimum.

Show that f_0 is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}.$$ **1**

(ii) Calculate the frequency f_0. **2**

(iii) State the minimum impedance of the circuit. **1**

(13)

15. A student constructs a simple air-insulated capacitor using two parallel metal plates, each of area A, separated by a distance d. The plates are separated using small insulating spacers as shown in Figure 15A.
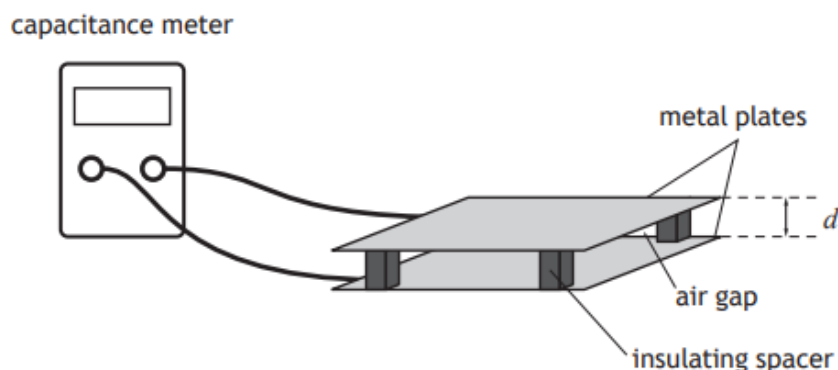
capacitance meter

metal plates

d

air gap

insulating spacer

Figure 15A

The capacitance C of the capacitor is given by

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

The student investigates how the capacitance depends on the separation of the plates. The student uses a capacitance meter to measure the capacitance for different plate separations. The plate separation is measured using a ruler.

The results are used to plot the graph shown in Figure 15B.

The area of each metal plate is $9 \cdot 0 \times 10^{-2}\,\text{m}^2$.

$C\,(\times 10^{-10}\,\text{F})$

$y = 8 \cdot 3x - 0 \cdot 20$

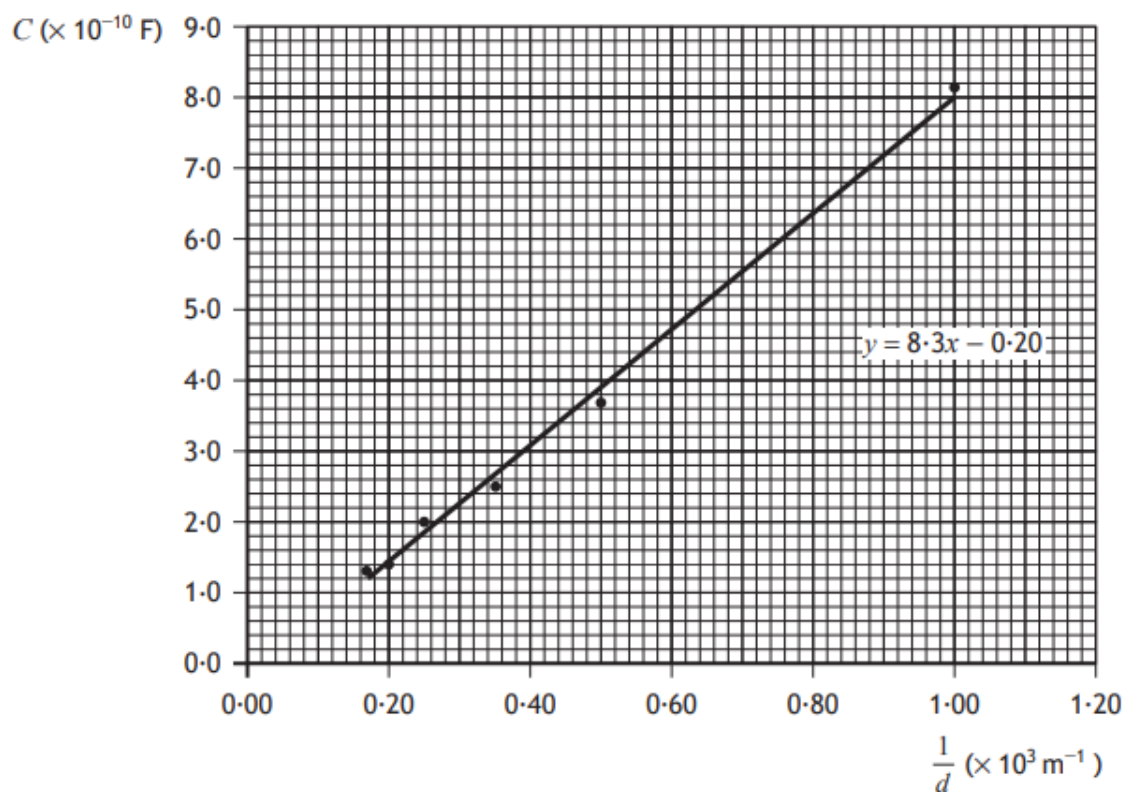$\frac{1}{d}\,(\times 10^3\,\text{m}^{-1})$

Figure 15B

(a) (i) Use information from the graph to determine a value for ε_o, the permittivity of free space. **3**

(ii) Use your calculated value for the permittivity of free space to determine a value for the speed of light in air. **3**

(b) The best fit line on the graph does not pass through the origin as theory predicts.

Suggest a reason for this. **1**

CfE AH 2017

13. A student purchases a capacitor with capacitance 1·0 F. The capacitor, which has negligible resistance, is used to supply short bursts of energy to the audio system in a car when there is high energy demand on the car battery.
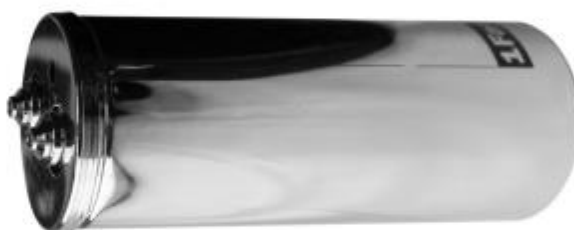
The instructions state that the capacitor must be fully charged from the 12 V d.c. car battery through a 1·0 kΩ series resistor.

(a) Show that the time constant for this charging circuit is $1 \cdot 0 \times 10^3$ s. **2**

(b) The student carries out an experiment to monitor the voltage across the capacitor while it is being charged.

(i) Draw a diagram of the circuit which would enable the student to carry out this experiment. **1**

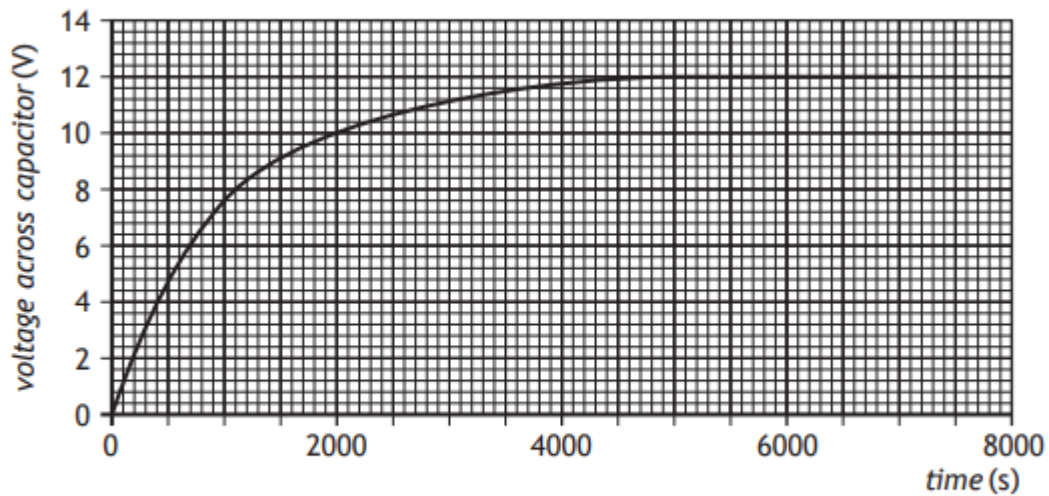(ii) The student draws the graph shown in Figure 13A.

Figure 13A

(A) Use information from the graph to show that the capacitor is 63% charged after 1 time constant. **2**

(B) Use information from the graph to determine how many time constants are required for this capacitor to be considered fully charged **1**

(c) The car audio system is rated at 12 V, 20 W.

Use your knowledge of physics to comment on the suitability of the capacitor as the only energy source for the audio system. **3**

14. A student designs a loudspeaker circuit.

A capacitor and an inductor are used in the circuit so that high frequency signals are passed to a small "tweeter" loudspeaker and low frequency signals are passed to a large "woofer" loudspeaker.

Each loudspeaker has a resistance of $8\cdot0\,\Omega$.
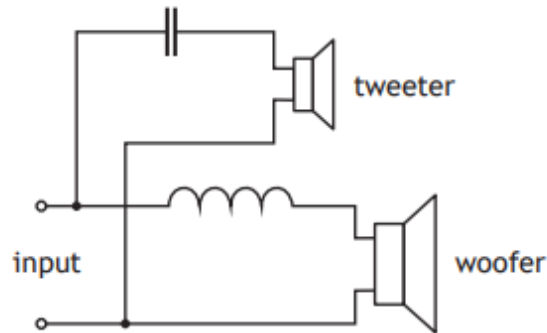
The circuit diagram is shown in Figure 14A.

Figure 14A

The circuit is designed to have a "crossover" frequency of $3\cdot0\,$kHz: at frequencies above $3\cdot0\,$kHz there is a greater current in the tweeter and at frequencies below $3\cdot0\,$kHz there is a greater current in the woofer.

(a) Explain how the use of a capacitor and an inductor allows:

    (i) high frequency signals to be passed to the tweeter;   **1**

    (ii) low frequency signals to be passed to the woofer.   **1**

(b) At the crossover frequency, both the reactance of the capacitor and the reactance of the inductor are equal to the resistance of each loudspeaker.

Calculate the inductance required to provide an inductive reactance of $8\cdot0\,\Omega$ when the frequency of the signal is $3\cdot0\,$kHz.   **3**

(c) In a box of components, the student finds an inductor and decides to determine its inductance. The student constructs the circuit shown in Figure 14B.
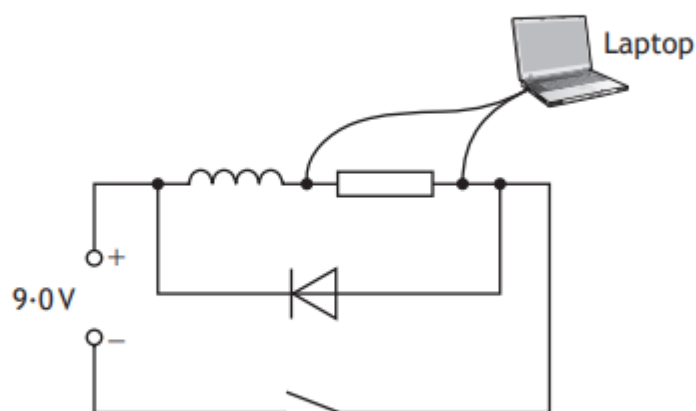

Figure 14B

The student obtains data from the experiment and presents the data on the graph shown in Figure 14C.
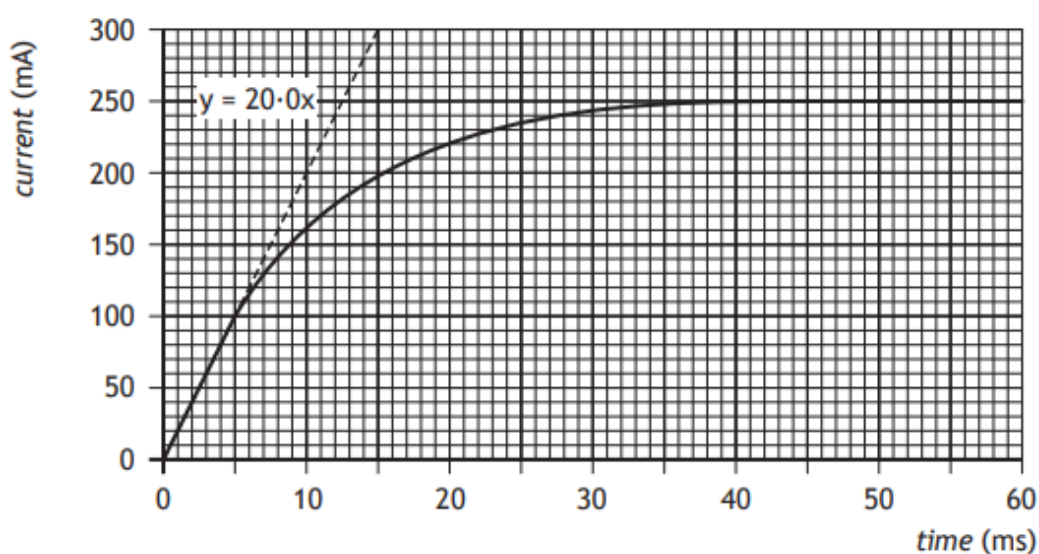

Figure 14C

(i) Determine the inductance of the inductor. **4**

(ii) The student was advised to include a diode in the circuit to prevent damage to the laptop when the switch is opened.

Explain why this is necessary. **1**

16. A student is investigating the charging and discharging of a capacitor. The circuit used is shown in Figure 16A.
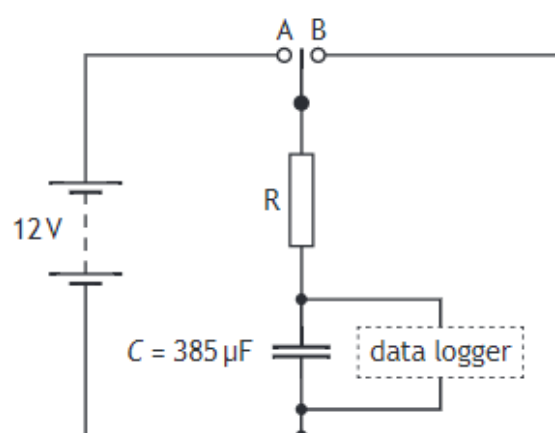

Figure 16A

With the switch in position A, the capacitor charges. To discharge the capacitor the switch is moved to position B. The data logger monitors the voltage across the capacitor.

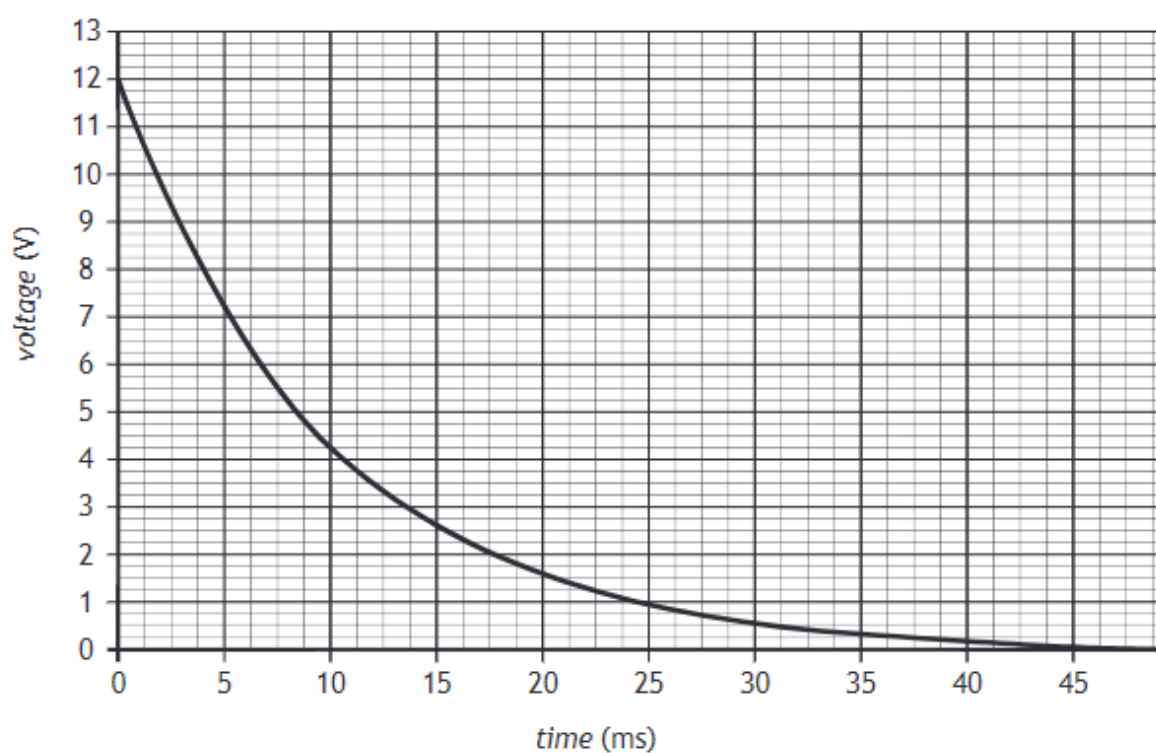The graph in Figure 16B shows how the voltage across the capacitor changes during discharge.

Figure 16B

(a) Determine the time constant from the graph. **2**

(b) Calculate the resistance of resistor R. **3**

CfE Specimen Paper

12. A student carries out a series of experiments to investigate properties of capacitors in a.c. circuits.

   (a) The student connects a 5·0 µF capacitor to an a.c. supply of e.m.f. $15\,V_{rms}$ and negligible internal resistance as shown in Figure 12A.
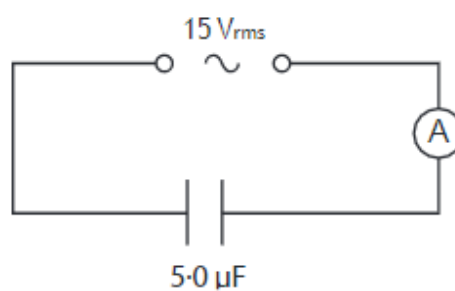
Figure 12A

The frequency of the a.c. supply is 65 Hz.

   (i) Calculate the reactance of the capacitor. **3**

(b) The student uses the following circuit to determine the capacitance of a second capacitor.
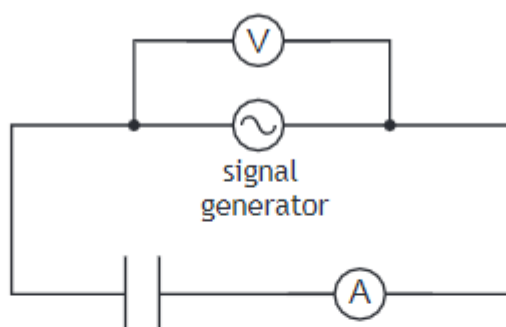

Figure 12B

The student obtains the following data.

Reactance (Ω)	Frequency (Hz)
$1\cdot60 \times 10^6$	10
$6\cdot47 \times 10^5$	40
$2\cdot99 \times 10^5$	100
$1\cdot52 \times 10^5$	200
$6\cdot35 \times 10^4$	500
$3\cdot18 \times 10^4$	1000

(i) On the square-ruled paper on *Page thirty*, plot a graph that would be suitable to determine the capacitance.

(ii) Use your graph to determine the capacitance of this capacitor.   **3**