Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

9063669085

PHYSICS **9702/42**

Paper 4 A Level Structured Questions **May/June 2021**

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS
- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION
- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **28** pages. Any blank pages are indicated.

DC (MS/JG) 197911/5

Data

speed of light in free space	$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
	$(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\mathrm{m\,F^{-1}})$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$
unified atomic mass unit	$1\,\mathrm{u} = 1.66 \times 10^{-27}\,\mathrm{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall	$g = 9.81\,\mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
gravitational potential	$\phi = -\frac{Gm}{r}$
hydrostatic pressure	$p = \rho gh$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega\sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy of charged capacitor	$W = \frac{1}{2}QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

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Answer **all** the questions in the spaces provided.

1 **(a)** Define *gravitational field strength*.

....

.... [1]

(b) An isolated planet is a uniform sphere of radius 3.39×10^6 m. Its mass of 6.42×10^{23} kg may be considered to be a point mass concentrated at its centre. The planet rotates about its axis with a period of 24.6 hours.

For an object resting on the surface of the planet at the equator, calculate, to three significant figures:

(i) the gravitational field strength

field strength = ... N kg^{-1} [2]

(ii) the centripetal acceleration

acceleration = ... m s^{-2} [2]

(iii) the force per unit mass exerted on the object by the surface of the planet.

force per unit mass = ... N kg^{-1} [1]

[Total: 6]

2 An ideal gas has a volume of $3.1 \times 10^{-3}\,\text{m}^3$ at a pressure of $8.5 \times 10^5\,\text{Pa}$ and a temperature of 290 K, as shown in Fig. 2.1.

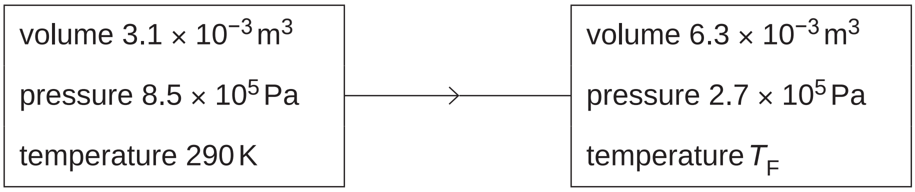

Fig. 2.1

The gas suddenly expands to a volume of $6.3 \times 10^{-3}\,\text{m}^3$. During the expansion, no thermal energy is transferred. The final pressure of the gas is $2.7 \times 10^5\,\text{Pa}$ at temperature T_F, as shown in Fig. 2.1.

(a) Show that the number of gas molecules is 6.6×10^{23}.

[3]

(b) **(i)** Show that the final temperature T_F of the gas is 190 K.

[1]

(ii) The average translational kinetic energy E_K of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where T is the thermodynamic temperature and k is the Boltzmann constant.

Calculate the increase in internal energy ΔU of the gas.

ΔU = ... J [3]

(c) Use the first law of thermodynamics to explain why the external work w done on the gas during the expansion is equal to the increase in internal energy in **(b)(ii)**.

....

....

.... [2]

[Total: 9]

3 A U-shaped tube contains some liquid. The liquid column in each half of the tube has length L, as shown in Fig. 3.1.

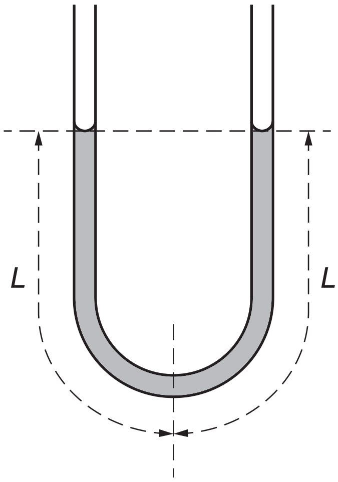

Fig. 3.1

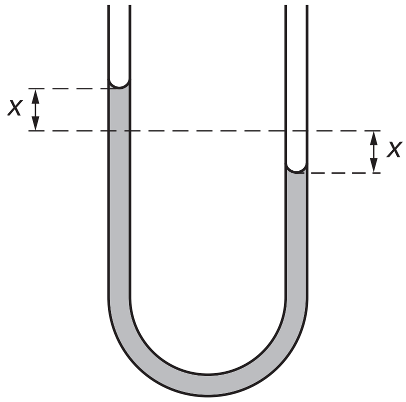

Fig. 3.2

The liquid columns are displaced vertically. The liquid then oscillates in the tube. The liquid levels are displaced from the equilibrium positions as shown in Fig. 3.2.

The acceleration a of the liquid in the tube is related to the displacement x by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where g is the acceleration of free fall.

(a) Explain how the expression shows that the liquid in the tube is undergoing simple harmonic motion.

....

....

....

....

.... [3]

(b) The length L of each liquid column is 18 cm.

Determine the period T of the oscillations.

T = ... s [3]

(c) The oscillations of the liquid in the tube are damped.
In any one complete cycle of the oscillations, the amplitude decreases by 6.0% of its value at the beginning of the oscillation.

Determine the ratio

$$\frac{\text{energy of oscillations after 3 cycles}}{\text{initial energy of oscillations}}\ .$$

ratio = ... [3]

[Total: 9]

4 **(a)** A sinusoidal carrier wave has a constant amplitude and a frequency of 1.2 MHz. The carrier wave is modulated by a signal wave such that a 1.0 V displacement of the signal wave causes a change in frequency of 25 kHz.

The signal wave has frequency 8.0 kHz and amplitude 2.0 V.

(i) State the name of this type of modulation of the carrier wave.

.... [1]

(ii) For this modulated carrier wave, determine the variation, if any, in:

1. its amplitude

....

....

2. its frequency.

....

....

....
[3]

(b) An audio signal is transmitted by means of a modulated radio wave.

The variation with frequency of the amplitude of the radio wave is shown in Fig. 4.1.

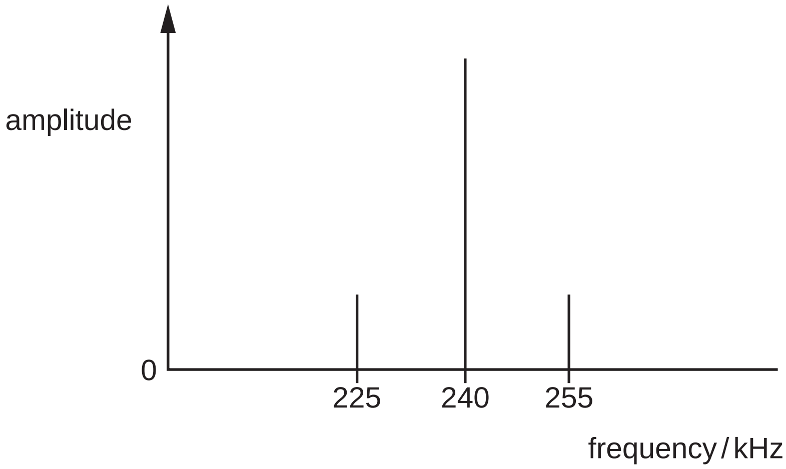

Fig. 4.1

For this transmission, determine:

(i) the wavelength, in km, of the carrier wave

wavelength = ... km [2]

(ii) the bandwidth

bandwidth = ... kHz [1]

(iii) the frequency of the audio signal.

frequency = ... kHz [1]

[Total: 8]

5 **(a)** An isolated metal sphere of radius r is charged so that the electric potential at its surface is V_0.

On Fig. 5.1, sketch the variation with distance x from the centre of the sphere of the electric potential. Your graph should extend from $x = 0$ to $x = 3r$.

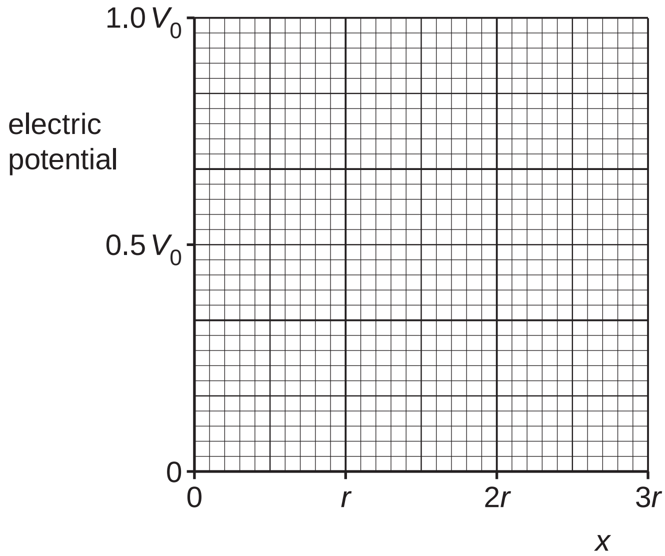

Fig. 5.1

[3]

(b) Photons having wavelength λ are incident on a metal surface.
The maximum wavelength for which there is emission of electrons is λ_0.
For photons of wavelength $\frac{\lambda_0}{2}$, the maximum kinetic energy of the emitted electrons is E_{MAX}.

On Fig. 5.2, sketch the variation with wavelength λ of the maximum kinetic energy for values of wavelength between $\lambda = \frac{\lambda_0}{3}$ and $\lambda = \lambda_0$.

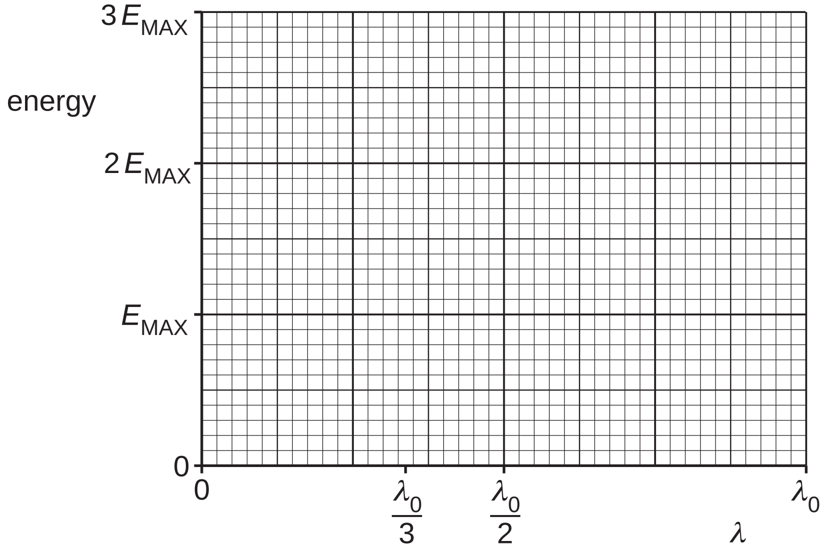

Fig. 5.2

[3]

(c) A pure sample of a radioactive isotope contains N_0 nuclei. The half-life of the isotope is $T_{\frac{1}{2}}$. The product of the radioactive decay is stable.

The variation with time t of the number N of nuclei of the radioactive isotope is shown in Fig. 5.3.

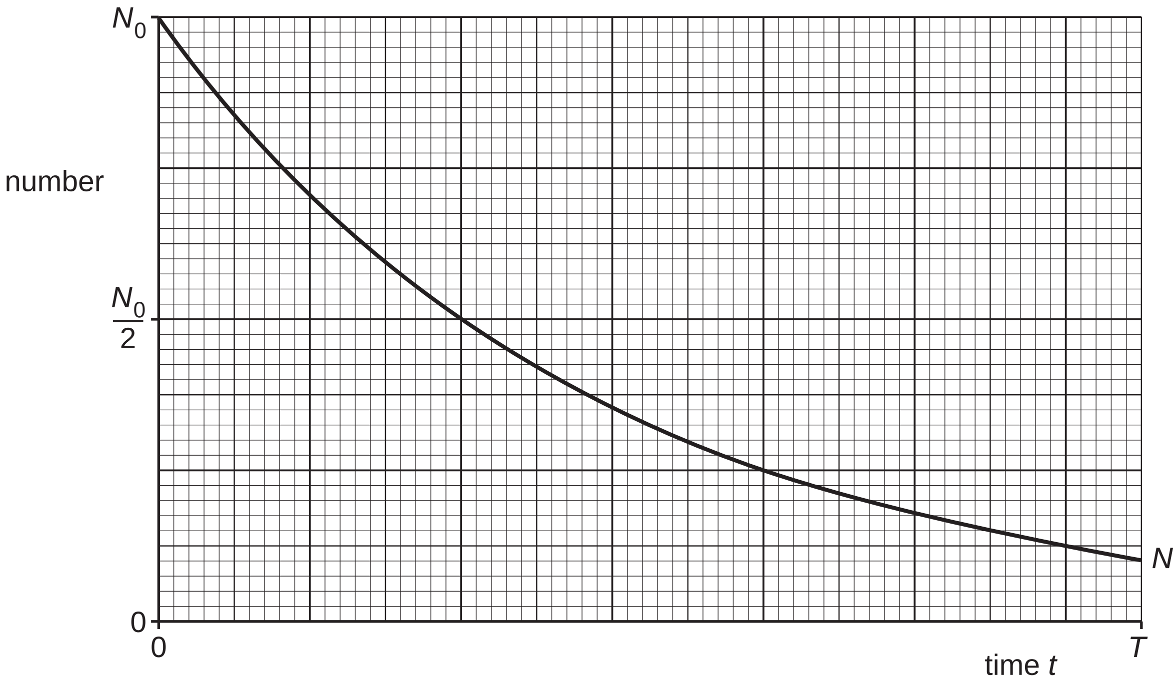

Fig. 5.3

On Fig. 5.3:

- label, on the time axis, the time $t = 1.0T_{\frac{1}{2}}$ and the time $t = 2.0T_{\frac{1}{2}}$
- sketch the variation with time t of the number of nuclei of the decay product for time $t = 0$ to time $t = T$.

[3]

[Total: 9]

6 **(a)** Two flat metal plates are held a small distance apart by means of insulating pads, as shown in Fig. 6.1.

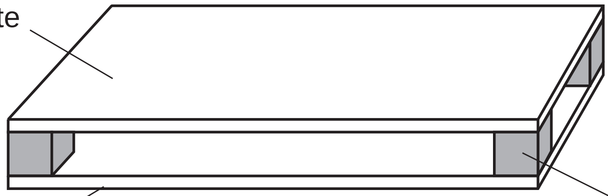

Fig. 6.1

Explain how the plates could act as a capacitor.

....

....

.... [2]

(b) The arrangement in Fig. 6.1 has capacitance C.
The arrangement is connected into the circuit of Fig. 6.2.

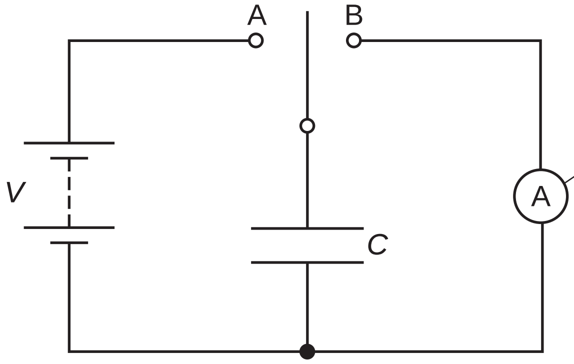

Fig. 6.2

When the two-way switch is moved to position A, the capacitor is charged so that the potential difference across it is V. When the switch moves to position B, the capacitor fully discharges through the sensitive ammeter.

The switch moves repeatedly between A and B so that the capacitor charges and then discharges with frequency f.

(i) Show that the average current I in the ammeter is given by

$$I = CVf.$$

[2]

(ii) For a potential difference V of 180 V and a frequency f of switching of 50 Hz, the average current I in the ammeter is 2.5 μA.

Calculate the capacitance, in pF, of the parallel plates.

capacitance = ... pF [2]

(c) A second capacitor is connected into the circuit of Fig. 6.2.
The two capacitors are connected in parallel.

State and explain the change, if any, in the average current in the ammeter.

....

....

.... [2]

[Total: 8]

7 **(a)** Two properties of an ideal operational amplifier (op-amp) are infinite input impedance and infinite bandwidth.

State what is meant by:

(i) *infinite input impedance*

....

.... [1]

(ii) *infinite bandwidth*.

....

.... [1]

(b) A student uses a negative temperature coefficient thermistor in the circuit of Fig. 7.1 to indicate changes in temperature.

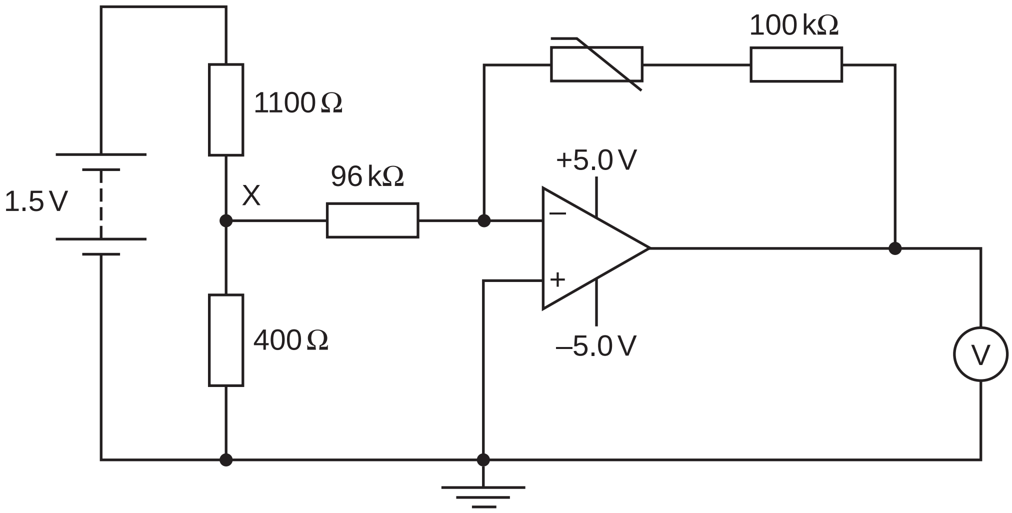

Fig. 7.1

(i) Show that the potential at point X is 0.40 V.

[1]

(ii) The thermistor has a resistance of 360 kΩ at a particular temperature.

For this temperature of the thermistor, calculate the magnitude of the reading on the voltmeter.

voltmeter reading = ... V [3]

(iii) The temperature of the thermistor increases.

State and explain the effect of this change on the magnitude of the reading on the voltmeter.

....

....

.... [2]

(iv) Explain why the amplifier circuit will no longer indicate temperature changes when the magnitude of the gain of the circuit is greater than 12.5.

....

.... [1]

[Total: 9]

8 **(a)** Define *magnetic flux density*.

....

....

.... [2]

(b) Electrons, each of mass m and charge q, are accelerated from rest in a vacuum through a potential difference V.

Derive an expression, in terms of m, q and V, for the final speed v of the electrons. Explain your working.

[2]

(c) The accelerated electrons in **(b)** are injected at point S into a region of uniform magnetic field of flux density B, as illustrated in Fig. 8.1.

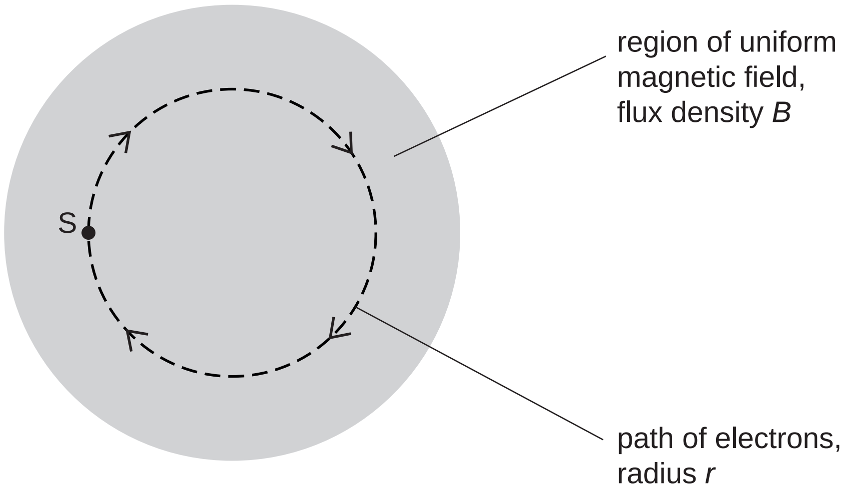

Fig. 8.1

The electrons move at right angles to the direction of the magnetic field. The path of the electrons is a circle of radius r.

(i) Show that the specific charge $\frac{q}{m}$ of the electrons is given by the expression

$$\frac{q}{m} = \frac{2V}{B^2 r^2}.$$

Explain your working.

[2]

(ii) Electrons are accelerated through a potential difference V of 230 V. The electrons are injected normally into the magnetic field of flux density 0.38 mT.
The radius r of the circular orbit of the electrons is 14 cm.

Use this information to calculate a value for the specific charge of an electron.

specific charge = ... $\mathrm{C\,kg^{-1}}$ [2]

(iii) Suggest why the arrangement outlined in **(ii)**, using the same values of B and V, is not practical for the determination of the specific charge of α-particles.

....

....

.... [2]

[Total: 10]

9 **(a)** State **two** situations in which a charged particle in a magnetic field does **not** experience a force.

1. ....

....

2. ....

....
[2]

(b) A loosely coiled metal spring is suspended from a fixed point, as shown in Fig. 9.1.

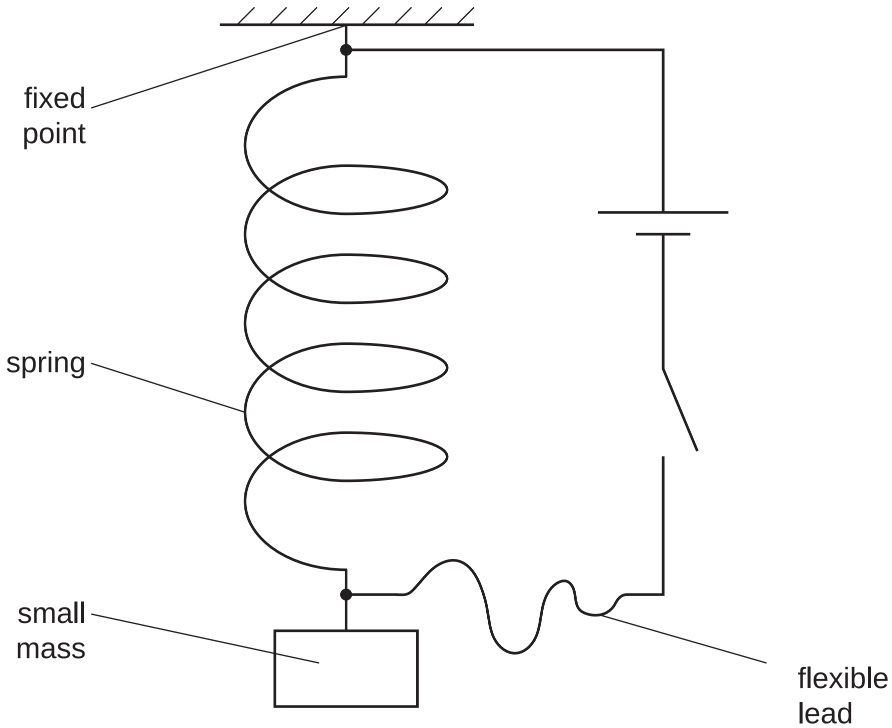

Fig. 9.1

Electrical connections are made to the ends of the spring by means of a flexible lead.

The length of the spring is measured before the switch is closed and then again after the switch is closed.

When the switch is closed, a magnetic field is set up around each coil of the spring.

By reference to these magnetic fields, explain why there is a change in length of the spring. State whether the spring extends or contracts.

....

....

....

....

....

.... [4]

(c) With the switch in **(b)** closed, the small mass on the free end of the spring is now made to oscillate vertically.

Use the principles of electromagnetic induction to explain why small fluctuations in the current in the spring are found to occur.

....

....

....

.... [3]

[Total: 9]

10 (a) By reference to heating effect, explain what is meant by the *root-mean-square* (*r.m.s.*) value of an alternating current.

....

....

.... [2]

(b) The variations with time *t* of two currents I_1 and I_2 are shown in Fig. 10.1 and Fig. 10.2.

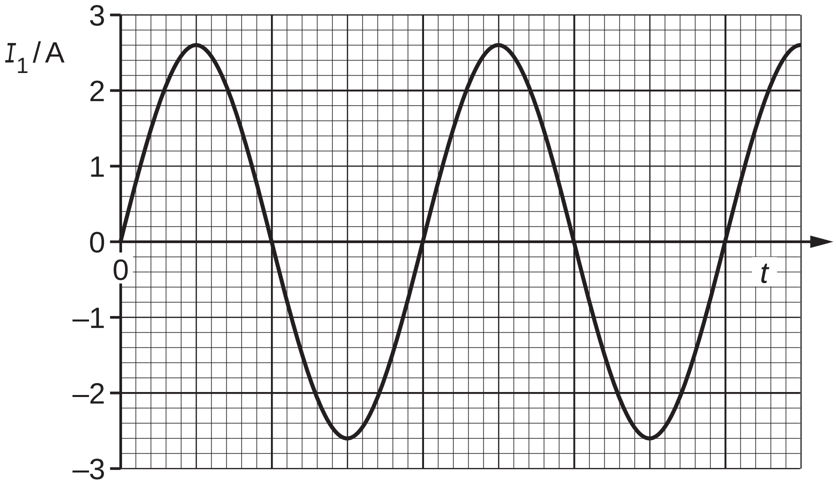

Fig. 10.1

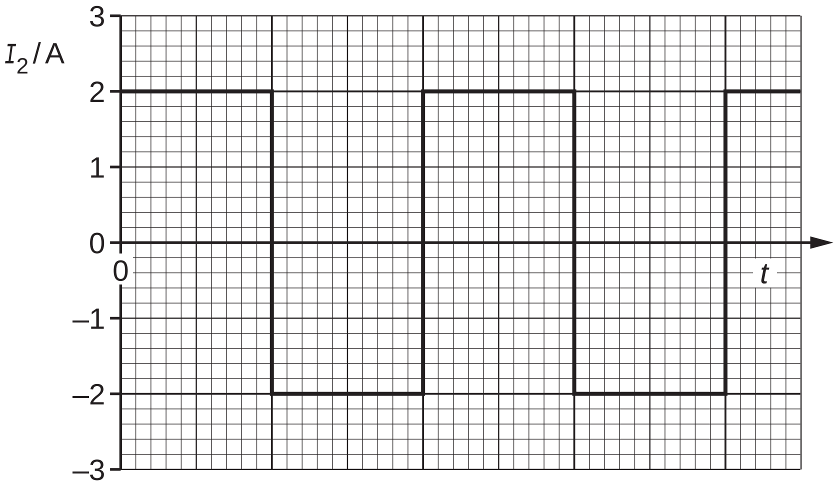

Fig. 10.2

(i) Use Fig. 10.1 to determine the peak value and the r.m.s. value of the current I_1.

peak value = ... A

r.m.s. value = ... A
[1]

(ii) Use Fig. 10.2 to determine the peak value and the r.m.s. value of the current I_2.

peak value = ... A

r.m.s. value = ... A
[1]

(c) The variation with time *t* of the supply voltage *V* to a house is given by the expression

$$V = 240 \sin kt$$

where *V* is in volts, *t* is in seconds and *k* is a constant with unit rad s^{-1}.

(i) The frequency of the supply voltage is 50 Hz.

Determine *k* to two significant figures.

k = ... rad s^{-1} [2]

(ii) The supply voltage is applied to a heater. The mean power of the heater is 3.2 kW.

Calculate the resistance of the heater.

resistance = ... Ω [2]

[Total: 8]

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11 **(a)** State the purpose of computed tomography (CT scanning).

....

.... [1]

(b) Outline the principles of CT scanning.

....

....

....

....

....

....

....

....

....

.... [5]

[Total: 6]

12 **(a)** State what is meant by a *photon*.

....

....

.... [2]

(b) A stationary nucleus of samarium-157 ($^{157}_{62}Sm$) emits a gamma-ray (γ-ray) photon of energy 0.57 MeV.

Determine, for one γ-ray photon:

(i) its wavelength

wavelength = ... m [2]

(ii) its momentum.

momentum = ... N s [2]

(c) **(i)** Using your answer to **(b)(ii)**, determine the speed of the samarium-157 nucleus after emission of the photon.

speed = ... $m s^{-1}$ [2]

(ii) By reference to your answer in **(c)(i)**, explain quantitatively why the speed of the samarium-157 nucleus may be assumed to be negligible compared with the speed of the photon.

....

.... [1]

[Total: 9]

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