Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

0592294319

PHYSICS **9702/42**

Paper 4 A Level Structured Questions **February/March 2022**

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 **32** pages. Any blank pages are indicated.

DC (RW/CB) 303284/3

Data

acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$
speed of light in free space	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\ \text{C}$
unified atomic mass unit	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
rest mass of proton	$m_\text{p} = 1.67 \times 10^{-27}\ \text{kg}$
rest mass of electron	$m_\text{e} = 9.11 \times 10^{-31}\ \text{kg}$
Avogadro constant	$N_\text{A} = 6.02 \times 10^{23}\ \text{mol}^{-1}$
molar gas constant	$R = 8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^{2}\ \text{kg}^{-2}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$ $(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \text{m F}^{-1})$
Planck constant	$h = 6.63 \times 10^{-34}\ \text{J s}$
Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
upthrust	$F = \rho g V$
Doppler effect for sound waves	$f_\text{o} = \dfrac{f_\text{s} v}{v \pm v_\text{s}}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \ldots$

gravitational potential	$\phi = -\dfrac{GM}{r}$
gravitational potential energy	$E_P = -\dfrac{GMm}{r}$
pressure of an ideal gas	$p = \frac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm\, \omega \sqrt{(x_0^{\,2} - x^2)}$
electric potential	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
electrical potential energy	$E_P = \dfrac{Qq}{4\pi\varepsilon_0 r}$
capacitors in series	$\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \dfrac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \dfrac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\dfrac{I_R}{I_0} = \dfrac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

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1 **(a)** The point P in Fig. 1.1 represents a point mass.

On Fig. 1.1, draw lines to represent the gravitational field around P.

Fig. 1.1

[2]

(b) A moon is in circular orbit around a planet.

Explain why the path of the moon is circular.

....

....

....

.... [2]

(c) Many moons are in circular orbit about a planet.

The angular velocity of a moon is ω when the orbit of the moon has a radius r about the planet.

Fig. 1.2 shows the variation of r^3 with $1/\omega^2$ for these moons.

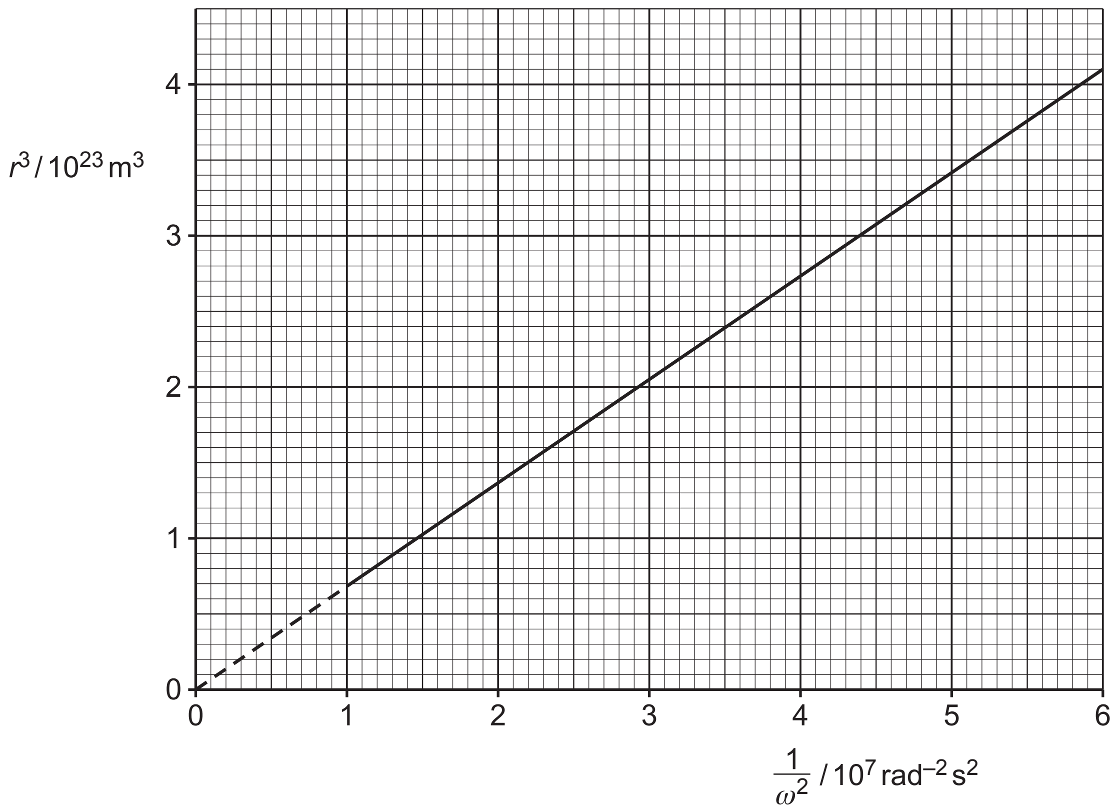

Fig. 1.2

(i) Show that the mass M of the planet is given by the expression

$$M = \frac{\text{gradient}}{G}$$

where G is the gravitational constant.

[2]

(ii) Use Fig. 1.2 and the expression in **(c)(i)** to show that the mass M of the planet is 1.0×10^{26} kg.

[1]

(iii) Determine the speed of a moon in orbit around the planet with an orbital radius of 1.2×10^{8} m.

speed = ... m s^{-1} [3]

[Total: 10]

2 A fixed mass of an ideal gas has a volume V and a pressure p.

The gas undergoes a cycle of changes, X to Y to Z to X, as shown in Fig. 2.1.

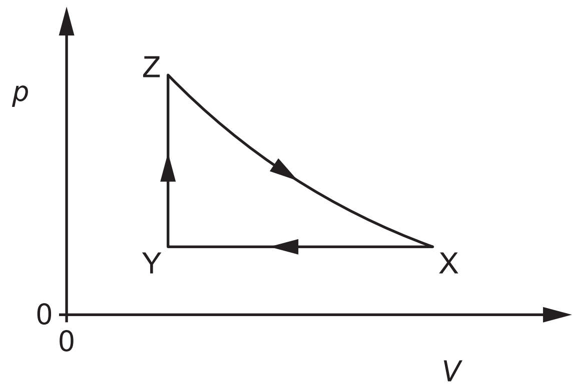

Fig. 2.1

Table 2.1 shows data for p, V and temperature T for the gas at points X, Y and Z.

Table 2.1

	p / 10^5 Pa	V / 10^{-3} m^3	T / K
X	1.5	4.2	540
Y			230
Z	5.1		782

(a) State the change in internal energy ΔU for one complete cycle, XYZX.

ΔU = ... J [1]

(b) Calculate the amount n of gas.

n = ... mol [2]

(c) Complete Table 2.1.
Use the space below for any working.

[2]

(d) **(i)** The first law of thermodynamics for a system may be represented by the equation

$$\Delta U = q + W.$$

State, with reference to the system, what is meant by:

ΔU: ....

q: ....

W: ....
[3]

(ii) Explain how the first law of thermodynamics applies to the change Z to X.

....

....

....

.... [2]

[Total: 10]

3 A small wooden block (cuboid) of mass m floats in water, as shown in Fig. 3.1.

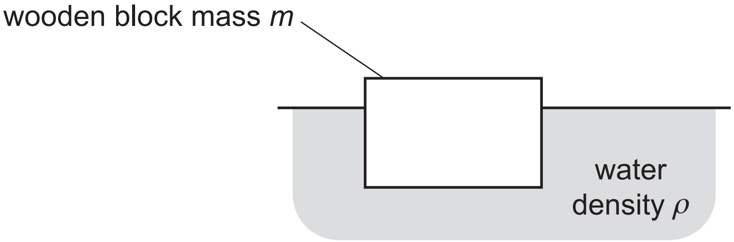

Fig. 3.1

The top face of the block is horizontal and has area A. The density of the water is ρ.

(a) State the names of the two forces acting on the block when it is stationary.

.... [1]

(b) The block is now displaced downwards as shown in Fig. 3.2 so that the surface of the water is higher up the block.

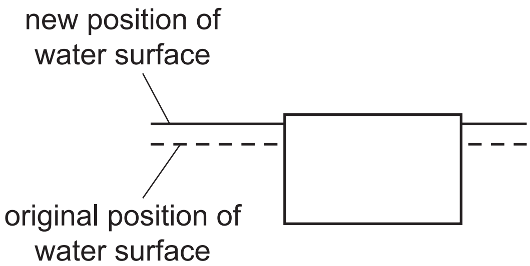

Fig. 3.2

State and explain the direction of the resultant force acting on the wooden block in this position.

....

.... [1]

(c) The block in **(b)** is now released so that it oscillates vertically.

The resultant force F acting on the block is given by

$$F = -Ag\rho x$$

where g is the gravitational field strength and x is the vertical displacement of the block from the equilibrium position.

(i) Explain why the oscillations of the block are simple harmonic.

....

....

.... [2]

(ii) Show that the angular frequency ω of the oscillations is given by

$$\omega = \sqrt{\frac{A\rho g}{m}}.$$

[2]

(d) The block is now placed in a liquid with a greater density. The block is displaced and released so that it oscillates vertically. The variation with displacement x of the acceleration a of the block is measured for the first half oscillation, as shown in Fig. 3.3.

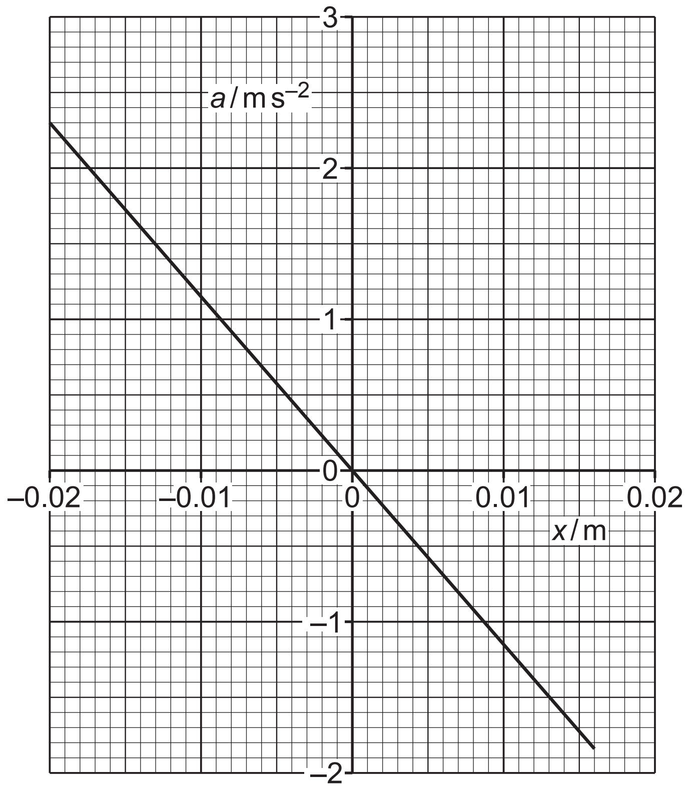

Fig. 3.3

(i) Explain why the maximum negative displacement of the block is not equal to its maximum positive displacement.

....

....

.... [1]

(ii) The mass of the block is 0.57 kg.

Use Fig. 3.3 to determine the decrease ΔE in energy of the oscillation for the first half oscillation.

E = ... J [3]

[Total: 10]

4 **(a)** State what is represented by an electric field line.

....

.... [2]

(b) Two point charges P and Q are placed 0.120 m apart as shown in Fig. 4.1.

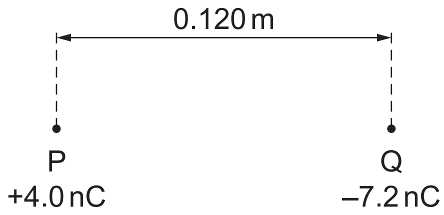

Fig. 4.1

(i) The charge of P is +4.0 nC and the charge of Q is –7.2 nC.

Determine the distance from P of the point on the line joining the two charges where the electric potential is zero.

distance = ... m [2]

(ii) State and explain, without calculation, whether the electric field strength is zero at the same point at which the electric potential is zero.

....

....

.... [1]

(iii) An electron is positioned at point X, equidistant from both P and Q, as shown in Fig. 4.2.

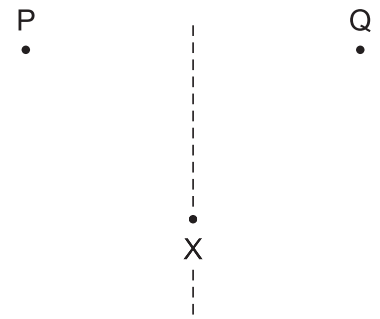

Fig. 4.2

On Fig. 4.2, draw an arrow to represent the direction of the resultant force acting on the electron. [1]

[Total: 6]

5 The variation with potential difference V of the charge Q on one of the plates of a capacitor is shown in Fig. 5.1.

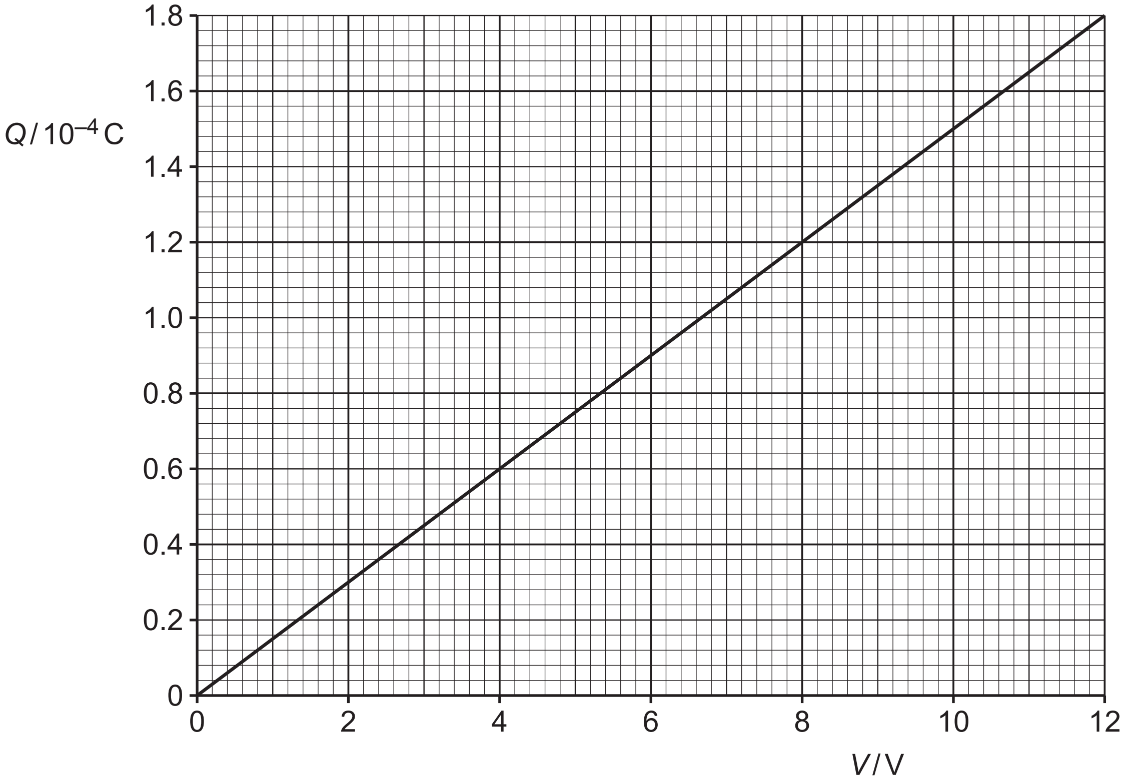

Fig. 5.1

The capacitor is connected to an 8.0 V power supply and two resistors R and S as shown in Fig. 5.2.

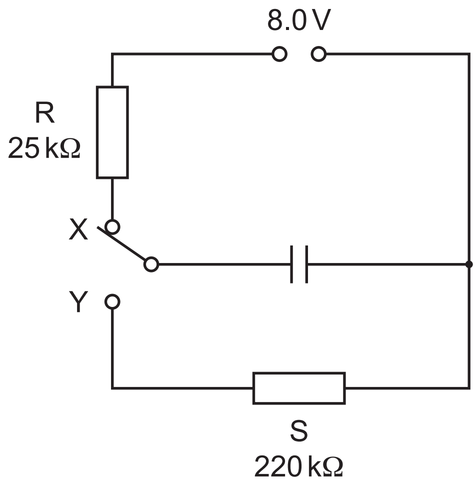

Fig. 5.2

The resistance of R is 25 kΩ and the resistance of S is 220 kΩ.

The switch can be in either position X or position Y.

(a) The switch is in position X so that the capacitor is fully charged.

Calculate the energy E stored in the capacitor.

E = ... J [2]

(b) The switch is now moved to position Y.

(i) Show that the time constant of the discharge circuit is 3.3 s.

[2]

(ii) The fully charged capacitor in **(a)** stores energy E.

Determine the time t taken for the stored energy to decrease from E to $E/9$.

t = ... s [4]

(c) A second identical capacitor is connected in parallel with the first capacitor.

State and explain the change, if any, to the time constant of the discharge circuit.

....

....

.... [2]

[Total: 10]

6 A small solenoid of area of cross section $1.6 \times 10^{-3}\,m^2$ is placed inside a larger solenoid of area of cross-section $6.4 \times 10^{-3}\,m^2$, as shown in Fig. 6.1.

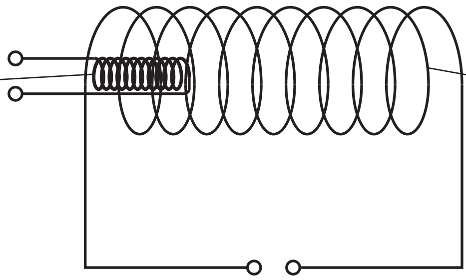

Fig. 6.1 (not to scale)

The larger solenoid has 600 turns and is attached to a d.c. power supply to create a magnetic field.

The smaller solenoid has 3000 turns.

(a) Compare the magnetic flux in the two solenoids.

....

....

.... [1]

(b) Compare the magnetic flux linkage in the two solenoids.

....

....

.... [1]

(c) **(i)** State Lenz's law of electromagnetic induction.

....

....

.... [2]

(ii) The terminals of the smaller solenoid are connected together. The smaller solenoid is then removed from inside the larger solenoid.

With reference to magnetic fields, explain why a force is needed to remove the smaller solenoid.

....

....

....

....

....

.... [3]

[Total: 7]

7 **(a)** Alternating current (a.c.) is converted into direct current (d.c.) using a full-wave rectification circuit. Part of the diagram of this circuit is shown in Fig. 7.1.

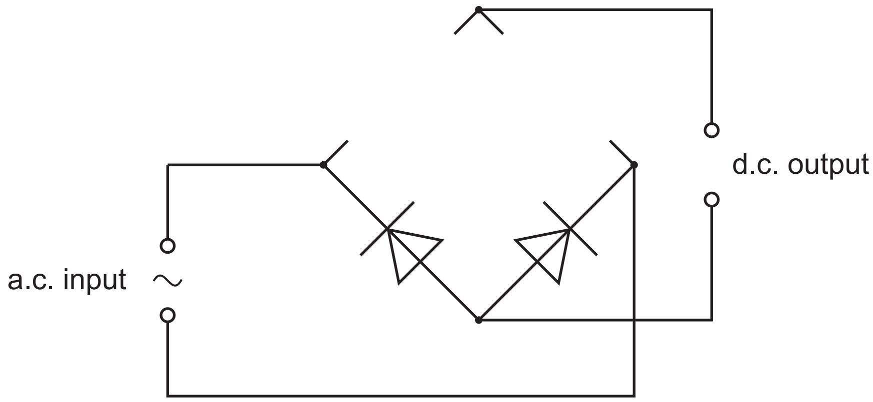

Fig. 7.1

(i) Complete the circuit in Fig. 7.1 by adding the necessary components in the gaps. [1]

(ii) On Fig. 7.1 mark with a + the positive output terminal of the rectifier. [1]

(b) The output voltage V of an a.c. power supply varies sinusoidally with time t as shown in Fig. 7.2.

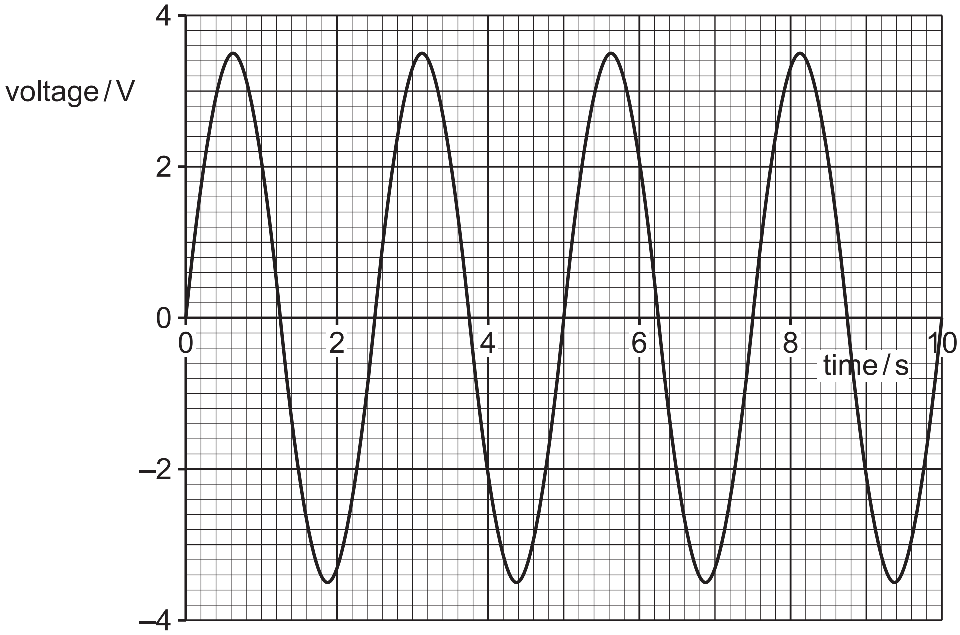

Fig. 7.2

(i) Determine the equation for V in terms of t, where V is in volts and t is in seconds.

V = ... [2]

(ii) The supply is connected to a 12 Ω resistor. Calculate the mean power dissipated in the resistor.

mean power = ... W [2]

[Total: 6]

8 **(a)** State the formula for the de Broglie wavelength λ of a moving particle.

State the meaning of any other symbol used.

....

....

.... [2]

(b) Electrons accelerate through a potential difference, pass through a thin crystal and are then incident on a fluorescent screen.

The pattern in Fig. 8.1 is observed on the fluorescent screen.

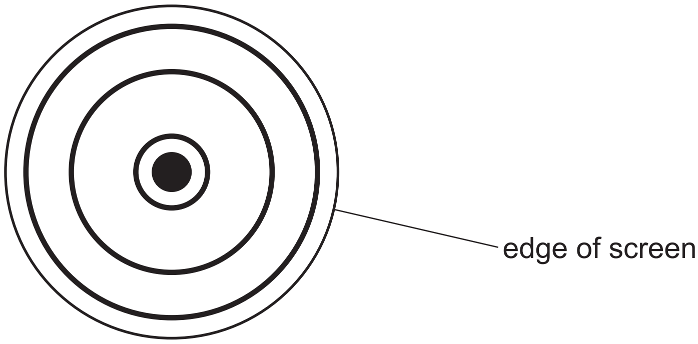

Fig. 8.1 not to scale

(i) State the name of the phenomenon shown by the electrons at the crystal.

.... [1]

(ii) State what this phenomenon shows about the nature of electrons.

....

.... [1]

(iii) Suggest why the thin crystal causes the phenomenon in **(b)(i)**.

....

.... [1]

(iv) The electron is accelerated through a different potential difference. The new pattern observed on the screen is shown in Fig. 8.2.

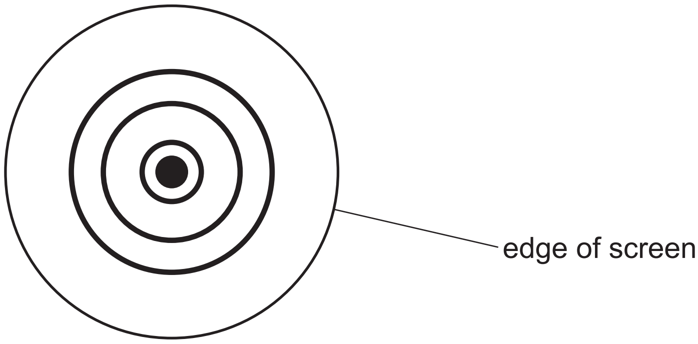

Fig. 8.2 not to scale

State and explain the change that has been made to the potential difference to create the pattern shown in Fig. 8.2.

....

....

....

.... [2]

[Total: 7]

9 Polonium-211 ($^{211}_{84}Po$) decays by alpha emission to form a stable isotope of lead (Pb).

(a) Complete the equation for this decay.

$$^{211}_{84}\text{Po} \rightarrow \,^{\dots\dots}_{\dots\dots}\text{Pb} + \,^{\dots\dots}_{\dots\dots}\alpha$$

[2]

(b) The variation with time t of the number of unstable nuclei N in a sample of polonium-211 is shown in Fig. 9.1.

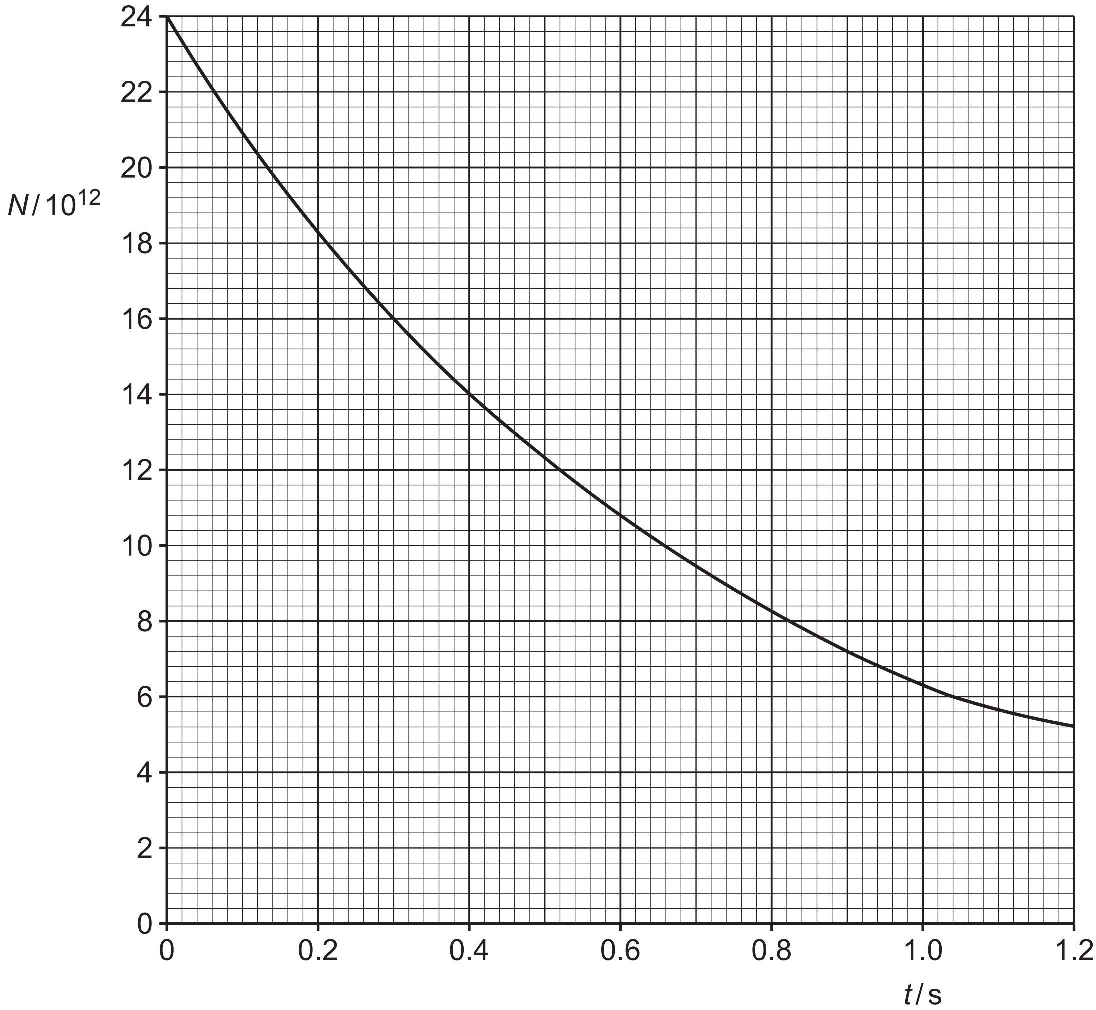

Fig. 9.1

At time t = 0, the sample contains only polonium-211.

(i) Use Fig. 9.1 to determine the decay constant λ of polonium-211. Give a unit with your answer.

λ = ... unit .... [2]

(ii) Use your answer in **(b)(i)** to calculate the activity at time $t = 0$ of the sample of polonium-211.

activity = ... Bq [1]

(iii) On Fig. 9.1, sketch a line to show the variation with t of the number of lead nuclei in the sample. [2]

(c) Each decay releases an alpha particle with energy 6900 keV.

(i) Calculate, in J, the total amount of energy given to alpha particles that are emitted between time $t = 0.30$ s and time $t = 0.90$ s.

energy = ... J [3]

(ii) Suggest why the total amount of energy released by the decay process between time $t = 0.30$ s and time $t = 0.90$ s is greater than your answer in **(c)(i)**.

....

....

.... [1]

[Total: 11]

10 In an X-ray tube, electrons are accelerated through a potential difference of 75 kV. The electrons then strike a tungsten target of effective mass 15 g.

The electron energy is converted into the energy of X-ray photons with an efficiency of 5.0%. The rest of the energy is converted into thermal energy.

(a) The X-ray tube produces an image using a current of 0.40 A for a time of 20 ms.

The specific heat capacity of tungsten is 130 J kg^{-1} K^{-1}.

Determine the temperature rise ΔT of the tungsten target.

ΔT = ... K [3]

(b) The linear attenuation coefficient of the X-ray photons in muscle is 0.22 cm^{-1}.

Calculate the thickness t of muscle that will absorb 80% of the incident X-ray intensity.

t = ... cm [2]

(c) Table 10.1 shows the linear attenuation coefficient μ for the X-ray photons in different tissues.

Table 10.1

	μ / cm^{-1}
bone	3.0
blood	0.23
muscle	0.22

Two X-ray images are taken, one of equal thicknesses of bone and muscle and another of equal thicknesses of blood and muscle.

Explain why one of these images has good contrast, but the other does not.

....

....

....

.... [2]

[Total: 7]

11 Positron emission tomography (PET scanning) obtains diagnostic information from a person. The information is used to form an image.

(a) PET scanning uses a tracer.

Explain what is meant by a tracer.

....

.... [1]

(b) PET scanning involves annihilation.

(i) Explain what is meant by annihilation.

....

.... [1]

(ii) State the names of the particles involved in the annihilation process.

.... [1]

(c) **(i)** Calculate the total energy released in one annihilation event in **(b)**.

energy = ... J [1]

(ii) Calculate the wavelength of each gamma photon released.

wavelength = ... m [2]

(d) Explain how the gamma photons are used to produce an image.

....

....

....

....

....

.... [3]

[Total: 9]

12 **(a)** State what is meant by luminosity of a star.

....

.... [1]

(b) The luminosity of the Sun is 3.83×10^{26} W. The distance between the Earth and the Sun is 1.51×10^{11} m.

Calculate the radiant flux intensity F of the Sun at the Earth. Give a unit with your answer.

F = ... unit .... [2]

(c) Use data from **(b)** to calculate the mass that is converted into energy every second in the Sun.

mass = ... kg [1]

(d) The radius of the Sun is 6.96×10^{8} m.

Show that the temperature T of the surface of the Sun is 5770 K.

[1]

(e) The wavelength λ_{max} of light for which the maximum rate of emission occurs from the Sun is 5.00×10^{-7} m.
The temperature of the surface of the star Sirius is 9940 K.

Use information from **(d)** to determine the wavelength of light for which the maximum rate of emission occurs from Sirius.

wavelength = ... m [2]

[Total: 7]

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