Name: ______________________________ (   )   Class: 23 / ______

ANDERSON SERANGOON JUNIOR COLLEGE

2023 JC2 Preliminary Examination

PHYSICS Higher 2 — 9749/02

Paper 2 Structured Questions — **Wednesday 13 September 2023**

2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class index number and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Paper 2 (80 marks)	
1	
2	
3	
4	
5	
6	
7	
8	
Deductions	
Total	

This document consists of **26** printed pages and **2** blank pages.

Data

speed of light in free space	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	$\mu_o = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	$\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1}
	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	$e = 1.60 \times 10^{-19}$ C
the Planck constant	$h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant	$u = 1.66 \times 10^{-27}$ kg
rest mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
molar gas constant	$R = 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall	$g = 9.81$ 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	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/\text{K} = T/°\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm\omega\sqrt{x_o^{\ 2} - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_o NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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

1 A spring has an unstretched length of 6.0 cm. The top of the spring is attached to a fixed point.

A brass block of mass 180 g and volume 2.0×10^{-5} m^3 is suspended from the lower end so that the length of the spring increases to 9.6 cm, shown in Fig. 1.1.

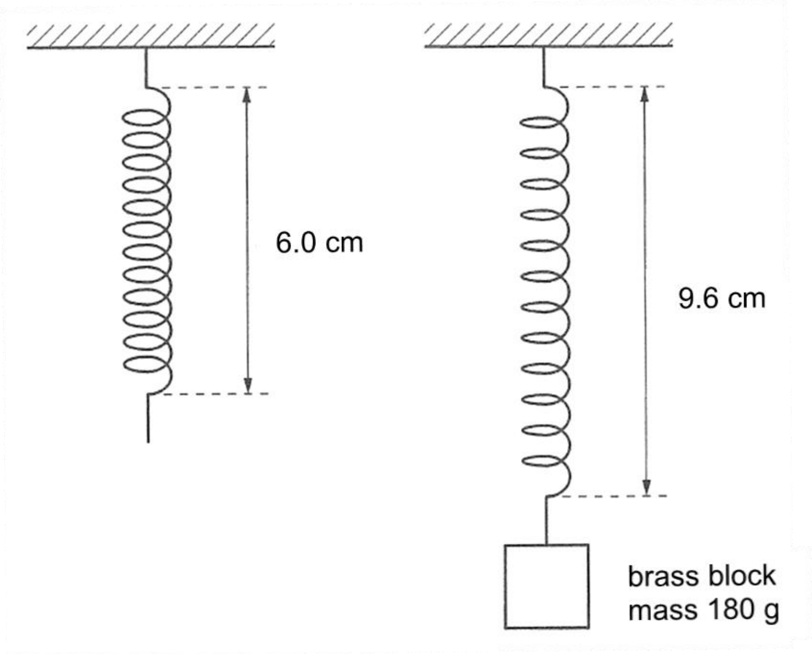

Fig. 1.1

Fig 1.1 is not drawn to scale.

(a) Calculate the force constant of the spring.

force constant = ……………………… N m^{-1} [2]

(b) The percentage uncertainty in the mass is ± 2.0%. The actual uncertainty in each measurement of the length of the spring is ± 1 mm.

Calculate the actual uncertainty in the force constant.

actual uncertainty = ……………………… N m^{-1} [2]

(c) The block is submerged in a liquid of density ρ. The length of the spring is now 9.0 cm, as shown in Fig. 1.2.

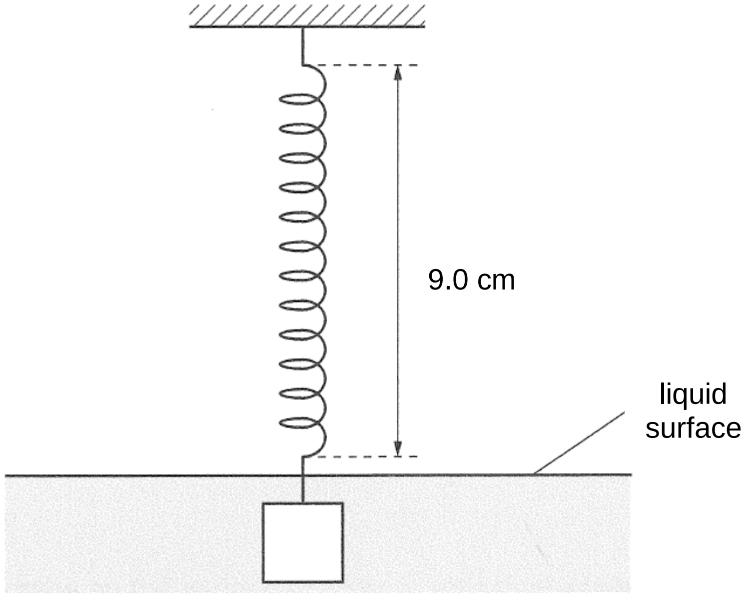

Fig. 1.2

(i) Using the definitions of pressure and density, show that the hydrostatic pressure p at a depth h below the surface of the liquid is given by

$$p = \rho g h$$

where g is the acceleration of free fall.

[2]

(ii) Hence, or otherwise, determine ρ.

ρ = ……………………… kg m^{-3} [3]

[Total: 9]

2 Two blocks travel directly towards each other along a horizontal, frictionless surface, as illustrated in Fig. 2.1.

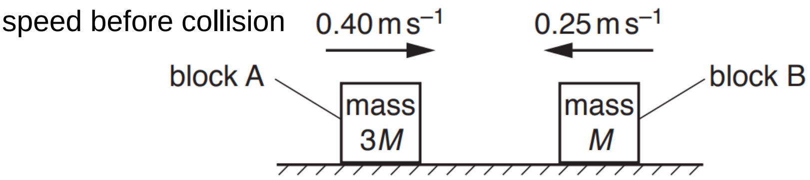

Fig. 2.1

Block A has a mass 3*M* and is moving towards block B with a speed of 0.40 m s^{-1}. Block B has a mass *M* and is moving towards block A with a speed of 0.25 m s^{-1}.

(a) Explain whether, during the collision, it is possible for both blocks to be at rest simultaneously.

……………………………………………………………………………………………………..

……………………………………………………………………………………………………..

…………………………………………………………………………………………….........[2]

(b) **(i)** After the blocks collide, block A continues its direction of motion and moves off with a speed of 0.20 m s^{-1}.

Calculate the speed of block B after the collision.

speed = ……………………………..m s^{-1} [1]

(ii) Use your answer in **(b)(i)**, state and explain the direction of motion of block B.

……………………………………………………………………………….....................

…………………………………………………………………………………………..... [1]

(c) A light plasticine is placed on block A so that the two blocks stick together after collision.

State and explain whether the collision is elastic or inelastic.

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…………………………………………………………………………………………….........[2]

[Total: 6]

Question 3 starts on the next page.

3 **(a)** **(i)** Define *gravitational potential* at a point.

....

....

.... [1]

(ii) Suggest why, for small changes in height near the Earth's surface, gravitational potential is approximately constant.

....

....

....

.... [2]

(b) An isolated solid sphere of radius r may be assumed to have its mass M concentrated at its centre. The magnitude of the gravitational potential at the surface of the sphere is ϕ.

On Fig. 3.1, show the variation of the gravitational potential with distance d from the centre of the sphere for values of d from $d = r$ to $d = 4r$.

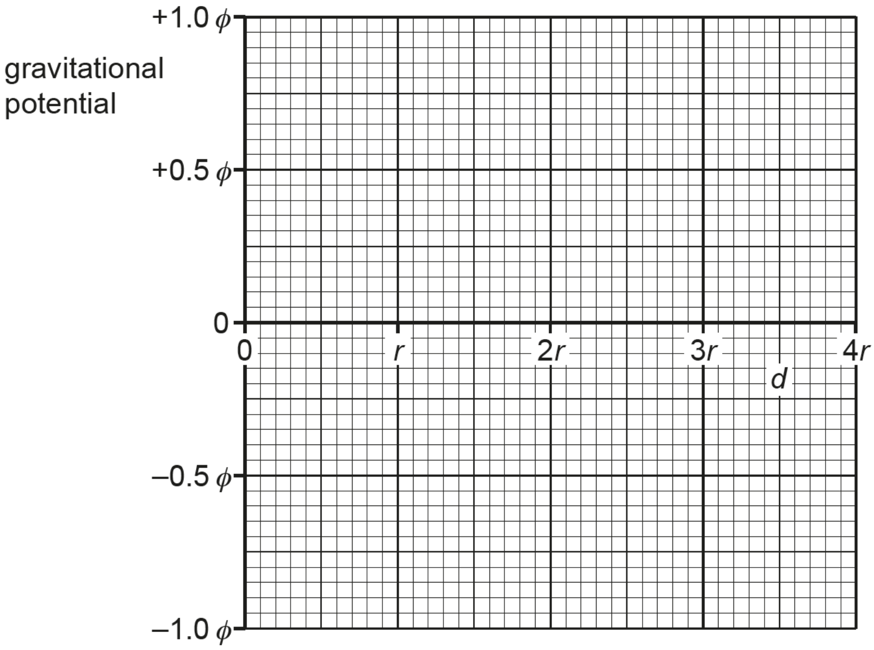

Fig. 3.1

[2]

(c) The sphere in **(b)** is a planet with radius r of 6.4×10^6 m and mass M of 6.0×10^{24} kg. The planet has no atmosphere.

A rock, initially at rest a long distance from the planet, travels towards its surface.

Calculate the change in speed of the rock as its distance from the centre of the planet changes from $4r$ to $3r$.

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

[Total: 8]

4 Fig. 4.1 shows the variation with time t of the height h above the ground of an object of mass 36 kg that is undergoing vertical simple harmonic motion.

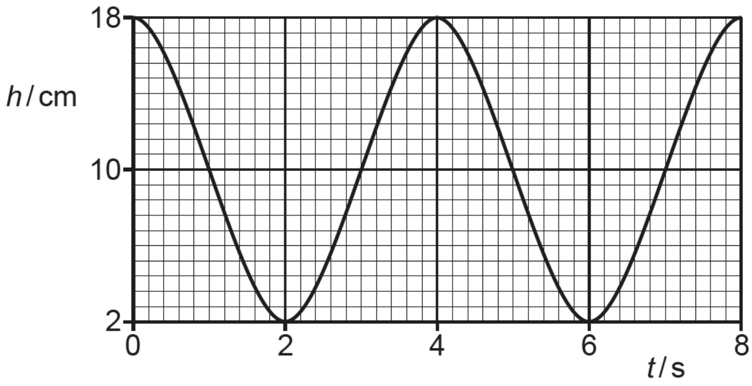

Fig. 4.1

(a) State the defining equation for simple harmonic motion. Identify the meaning of each of the symbols used to represent physical quantities.

……..

……..

…………………………………………………………………………………………………..........[1]

(b) For the oscillations of the object,

(i) show that the angular frequency ω is 1.6 rad s^{-1},

[1]

(ii) determine the total energy E.

E = ... J [3]

(c) On Fig. 4.2, sketch the variation with h of the kinetic energy E_K of the object.

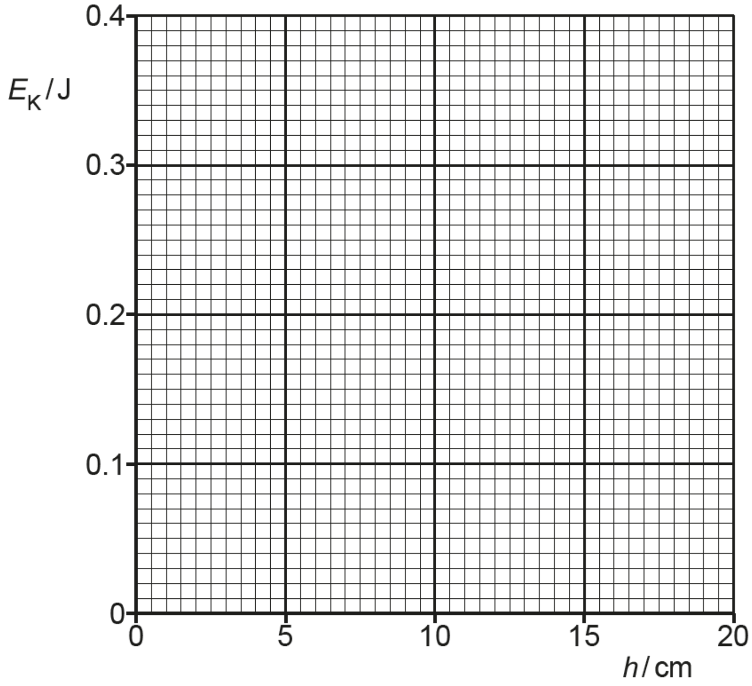

Fig. 4.2

[3]

[Total: 8]

5 **(a)** State the relationship between electric potential and electric field strength at a point.

....

....

.... [2]

(b) Two parallel metal plates A and B are situated a distance 1.2 cm apart in a vacuum, as shown in Fig. 5.1.

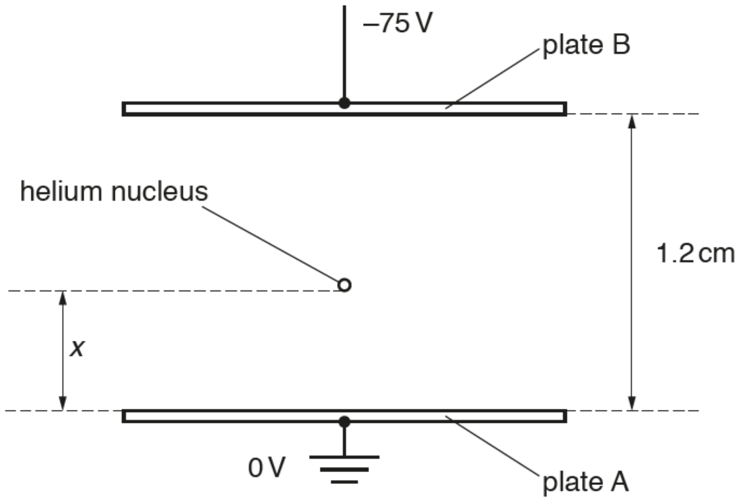

Fig. 5.1

Plate A is earthed and plate B is at a potential of –75 V.

A helium nucleus is situated between the plates, a distance x from plate A.

Initially, the helium nucleus is at rest on plate A where x = 0.

(i) On Fig. 5.1, draw an arrow to show the direction of the electric field. [1]

(ii) Determine the magnitude E of the electric field strength.

E = ... V m^{-1} [1]

(iii) The helium nucleus is free to move between the plates. By considering energy changes of the helium nucleus, explain why the speed at which it reaches plate B is independent of the separation of the plates.

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……………………………………………………………………………………...................

……………………………………………………………………………………….... [1]

(iv) As the helium nucleus moves from plate A towards plate B, its distance *x* from plate A increases.

Calculate the speed of the nucleus after it has moved a distance $x = 0.40$ cm from plate A.

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

[Total: 8]

6 **(a)** Explain what is meant by a progressive transverse wave.

progressive ……………………………………………………………………………………………..

………………………………………………………………………………………………………..

………………………………………………………………………………………………………..

transverse ...………………………………………………………………………………………..

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……………………………………………………………………………………………........[2]

(b) A wave of frequency f and wavelength λ has speed v.

Using the definition of speed, deduce the equation $v = f\lambda$.

[2]

(c) Light is polarised when it passes through a sheet of material known as polaroid.

Two sheets of polaroid P and Q are placed close to one another, with their planes parallel, as shown in Fig. 6.1.

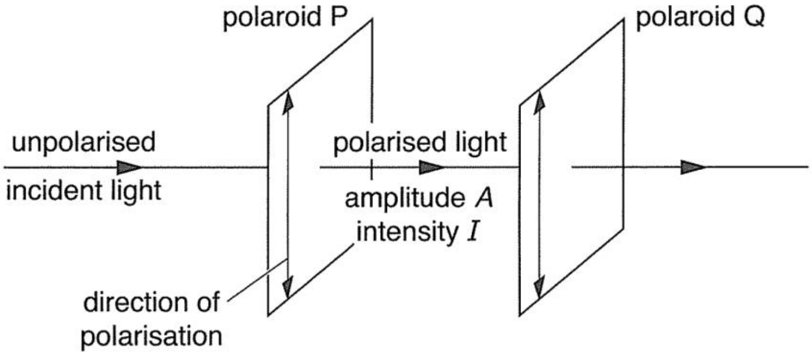

Fig. 6.1

A parallel beam of light passes through polaroid P. The beam, after passing through polaroid P, has amplitude A and intensity I.

(i) The polaroid Q is now rotated about the axis of the light beam, as shown in Fig. 6.2.

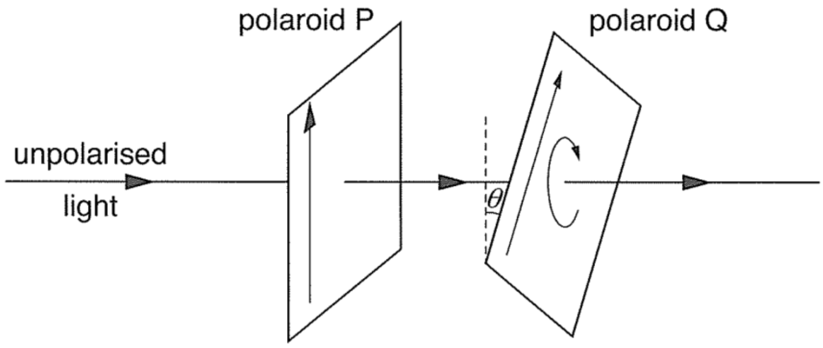

Fig. 6.2

The plane of polaroid Q remains parallel to the plane of polaroid P.

The angle between the direction of polarisation of polaroid P and of polaroid Q is θ.

Complete Table 6.1 to show the amplitude, in terms of A, and the intensity, in terms of I, of the light transmitted through polaroid Q for angle θ equal to 180°, 90° and 60°.

Table 6.1

angle θ	amplitude	intensity
180°		
90°		
60°		

[3]

(ii) Another polaroid R is placed close to polaroid P and Q, with their planes parallel, as shown in Fig. 6.3.

The polaroid Q is rotated about the axis of the light beam, as shown in Fig. 6.3.

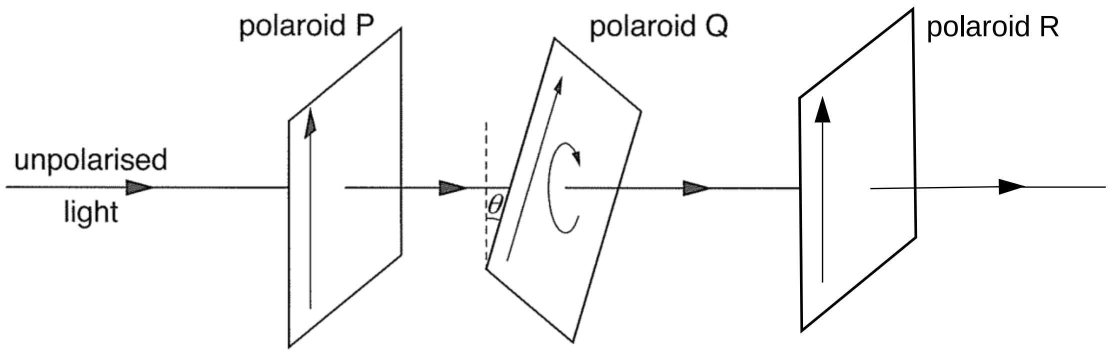

Fig. 6.3

The plane of polaroid Q remains parallel to the plane of polaroid P and R.

The angle between the direction of polarisation of polaroid P and of polaroid Q is θ.

Complete Table 6.2 to show all values of angle θ for the intensity of the light transmitted through polaroid R, that is equal to zero, maximum and $\frac{I}{2}$ respectively, as polaroid Q is rotated from 0° to 180°.

Table 6.2

intensity	θ /°
zero	
maximum	
$\frac{I}{2}$	

[2]

[Total: 9]

Question 7 starts on the next page.

7 Fig 7.1 shows an experimental set-up to produce the emission line spectrum of a hydrogen gas.

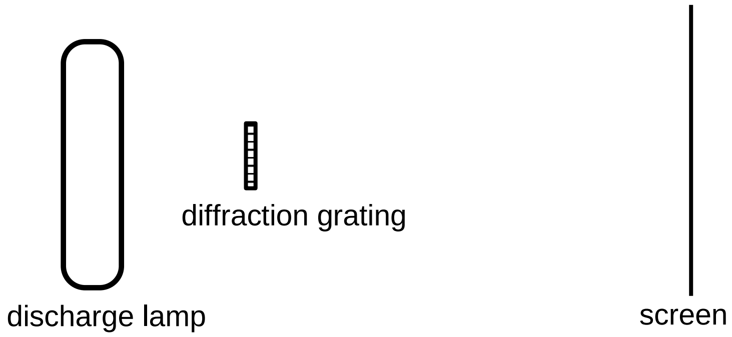

Fig. 7.1

(a) Explain how the line spectrum of hydrogen provides evidence for the existence of discrete electron energy levels in atoms.

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……..

……………………………………………………………………………………………………..........[2]

(b) Some of the lines of the emission spectrum of atomic hydrogen for the 1st order maxima are shown in Fig 7.2, which is drawn to scale.

Fig. 7.2 (drawn to scale)

Estimate the wavelength of the photon emitted for emission line labelled X. You can use the equation of $d \sin\theta = \lambda$ and assume θ is small such that $\sin\theta \approx \tan\theta \approx \theta$ in your answer.

wavelength = …………………………….m [2]

(c) Fig. 7.3 shows a partially completed diagram depicting the energy levels of a hydrogen atom. The energy changes corresponding to photon emissions of wavelength 486 nm and 434 nm are also shown.

Draw on Fig. 7.3 the energy level that shows the corresponding energy change that gives rise to photons of wavelength 410 nm. Label with appropriate values.

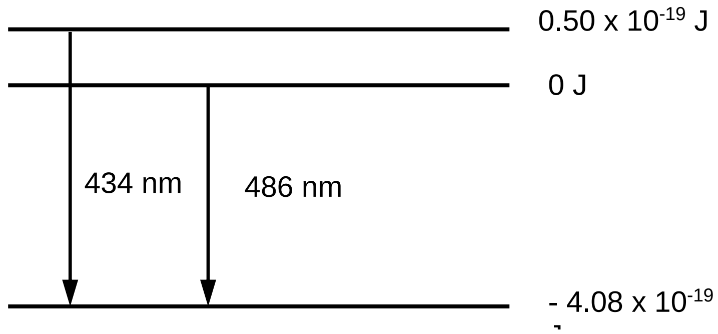

Fig. 7.3

[3]

(d) When each accelerated electron in the discharge tube has a kinetic energy of 4.08 x 10^{-19} J, they do not cause the excitation of the cool hydrogen gas atoms.

By reference to Fig. 7.3, explain this observation.

……………………………………………………………………………………………………..

……………………………………………………………………………………………..........[1]

(e) Describe a situation in which the electrons mentioned in **(d)** can be shown to have a wave nature.

……………………………………………………………………………………………………..

……………………………………………………………………………………………………..

……………………………………………………………………………………………..........[2]

(f) Determine the de Broglie wavelength of the electrons in the discharge tube that has a kinetic energy of 4.08 x 10^{-19} J.

wavelength = ……………………………..m [2]

[Total: 12]

8 Read the article and then answer the questions that follow.

Photovoltaic (PV) Efficiency: The Temperature Effect

A photovoltaic (PV) cell absorbs light energy and converts this into electrical energy. A PV panel consists of a large number of photovoltaic cells. A PV system consists of a PV panel and the rest of the circuit to which it is connected.

Temperature generally affects current in an electrical circuit by changing the speed at which the electrons travel. In metals, this is due to an increase in resistance of the circuit that results from an increase in temperature. The opposite effect is seen in semiconductor materials where an increased temperature results in a decrease in resistance due to a change in the number density of charge carriers.

It is important that the equipment associated with a PV panel is appropriate for the context in which it will be used. The current and voltage output of a PV cell is affected by changing weather conditions. A PV system at a higher temperature will have a lower maximum voltage, lower efficiency and lower power output than the same system at a lower temperature.

Engineers must carefully choose the PV system for different temperature environments to ensure that the output voltage is not too high, which could damage the equipment. It is also important to consider the average operating voltage and current of a PV system for safety concerns, equipment capabilities and choices, and to minimize the amount of wire required for construction.

Since PV panels are more efficient at lower temperatures, engineers design systems with active and passive cooling. An example of active cooling is to pump water behind the panels to remove the heat. An example of passive cooling is to let the system be cooled by convection currents in the air.

While it is important to know the temperature of a solar PV panel to predict its power output, it is also important to know the PV panel materials because the efficiencies of different materials have varied levels of dependence on temperature. Therefore, a PV system must be engineered not only according to the maximum, minimum and average environmental temperatures at each location, but also with an understanding of the materials used.

The temperature dependence of a material is described with a temperature coefficient. For monocrystalline PV panels, if the temperature decreases by 1 °C, the voltage increases by 0.48 V, so the temperature coefficient is 0.48 V°C^{-1}. The general equation for estimating the open circuit voltage V of a material at the temperature T of the panel is

$$V = \mu(T_R - T) + V_R$$

where μ is the temperature coefficient, T_R is a reference temperature and V_R is the open circuit voltage at the reference temperature. The temperatures are in degree Celsius.

The variation with voltage of current at two different temperatures for one cell of the panel is shown in Fig. 8.1

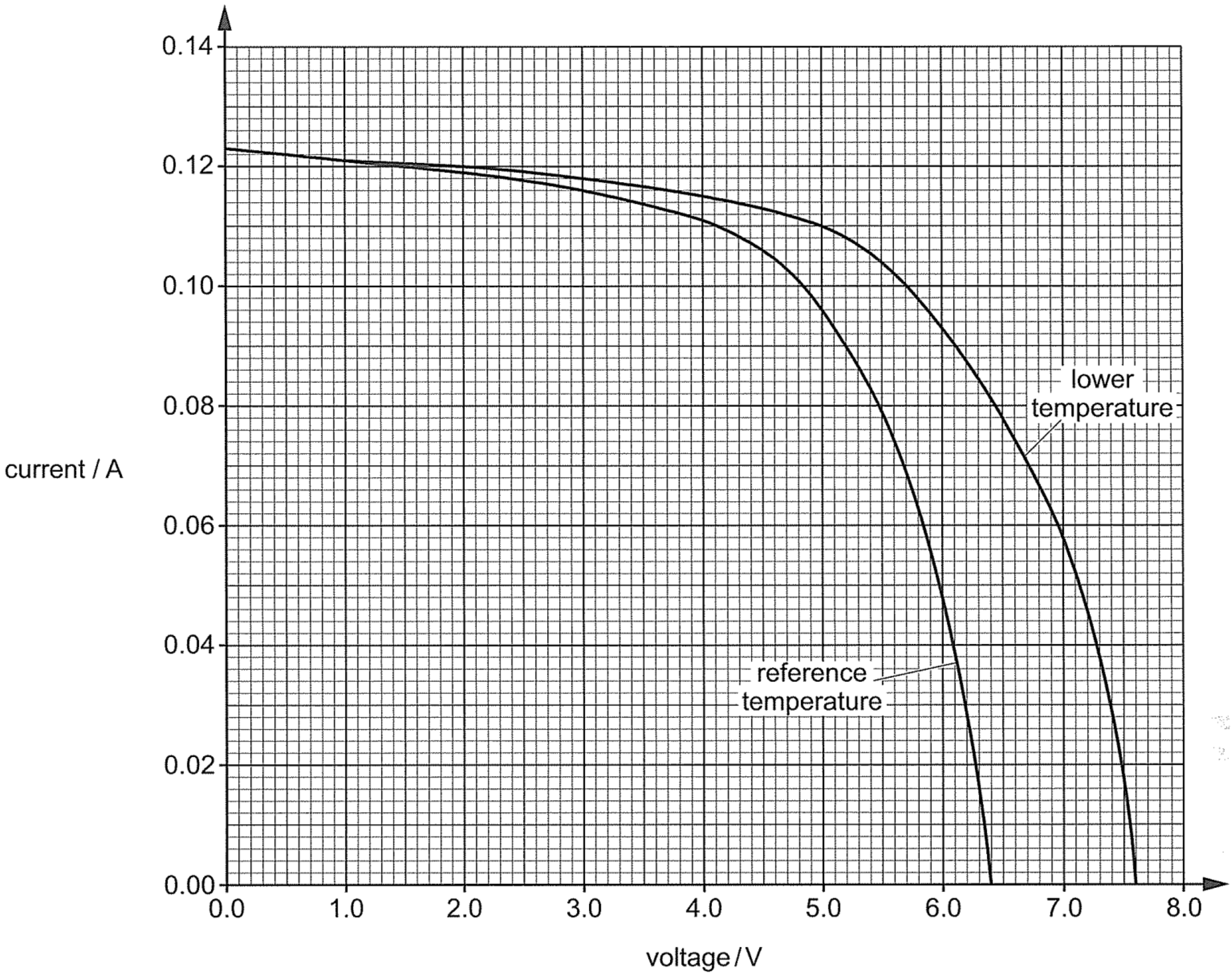

Fig. 8.1

(a) State and explain why the resistance of metals increases with temperature.

……..

……..

……………………………………………………………………………………………………....... [2]

(b) The panel produces a much larger voltage or current than an individual cell. State how the cells are connected in a panel so that

(i) the voltage is increased,

……………………………………………………………………………………………... [1]

(ii) the current is increased.

……………………………………………………………………………………………... [1]

(c) Suggest why engineers do not design systems with active cooling alone.

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………………………………………………………………………………………………………..

……………………………………………………………………………………………..........[1]

(d) Suggest how passive air cooling may be enhanced for a PV panel.

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……………………………………………………………………………………………..........[1]

(e) **(i)** Use Fig. 8.1 to state the open circuit voltage (e.m.f.) of the PV cell at both the reference temperature and the lower temperature.

V_R = ... V

V = ... V [1]

(ii) Use Fig. 8.1 to describe qualitatively the variation with temperature of the current in the cell.

……………………………………………………………………………………....................

……………………………………………………………………………………....................

……………………………………………………………………………………....................

……………………………………………………………………………………....................

…………………………………………………………………………………………..... [2]

Question 8 continues on the next page.

(iii) Fig. 8.2 shows the variation with temperature T of the open circuit voltage V. Draw the line of best fit. [1]

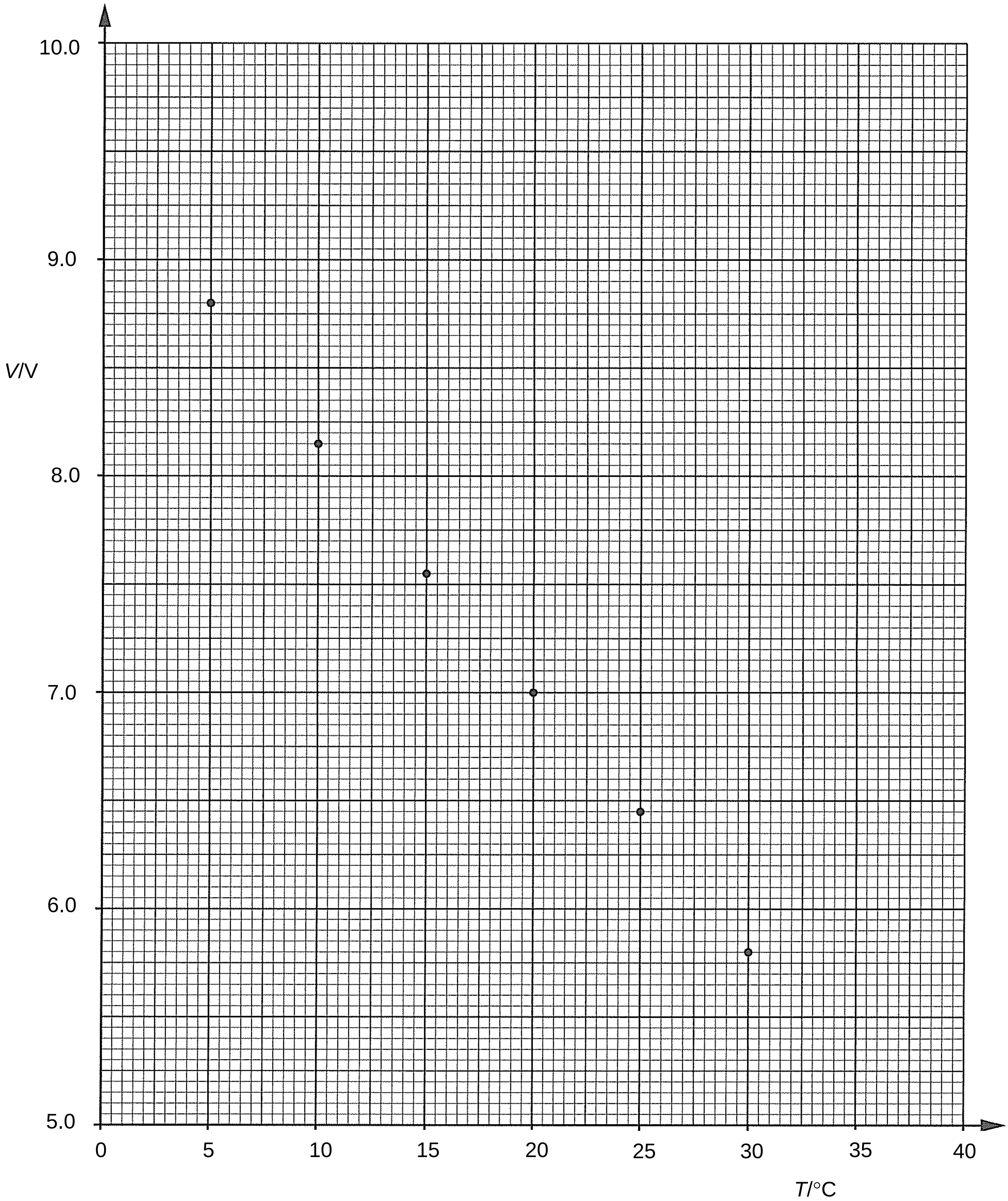

Fig. 8.2

(iv) Use Fig. 8.2 to determine the constants μ and T_R.

μ = ... V °C^{-1}

T_R = ... °C [4]

(v) Use your answers to **(e)(i)** and **e(iv)** to determine the lower temperature used to obtain the data for Fig. 8.1.

lower temperature = ... °C [1]

(vi) The PV cell is producing 6.0 V at the reference temperature.

On Fig. 8.1, indicate the area which represents the output power of the cell. [1]

(vii) Use Fig. 8.1 to estimate the maximum power output of the PV cell at the reference temperature.

maximum power output = ... W [2]

(f) **(i)** A PV cell may have multiple layers of different semi-conducting materials. As the number of layers increase, the efficiency of conversion of light energy to electrical energy increases.

Suggest a reason why the efficiency increases.

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……………………………………………………………………………………………..................

……………………………………………………………………………………………….... [1]

(ii) Suggest how the angle between the PV panel and the incident sunlight affects the power output of the PV panel.

……………………………………………………………………………………………..................

……………………………………………………………………………………………….... [1]

[Total: 20]

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