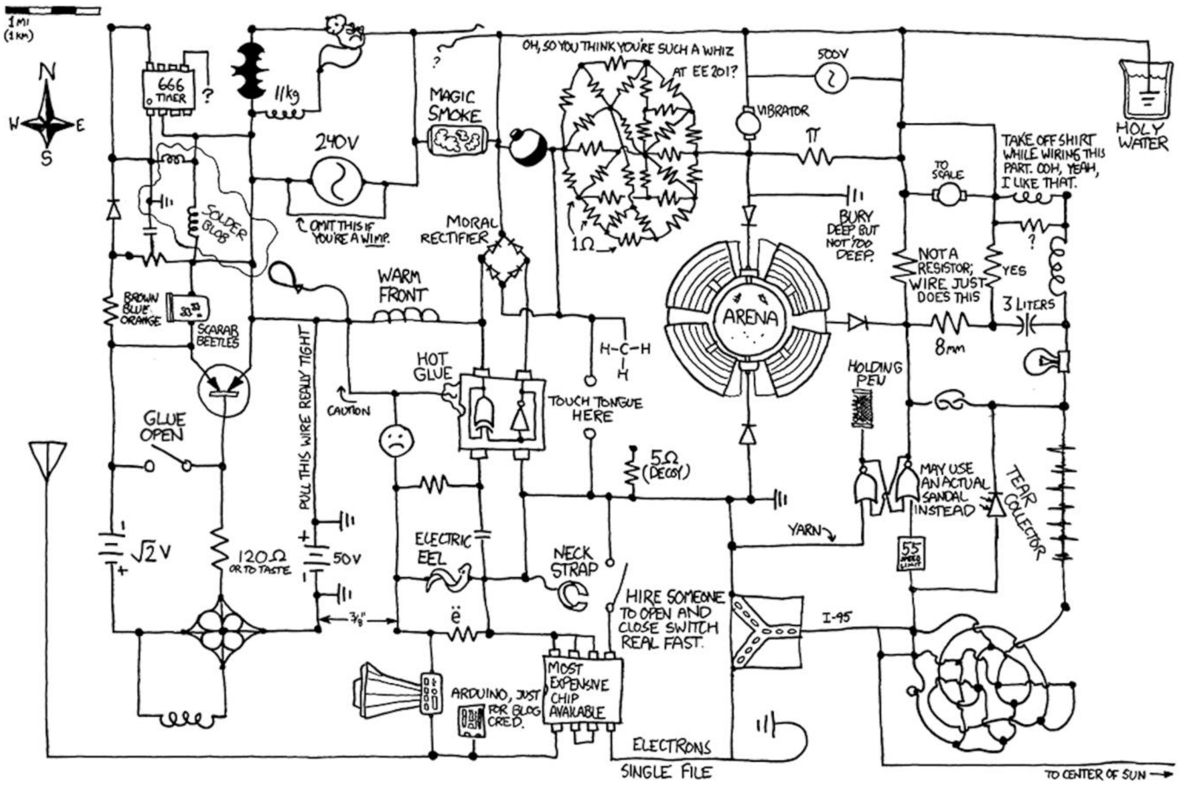
Advanced Higher Physics

Past Paper Questions

3.2 Circuits



12. A velocity selector is used as the initial part of a larger apparatus that is designed to measure properties of ions of different elements.

The velocity selector has a region in which there is a uniform electric field and a uniform magnetic field. These fields are perpendicular to each other and also perpendicular to the initial velocity v of the ions.

This is shown in Figure 12A.

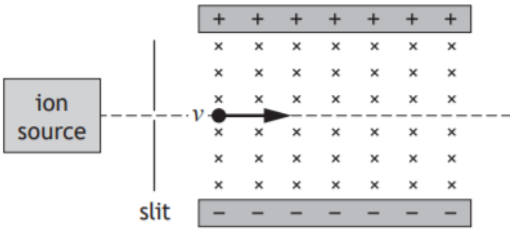


Figure 12A

A beam of chlorine ions consists of a number of isotopes including $^{35}Cl^{+}$.

The magnitude of the charge on a $^{35}Cl^{+}$ ion is $1{\cdot}60 \times 10^{-19}$ C.

The magnitude of electric force on a $^{35}Cl^{+}$ chlorine ion is $4{\cdot}00 \times 10^{-15}$ N.

The ions enter the apparatus with a range of speeds.

The magnetic induction is 115 mT.

(a) State the direction of the magnetic force on a $^{35}Cl^{+}$ ion. **1**

(b) By considering the electric and magnetic forces acting on a $^{35}Cl^{+}$ ion, determine the speed of the $^{35}Cl^{+}$ ions that will pass through the apparatus without being deflected. **3**

(c) $^{35}Cl^{+}$ ions that are travelling at a velocity less than that determined in (b) are observed to follow the path shown in Figure 12B.

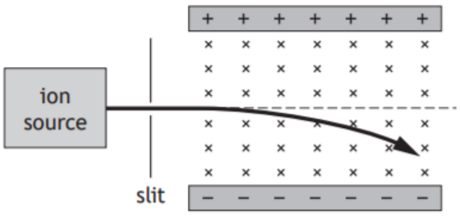


Figure 12B

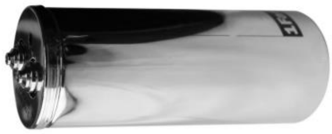
Explain, in terms of their velocity, why these ions follow this path. **2**

(d) $^{37}Cl^{2+}$ ions are also present in the beam. $^{37}Cl^{2+}$ ions have a greater mass and a greater charge than $^{35}Cl^{+}$ ions. Some $^{37}Cl^{2+}$ ions also pass through the apparatus without being deflected.

State the speed of these ions.

You must justify your answer. **2**

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.



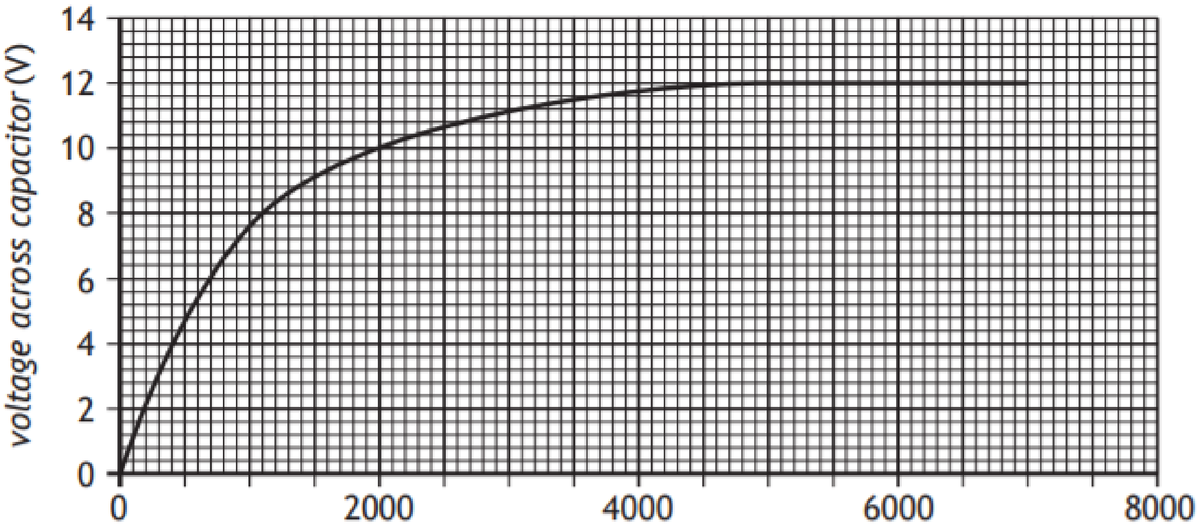
The instructions state that the capacitor must be fully charged from the 12 V d.c. car battery through a 1·0 kΩ series resistor.

(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.



(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 $8{\cdot}0\,\Omega$.

The circuit diagram is shown in Figure 14A.

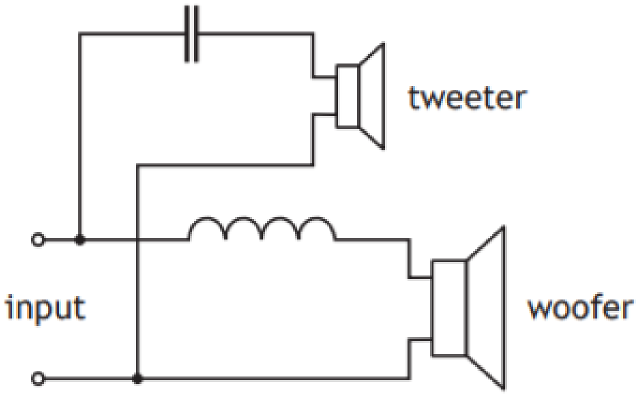


Figure 14A

The circuit is designed to have a "crossover" frequency of $3{\cdot}0\,\text{kHz}$: at frequencies above $3{\cdot}0\,\text{kHz}$ there is a greater current in the tweeter and at frequencies below $3{\cdot}0\,\text{kHz}$ 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 $8{\cdot}0\,\Omega$ when the frequency of the signal is $3{\cdot}0\,\text{kHz}$. **3**

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.

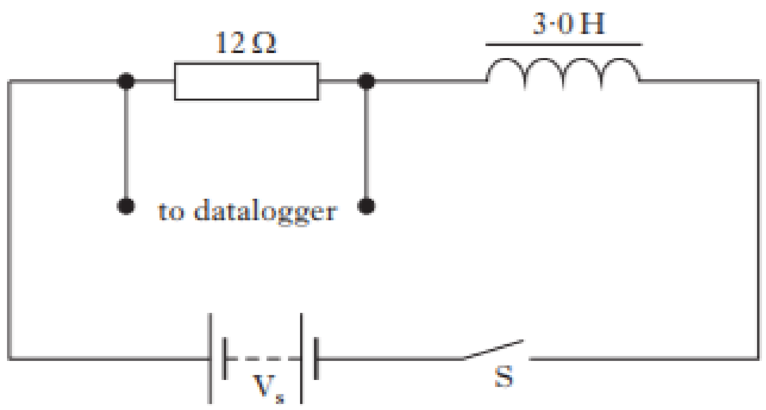


Figure 12A

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.

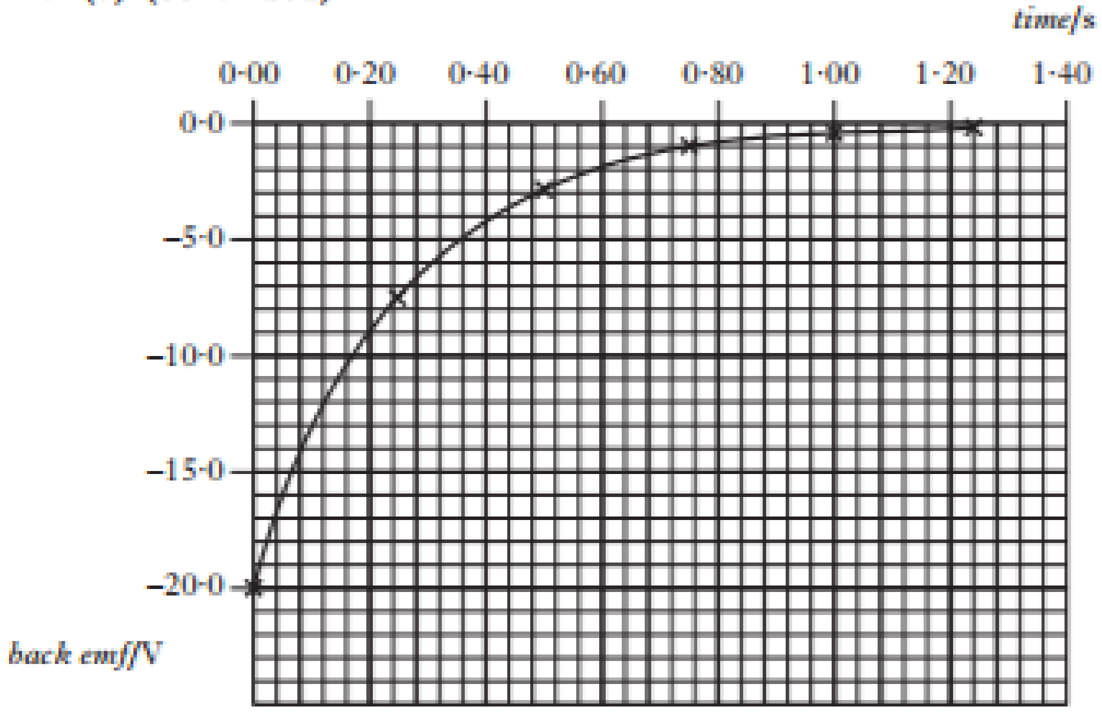


Figure 12B

(i) Determine the voltage across the resistor at $t = 0{\cdot}20$ s. **2**

(ii) Calculate the rate of change of current in the circuit at $t = 0{\cdot}40$ 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.

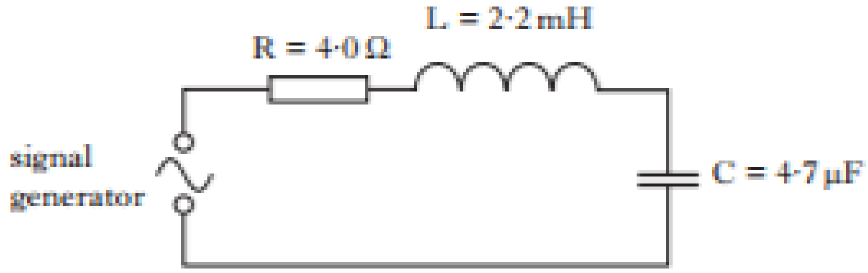


Figure 12C

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)

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.

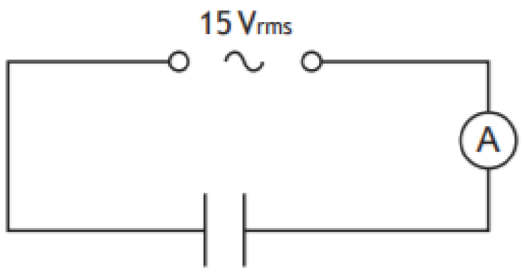


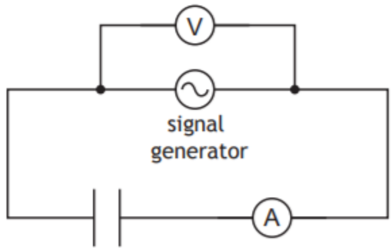
Figure 12A

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

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

(ii) Determine the value of the current in the circuit. **3**

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



The student obtains the following data.

Reactance (Ω)	*Frequency* (Hz)
$1{\cdot}60 \times 10^6$	10
$6{\cdot}47 \times 10^5$	40
$2{\cdot}99 \times 10^5$	100
$1{\cdot}52 \times 10^5$	200
$6{\cdot}35 \times 10^4$	500
$3{\cdot}18 \times 10^4$	1000

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

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

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

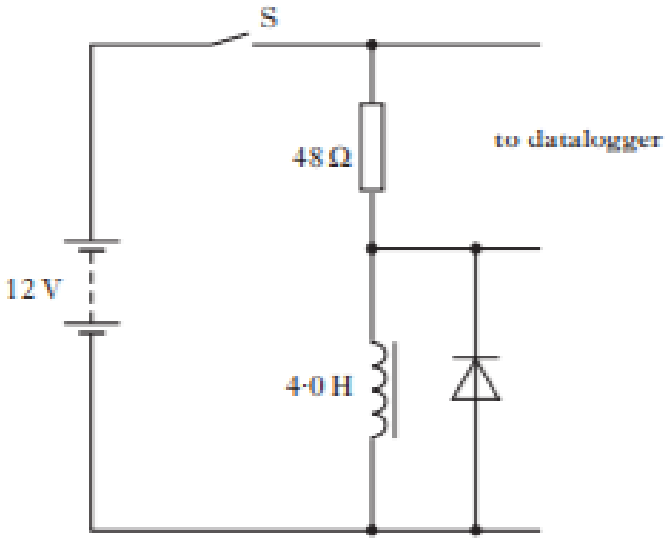


Figure 13A

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.

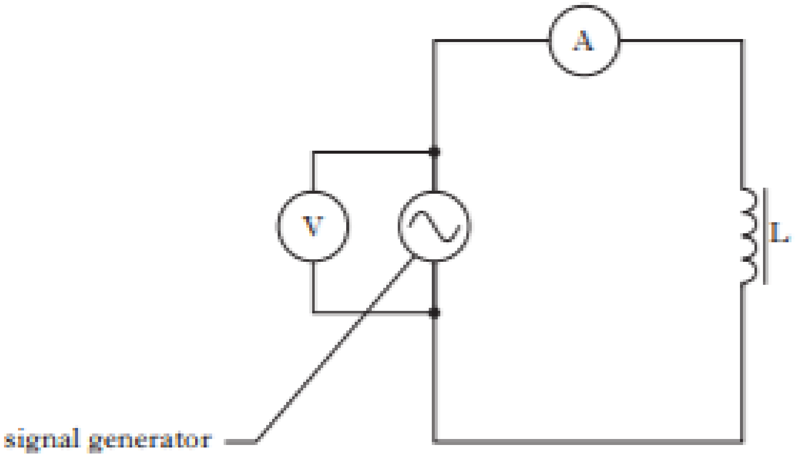


Figure 13B

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)

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

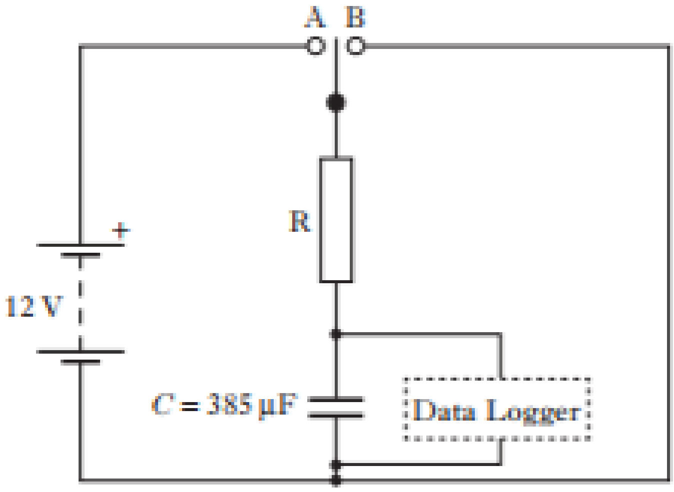


Figure 13A

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.

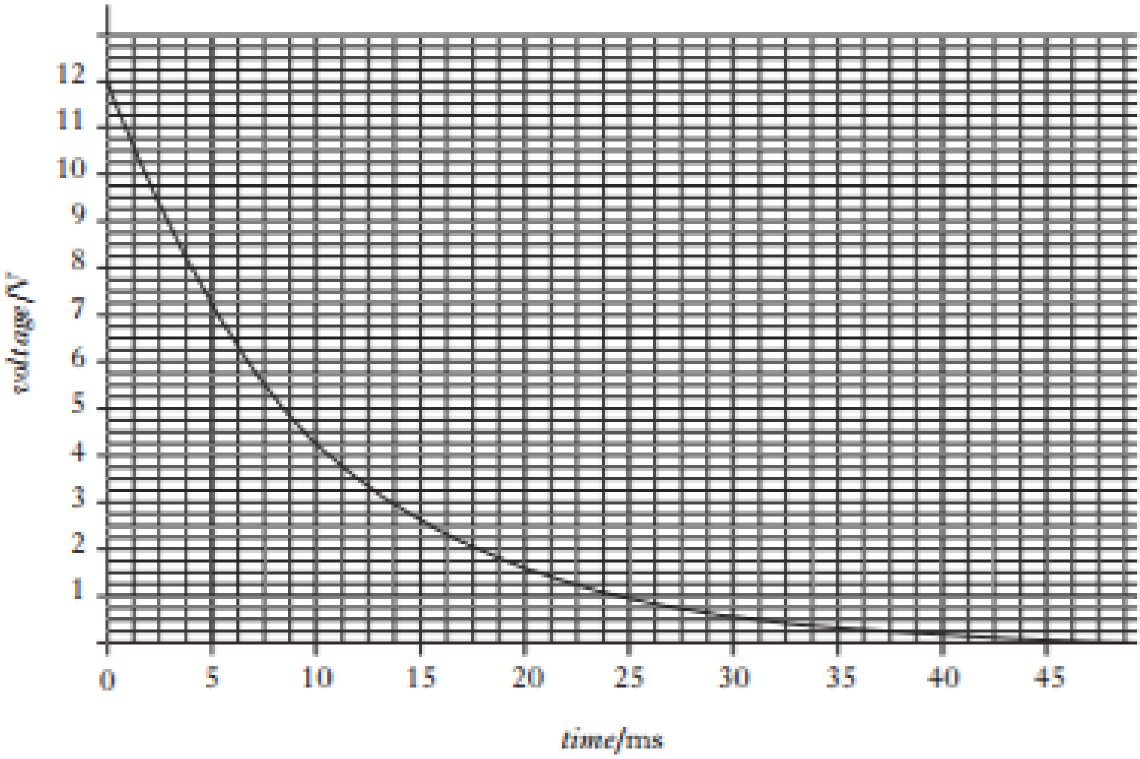


Figure 13B

(*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.

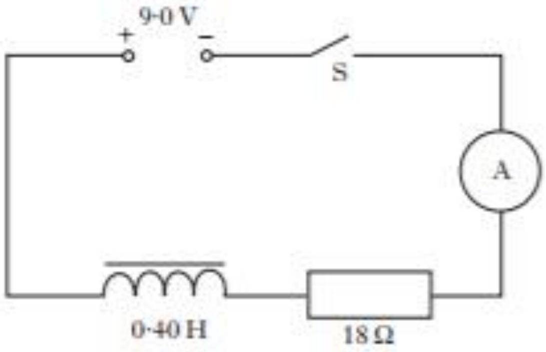


Figure 14

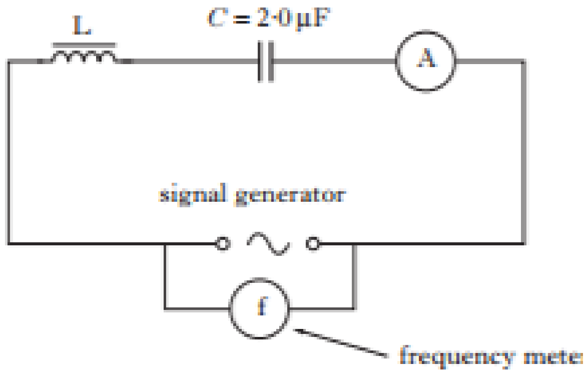
(*a*) (i) Sketch a graph of current against time after the switch S is closed. Numerical values are required on the current axis. 2

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

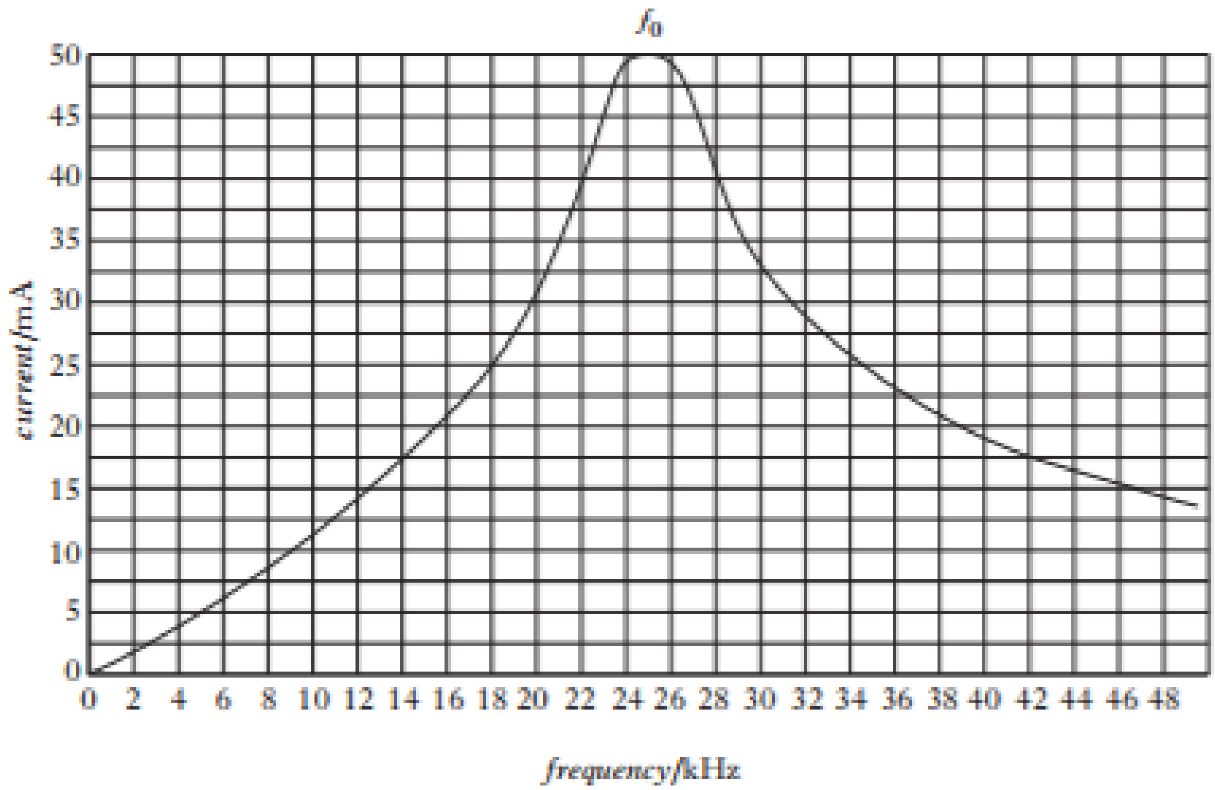
(*b*) Calculate the initial rate of change of current when switch S is closed. 2

(6)

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



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.



(*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 2·0 μF. 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)

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7. Precision inductors can be produced using laser technology.

A thin film of copper is deposited on a ceramic core. A carbon dioxide laser is then used to cut the copper to form a coil as shown in Figure 7A.

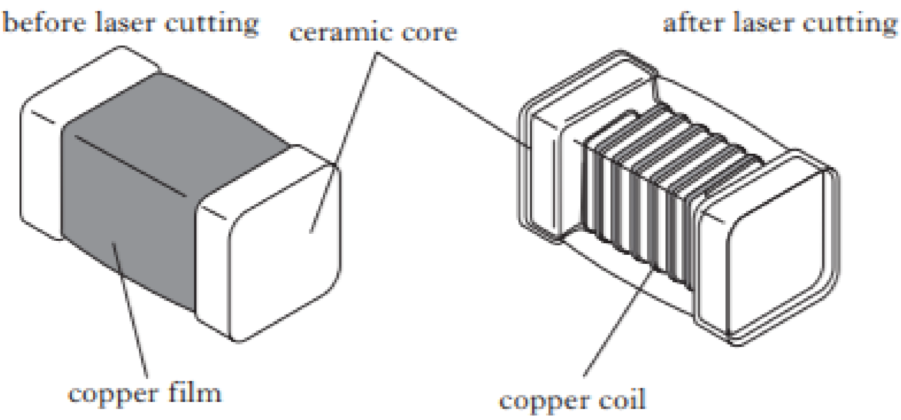


Figure 7A

(*a*) Each photon from the laser has a momentum of $6{\cdot}26 \times 10^{-29}$ kg m s^{-1}.

(i) Calculate the wavelength of each photon. **2**

(ii) The inductor has an inductance of 0·1 H.

Explain what is meant by an inductance of 0·1 H. **1**

(*b*) The rate of change of current for a **different inductor** is investigated using a datalogger as shown in Figure 7B. This inductor has inductance L and a resistance of 2 Ω.

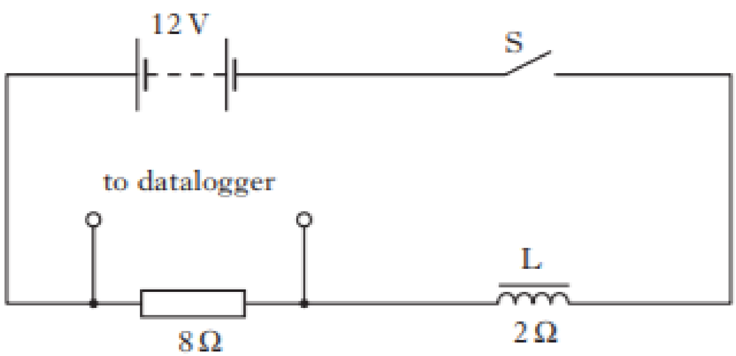


Figure 7B

The graph shown in Figure 7C shows how the rate of change of current dI/dt in the circuit varies with time from the instant switch S is closed.

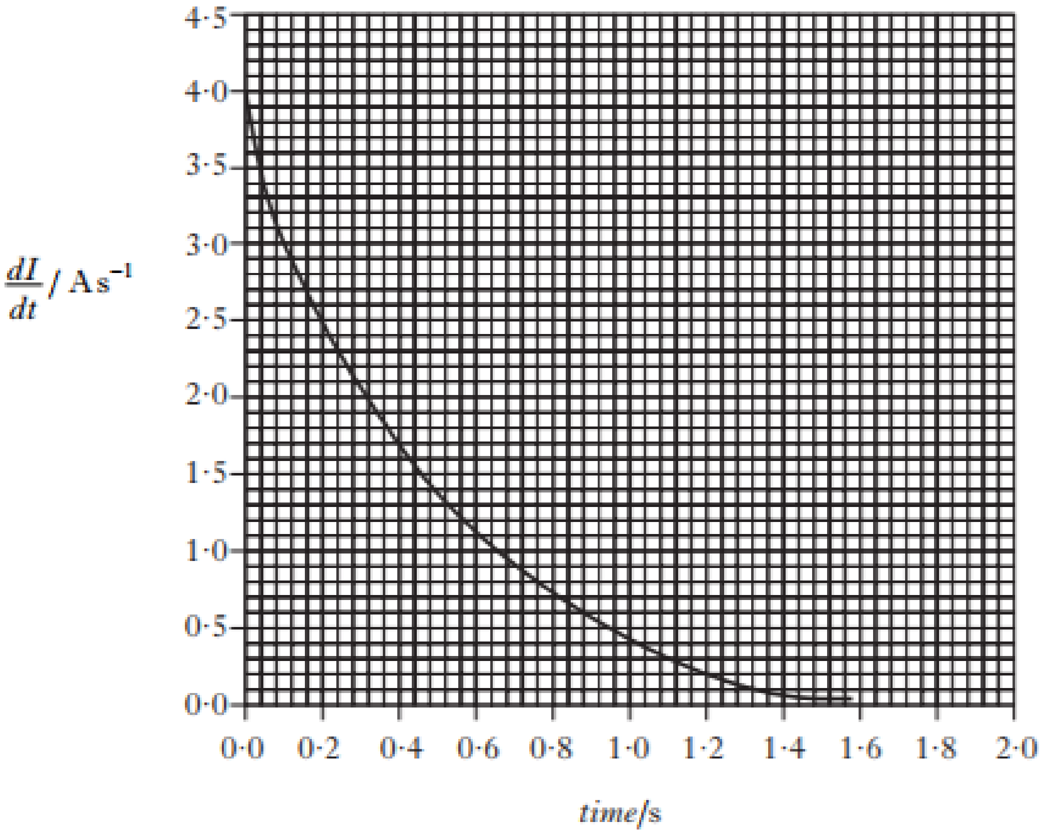


Figure 7C

(i) Describe what happens to the magnetic field strength associated with the inductor between 0 and 1·6 s. **1**

(ii) Use information from the graph to determine the inductance L. **2**

(iii) Sketch a graph to show how the voltage across the 8 Ω resistor varies during this time. Numerical values are required on both axes. **2**

(iv) Calculate the maximum energy stored by the inductor in this circuit. **2**

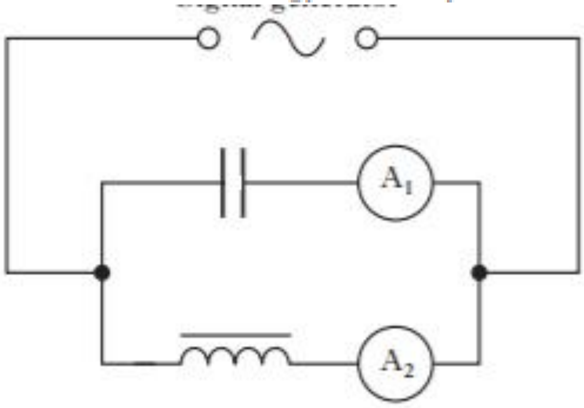


Figure 7D

At frequency of 75 Hz the readings on A_1 and A_2 are the same.

Explain what happens to the readings on each ammeter as the frequency is increased from 75 Hz to 150 Hz.

Assume that the supply voltage remains constant. **2**

(12)

Traditional 2011

Marks

6. Modern trains have safety systems to ensure that they stop before the end of the line. One system being tested uses a relay operated by a reed switch. The reed switch closes momentarily as it passes over a permanent magnet laid on the track. An inductor in the relay activates the safety system as shown in

Marks

6. (a) A 3·0 V battery is connected in series with a switch, a resistor and an inductor of negligible resistance. A neon lamp is connected across the inductor as shown in Figure 6A.

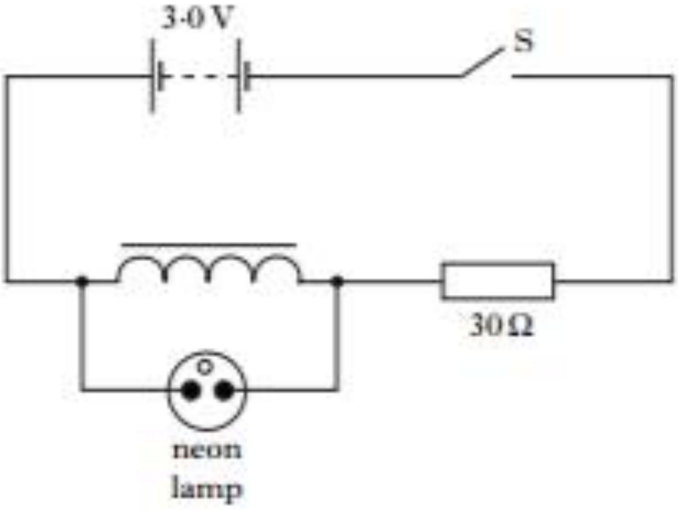


Figure 6A

(i) Sketch a graph to show how the current in the inductor varies with time from the instant the switch is closed.

Appropriate numerical values are required on the current axis. **2**

(ii) The neon lamp requires a potential difference of at least 110 V across it before it lights.

Explain why the lamp does not light when the switch is closed. **1**

(iii) After a few seconds the switch is opened and the lamp flashes.

Explain, in terms of the magnetic field, why the lamp flashes as the switch is opened. **2**

(iv) The neon lamp has an average power of 1·2 mW and a flash that lasts 0·25 s.

Assuming all the energy stored by the inductor is transferred to the lamp, calculate the inductance of the inductor. **3**

6. (continued)

(*b*) Figure 6B shows a circuit used to investigate the relationship between the current in an inductive circuit and the supply frequency.

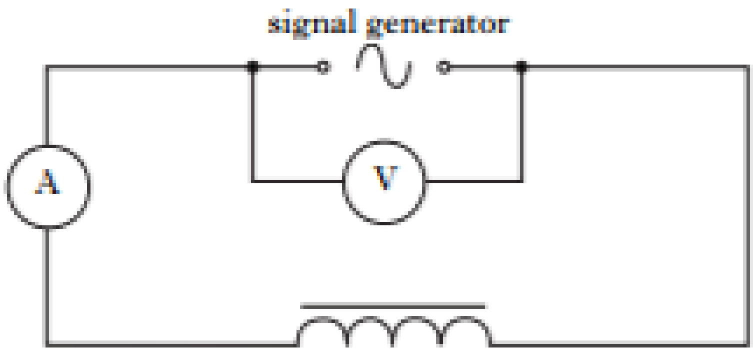


Figure 6B

The reading on the ammeter is noted for different values of supply frequency.

(i) State the purpose of the voltmeter. **1**

(ii) Describe how the data obtained should be analysed to determine the relationship between the current in the inductive circuit and the supply frequency. **1**

(iii) State the expected relationship. **1**

(*c*) A loudspeaker system is connected to a music amplifier. The system contains a capacitor, inductor and two loudspeakers, LS1 and LS2, as shown in Figure 6C.

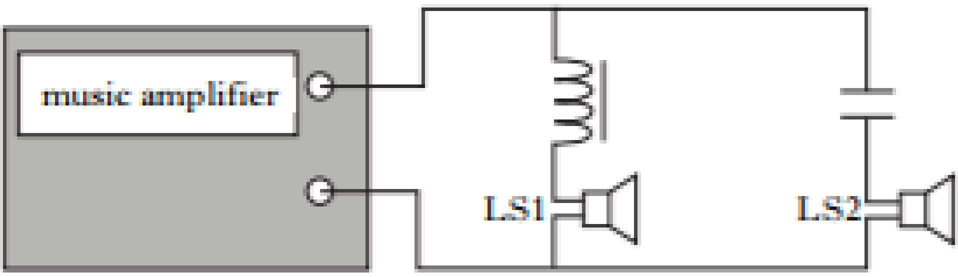


Figure 6C

The circuit is designed so that one loudspeaker emits low frequency sounds while the other emits high frequency sounds.

By comparing the capacitive and inductive reactances, describe the operation of this system. **2**

(13)

Marks

7. An inductor of negligible resistance is connected in the circuit shown in Figure 11.

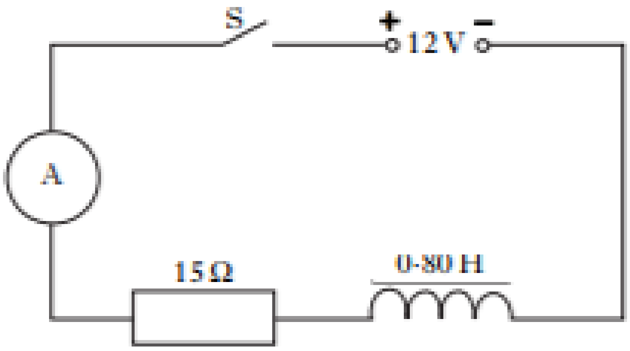


Figure 11

(*a*) The inductor has an inductance of 0·80 H.
Switch S is closed.

(i) Explain why there is a time delay before the current reaches its maximum value. **1**

(ii) Calculate the maximum current in the circuit. **2**

(iii) Calculate the maximum energy stored in the inductor. **2**

(iv) Calculate the rate of change of current when the current in the circuit is 0·12 A. **3**

(*b*) Switch S is opened and the iron core is removed from the inductor. Switch S is now closed.

(i) Will the maximum current be bigger, smaller or the same as the maximum current calculated in (*a*)(ii)? **1**

(ii) Explain any change in the time delay to reach the maximum current. **2**

(iii) Explain why the maximum energy stored in the inductor is less than in (*a*)(iii). **1**

(*c*) The iron core is replaced in the inductor. The d.c. supply is replaced with a variable frequency supply as shown in Figure 12.

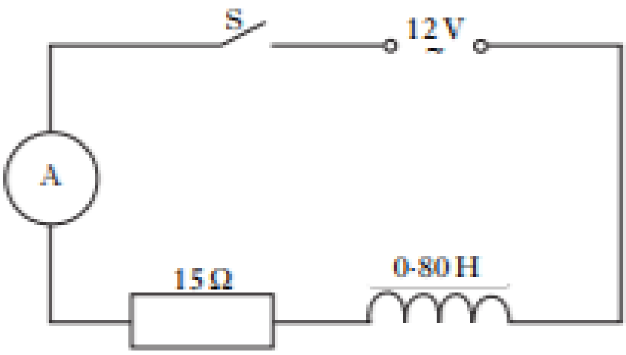


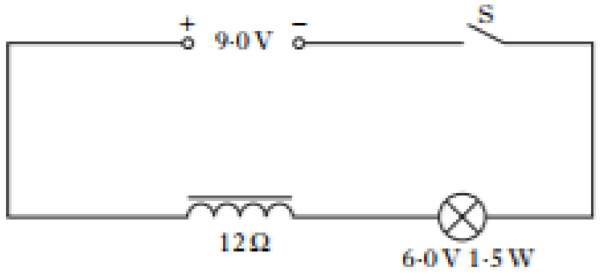
Figure 12

Sketch a graph to show how the current in the circuit varies with the frequency of the supply. Numerical values are not required. **1**

(13)

Marks

7. (*a*) Figure 11 shows a d.c. power supply in series with a switch, lamp and inductor.



The inductor consists of a coil of wire with a resistance of 12 Ω.
The lamp is rated at 6·0 V 1·5 W.
The 9·0 V d.c. power supply has negligible internal resistance.

(i) Explain why the lamp does not reach its maximum brightness immediately after the switch is closed. **2**

(ii) When the lamp reaches its maximum brightness it is operating at its stated power rating.

Calculate the current in the circuit. **1**

(iii) The maximum energy stored in the inductor is 75 mJ.

Calculate the inductance of the inductor. **2**

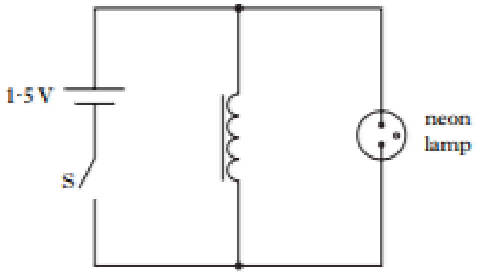
(iv) The inductor in Figure 11 is replaced with another inductor which has the same type of core and wire, but with twice as many turns.

State the effect this has on:

(A) the maximum current;

(B) the time to reach maximum current. **2**

(*b*) Figure 12 shows a neon lamp connected to an inductor, switch and a 1·5 V cell.



A neon lamp needs a potential difference of at least 80 V across it before it lights.
The switch is closed for 5 seconds.
The switch is then opened and the neon lamp flashes **briefly**.

Explain this observation. **2**

Marks

8. A datalogger is used to investigate the rate of change of current in the circuit shown in Figure 12.

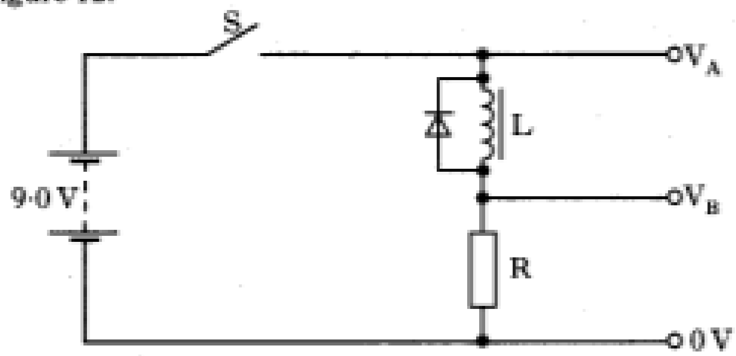


Figure 12

(a) The datalogger measures the potential V_A and the potential V_B.

What other piece of information is required to allow the computer software to determine the current in the circuit? **1**

(b) The switch S is closed and the datalogger software produces the graph shown in Figure 13.

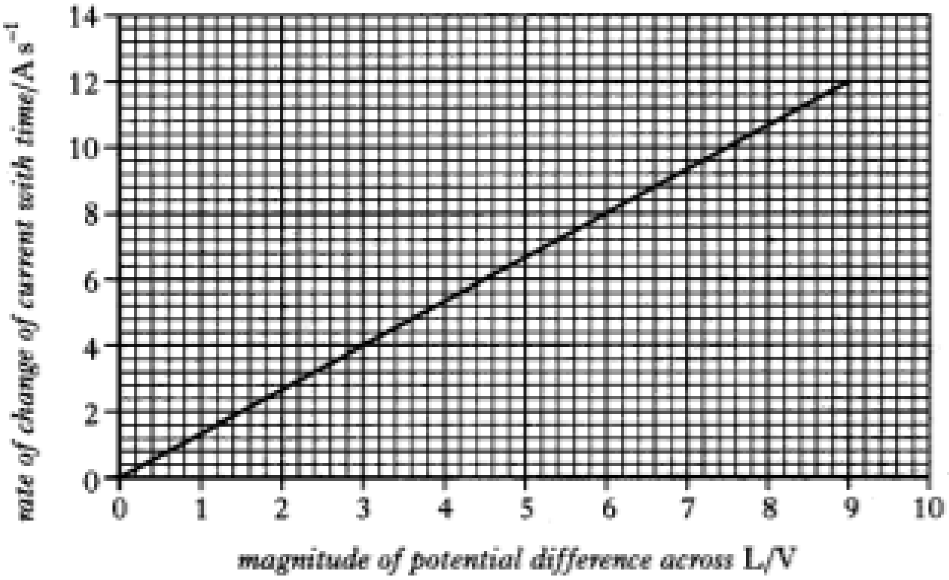


Figure 13

Assuming that the resistance of the inductor is negligible, calculate its inductance. **2**

(c) The current in the circuit eventually reaches a steady value of 100 mA.

Calculate the energy stored in the magnetic field of the inductor. **2**

(d) The diode in the circuit is necessary to protect the datalogger against the high voltage which can arise when the switch S is opened.

Explain why this high voltage is produced. **1**

(6)

Marks

8. (a) A coil of wire has an inductance of 2·0 H. State what is meant by *an inductance of 2·0 H*. **1**

(b) Figure 14 shows a circuit containing an inductor with negligible resistance, a resistor, switch and d.c. power supply connected in series. The d.c. power supply has negligible internal resistance.

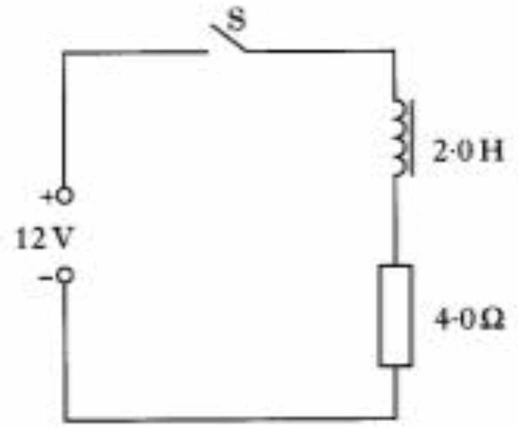


Figure 14

Calculate the rate of change of current immediately after switch S is closed. **2**

(c) A similar circuit, with some component values changed, is shown in Figure 15.

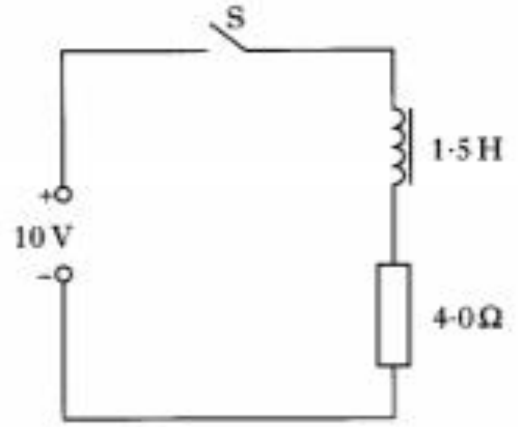


Figure 15

(i) Switch S is closed.
State **two** ways that the current in this circuit differs from the current in the circuit shown in Figure 14. **Justify your answers**. **2**

(ii) Calculate the maximum energy stored in the 1·5 H inductor. **2**

Marks

8. (continued)

(*d*) An airport metal detector consists of two fixed coils as shown in Figure 16.

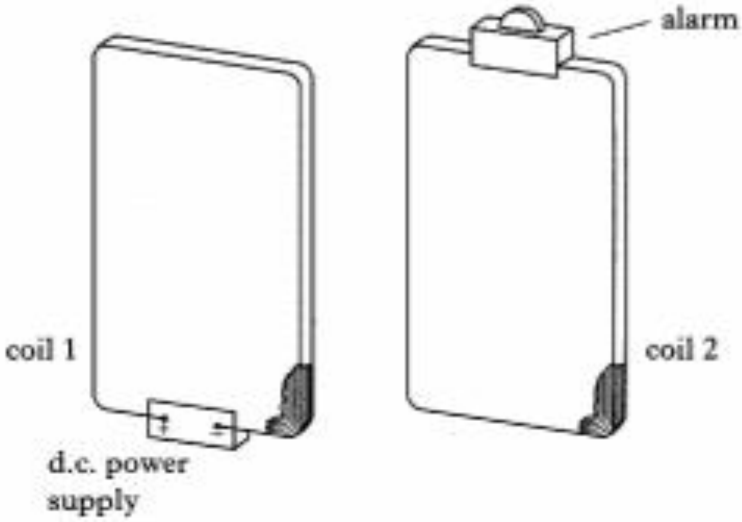


Figure 16

A d.c. power supply provides a current in coil 1.

Coil 2 has no power supply but is connected to an alarm. The alarm triggers when there is a current in coil 2.

A passenger wearing a gold bracelet walks between the coils as shown in Figure 17.

Figure 17

Explain why:

(i) a current is induced in the gold bracelet; 1

(ii) this triggers the alarm. 1

(9)

Marks

9. An inductor of negligible resistance is connected in the circuit shown in Figure 12.

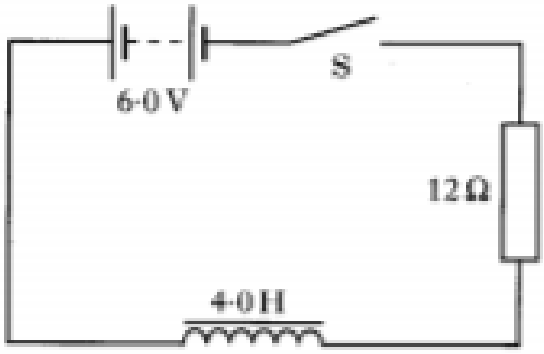


Figure 12

(*a*) Sketch a graph to show how the potential difference across the resistor varies with time after switch S is closed. A numerical scale is required on the potential difference axis. **2**

(*b*) At a point in time after switch S is closed, the current in the circuit is 0·20 A. Calculate the rate of change of current at this time. **3**

(5)

Marks

10. Two long parallel conductors, distance r apart, carry currents I_1 and I_2.

(*a*) Show that the force per unit length acting on each conductor is given by

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

where the symbols have their usual meanings. **2**

(*b*) In some countries direct current is used for transmitting power over long distances. Two direct current transmission cables each carry a current of 850 A. The currents are in opposite directions as shown in Figure 13.

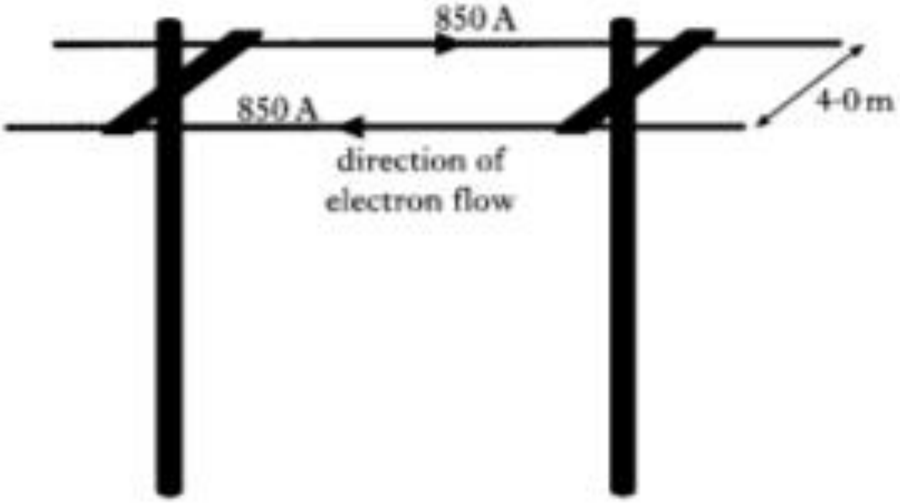


Figure 13

The cables are parallel and are separated by a distance of 4·0 m.

(i) Calculate the force per unit length between the cables due to the currents in the cables.

(ii) Does this force tend to move the cables together or apart?

(iii) Determine the magnitude **and** direction of the resultant magnetic induction, due to both cables, at a point midway between the cables. **5**

Marks

10. (continued)

(*c*) The direction of the Earth's magnetic field is at an angle of 60 degrees to one cable, as shown in Figure 14.

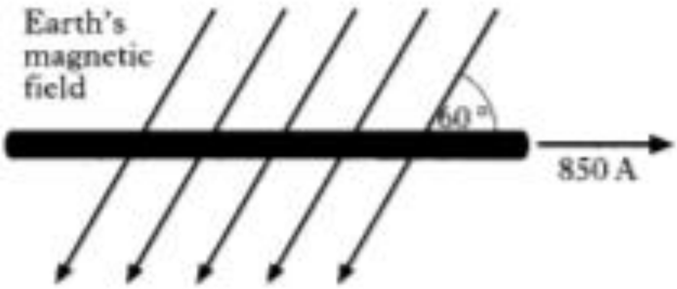


Figure 14

In the region of the cable, the magnetic induction of the Earth's field is 52 μT. Calculate the force per unit length on this cable due to the Earth's magnetic field and the current in this cable. **2**

(9)

Marks

7. (*a*) A long straight conductor PQ carries a current of 0·50 A.

Calculate the magnetic induction at a point 120 mm from the conductor. **2**

(*b*) A second long straight conductor RS is placed 120 mm from PQ. The conductors are parallel as shown in Figure 14.

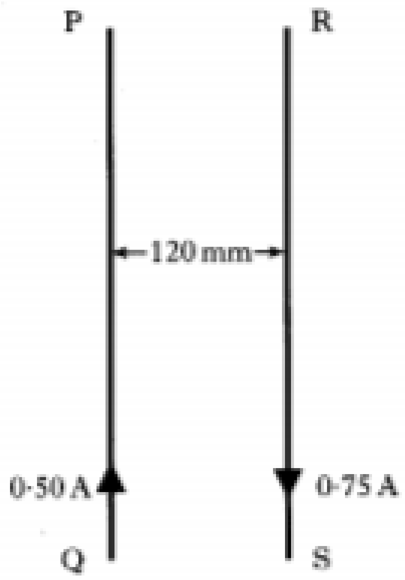


Figure 14

Conductor RS carries a current of 0·75 A in the opposite direction to the current in PQ.

Determine the magnitude and **direction** of the force per unit length exerted on conductor RS by conductor PQ. **3**

(5)

Marks

9. (*a*) The circuit shown in Figure 16 contains an inductor, a resistor and a switch connected in series with a cell of e.m.f. 2·0 V.

The cell has negligible internal resistance and the resistance of the inductor is negligible.

The current in the circuit is measured using a computer interface.

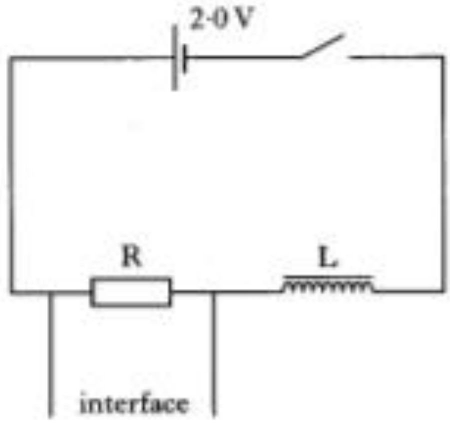


Figure 16

The switch is closed and the graph shown in Figure 17 is displayed on the computer screen.

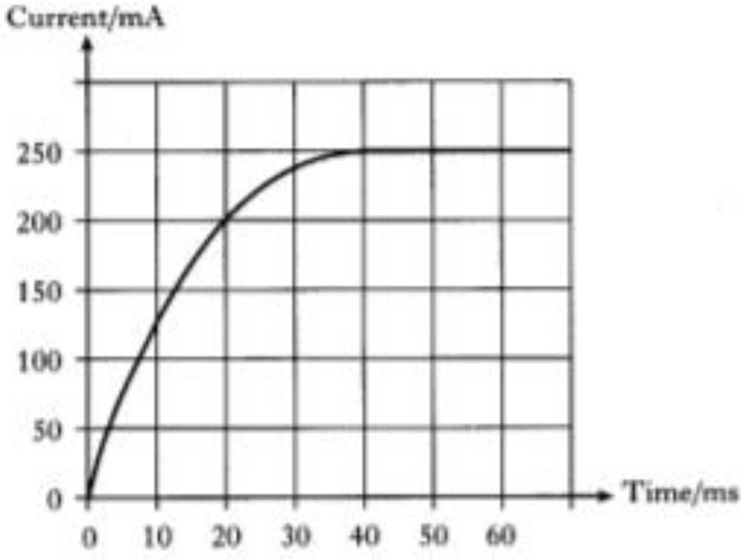


Figure 17

(i) Explain why there is a time delay in the current reaching its steady value.

(ii) Calculate the resistance of the circuit.

(iii) From the graph, the initial rate of change of current is estimated to be $20\ \text{A s}^{-1}$.

Calculate the self inductance of the coil.

(iv) Calculate the maximum energy stored in the inductor. **7**

Marks

9. **(continued)**

(*b*) A resistor and an inductor are connected in series to a variable frequency supply as shown in Figure 18.

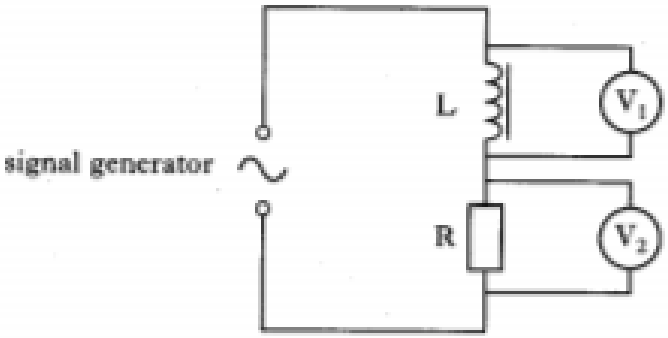


Figure 18

The supply voltage is kept constant as the frequency of the supply is increased.

State and **explain** the changes in the readings on voltmeters V_1 and V_2. **3**

(10)

Marks

9. In the circuit shown in Figure 7 the battery has e.m.f. 12 V and negligible internal resistance. The resistance of the inductor can be ignored.

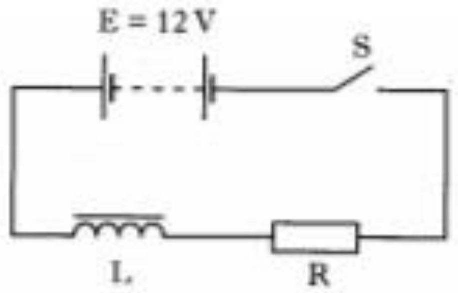


Figure 7

The graph in Figure 8 shows the growth of current in the circuit after switch S is closed.

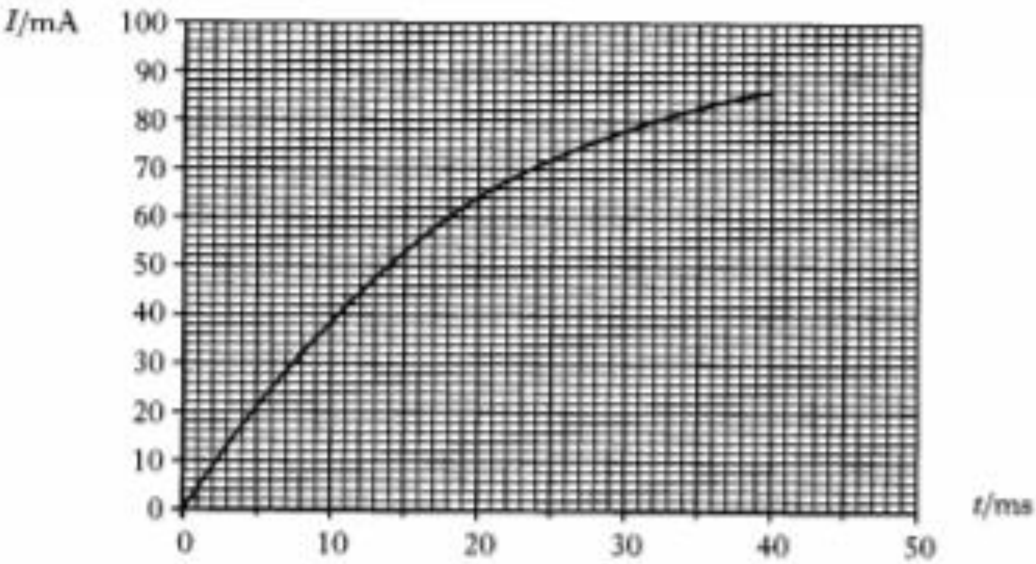


Figure 8

(*a*) State the magnitude of the back e.m.f. at the instant the switch is closed. **1**

(*b*) Use the graph to determine the initial rate of change of current. **1**

(*c*) Calculate the self-inductance of the coil. **2**

(*d*) The final steady current is 96 mA. Calculate the resistance of resistor R. **2**

(*e*) Calculate the maximum energy stored in the inductor. **2**

(8)

6. The force on a current carrying conductor in a magnetic field can be measured using a top pan balance.

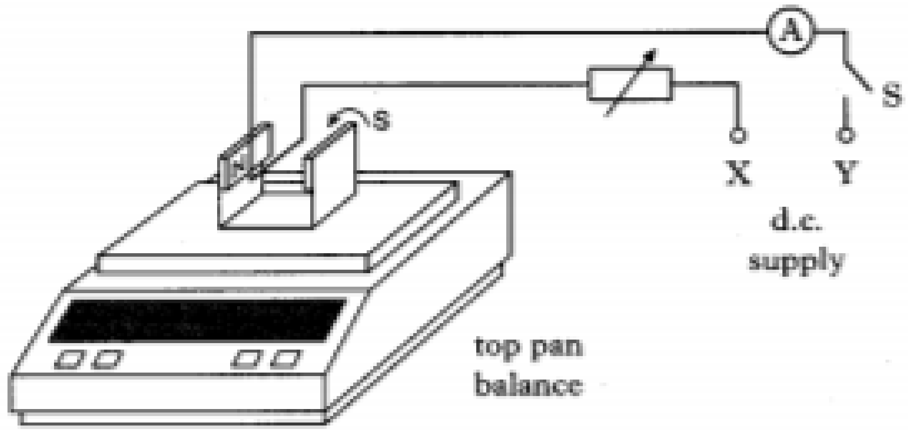


Figure 11

A magnet is placed on the balance. A rigid copper wire is clamped so that it remains in a fixed position between the poles of the magnet as shown in Figure 11.

(a) The reading on the balance increases when the switch S is closed.

State the polarities of X and Y. **1**

(b) With no current in the wire, the balance is zeroed.

The reading on the balance is recorded for several values of current. These readings and the associated uncertainties are shown in the following table.

Current/mA	0	100 ± 10	200 ± 10	300 ± 10	400 ± 10	500 ± 10	600 ± 10
Reading on balance/mg	0 ± 1	11 ± 1	25 ± 2	35 ± 2	48 ± 2	58 ± 3	75 ± 3

Figure 12 shows the corresponding graph with the best fit line for the readings.

(i) Calculate the gradient of this line.

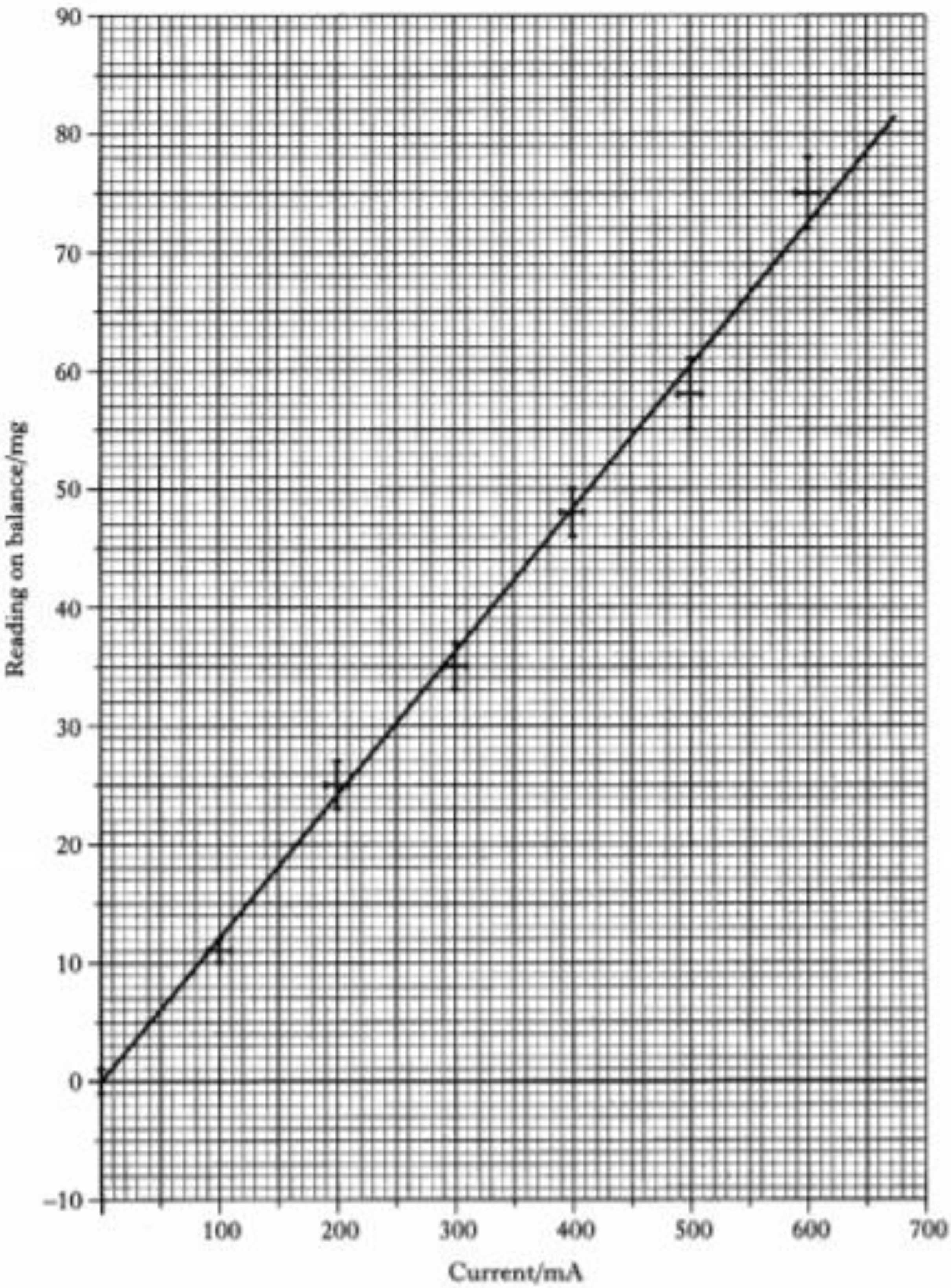
(ii) Calculate the absolute uncertainty in the gradient. **5**

(c) The horizontal part of the rigid copper wire in the magnetic field has a length of 0·060 m. It is fixed at right angles to the direction of the magnetic induction. Use the information obtained from Figure 12 to calculate the magnetic induction between the poles of the magnet.

The uncertainty in the magnetic induction is **not** required. **3**

(9)

6. (continued)



90
80
70
60
50
40
30
20
10
0
−10
Reading on balance/mg
100
200
300
400
500
600
700
Current/mA

Marks

8. The circuit shown in Figure 14 contains an inductor, resistor and switch in series with a d.c. supply.

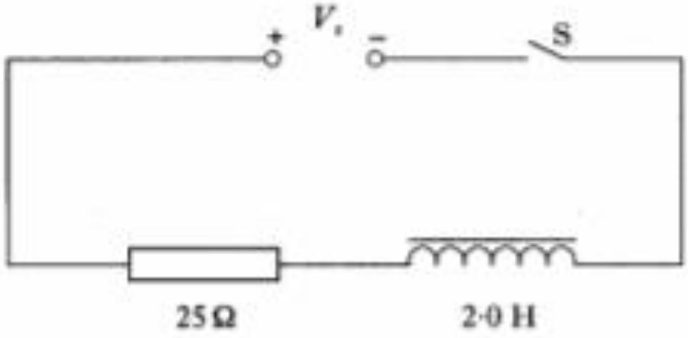


Figure 14

The 2·0 H inductor has negligible resistance.

Switch S is closed. The current reaches a maximum value of 400 mA after a time of 1·5 seconds.

(a) Explain why the current does not reach its maximum value immediately. **2**

(b) Calculate:

(i) the supply voltage V_s;

(ii) the maximum rate of change of current;

(iii) the maximum energy stored in the inductor. **6**

(c) Switch S is now opened and a spark occurs across the contacts of the switch. Explain why this happens. **2**

(10)