Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2022 Preliminary Examination

PHYSICS **9749/03**
Higher 2

21 September 2022
Paper 3 Longer Structured Questions **2 hours**

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

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use 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.

Section A
Answer **all** questions.

Section B
Answer **one** question only and **circle the question number** on the cover page.

You are advised to spend one and a half hours on Section A and half an hour on Section B.
The number of marks is given in brackets [ ] at the end of each question or part question.

***This booklet only contains Section A.**

For Examiner's Use		
Section A	**1**	/ 10
	2	/ 10
	3	/ 10
	4	/ 10
	5	/ 8
	6	/ 12
Section B (circle 1 question)	**7**	/ 20
	8	/ 20
Deduction		
Total		/ 80

This document consists of **15** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
		=	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-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	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T/K	=	T / °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	=	$v_0 \cos \omega t = \pm\omega\sqrt{x_0^2 - x^2}$
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	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

Section A

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

1 **(a)** The microscopic potential energy of an ideal gas is taken to be zero.
State the assumption of an ideal gas that leads to this result.

....

.... [1]

(b) Fig. 1.1 shows a sealed thermally insulated container with a smooth and light piston that separates two monatomic ideal gases, gas A and gas B. The piston does not allow gas A and gas B to mix but allows heat transfer between them.

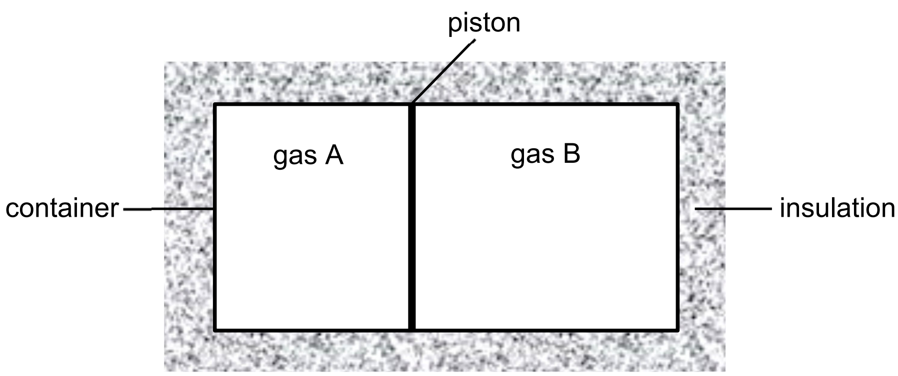

Fig. 1.1

(i) Initially, 1.8 mol of gas A at temperature 400 K and pressure 3.0×10^5 Pa occupies a volume of 2.0×10^{-2} m^3 while gas B at temperature of 300 K and pressure of 2.0×10^5 Pa occupies a volume of 3.0×10^{-2} m^3.

1. Show that the amount of gas B is 2.4 mol.

[1]

2. Determine the total internal energy of gas A and gas B.

total internal energy = ... J [2]

(ii) Due to the difference in pressure of the gases, the piston moves until both gases achieve thermal equilibrium and the piston is in translational equilibrium.

1. Calculate the final temperature of the gases. Explain your working.

temperature = ... K [2]

2. Use the first law of thermodynamics to explain the change in the temperature of gas A as the system achieves equilibrium.

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.... [3]

(iii) For the set-up in Fig. 1.1, gas B is now replaced by vacuum. The piston is then removed without any gas escaping or entering the container.

It is found that the final temperature of gas A at equilibrium remains at 400 K, which is the same as its initial temperature.

Explain why there is no change in the temperature of gas A.

....

....

.... [1]

2 A light spring hangs vertically from a fixed point. A load of mass m is attached to the free end of the spring and slowly lowered until equilibrium is reached as shown in Fig. 2.1. The spring has then stretched elastically by a distance of x_0 .

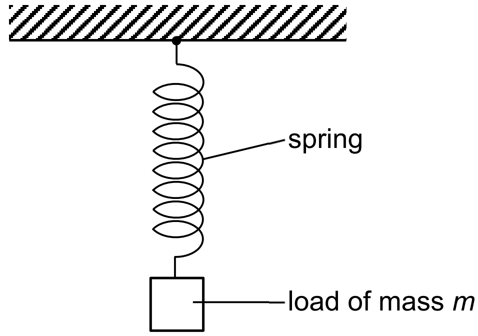

Fig. 2.1

(a) (i) Show, for the stretching of the spring, that the decrease in the gravitational potential energy of the mass is twice the increase in the elastic potential energy of the spring.

[2]

(ii) Account for the difference in the decrease in gravitational potential energy and the increase in elastic potential energy.

....

.... [1]

(b) The load on the spring is now made to oscillate vertically in simple harmonic motion with amplitude x_0 .

Take the lowest point of the oscillation as the position where the gravitational potential energy of the load is zero.

(i) Determine, in terms of m, x_0 and the acceleration of free fall g, the elastic potential energy of the spring when the load is at the lowest point of the oscillation.

elastic potential energy = ... [2]

(ii) Use your answers in **(a)(i)** and **(b)(i)** to draw, on the axes of Fig. 2.2, the variation with position of

1. the gravitational potential energy (label this line G.P.E.),

2. the elastic potential energy (label this line E.P.E.),

3. the kinetic energy (label this line K.E.),

4. the total energy (label this line T.E.).

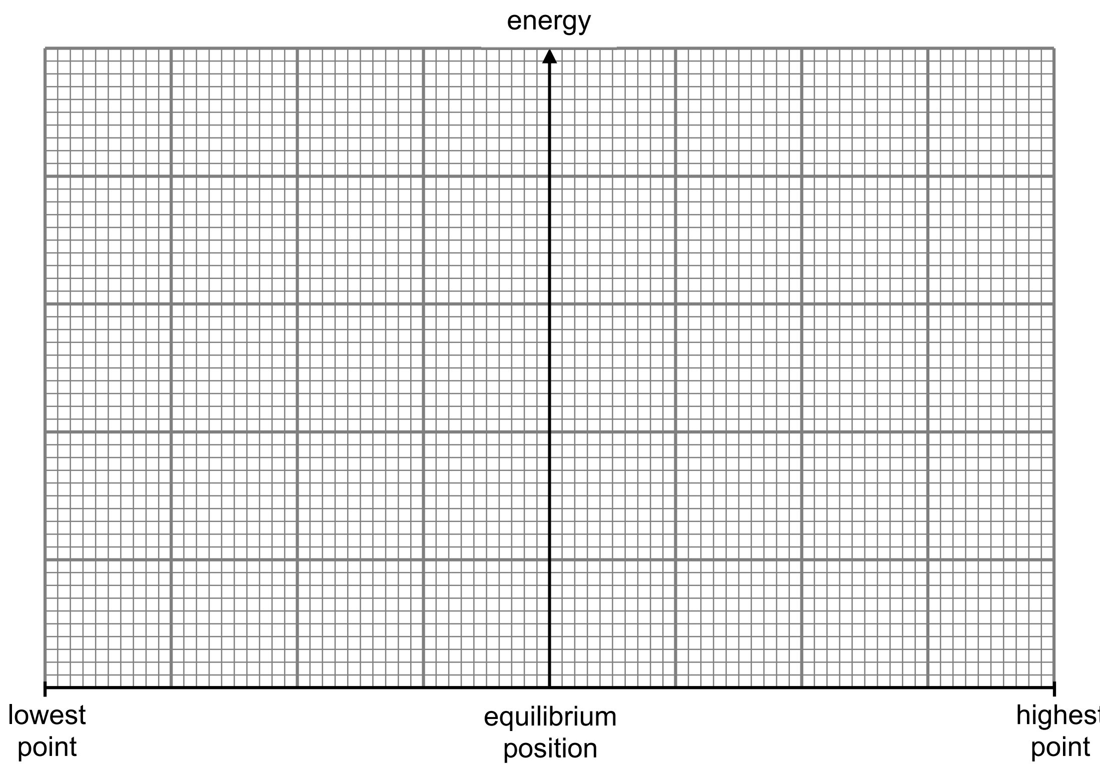

Fig. 2.2

[5]

3 Two identical metal spheres A and B, each with radius R and carrying charge $+Q$, are isolated in space with their centres a distance $2d$ apart as shown in Fig 3.1. Assume charges remain uniformly distributed on the surfaces of the spheres.

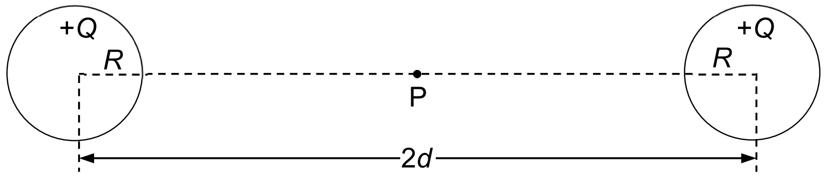

Fig. 3.1

Distance x is measured from the centre of sphere A along the line joining the centres of the two spheres.

Point P is the mid-point between the two metal spheres.

(a) (i) On Fig. 3.2, sketch the variation with distance x from $x = 0$ to $x = 2d$ of the electric potential V between the two spheres.

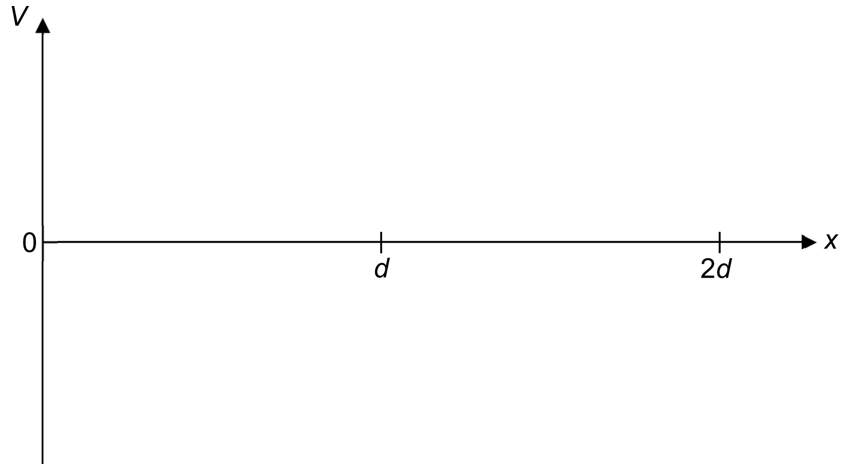

Fig. 3.2

[2]

(ii) On Fig. 3.3, sketch the variation with distance x from $x = 0$ to $x = 2d$ of the electric field strength E between the two spheres.

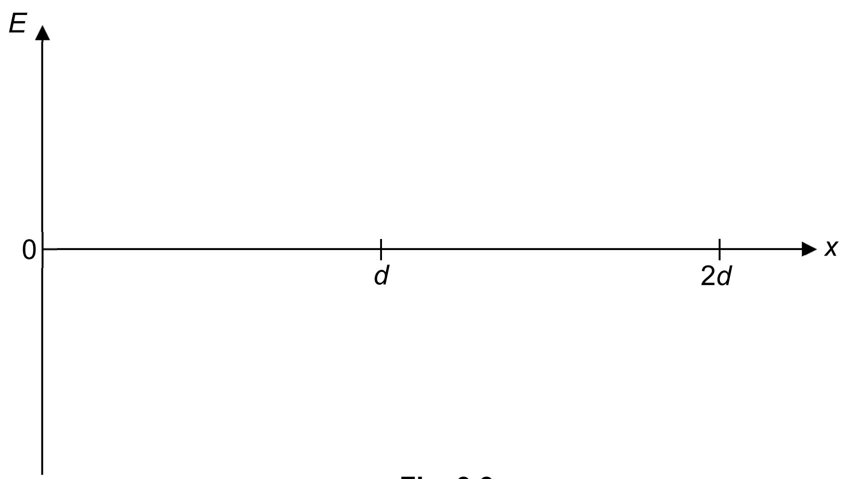

Fig. 3.3

[2]

(b) **(i)** An electron is placed at point P. State and explain the resultant force acting on the electron.

....

....

.... [1]

(ii) The electron is then displaced slightly upwards, perpendicular to the line joining the centres of the two spheres by a distance y from point P.

1. On Fig 3.4, draw and label with F_A and F_B, the force that sphere A and sphere B acts on the electron respectively.

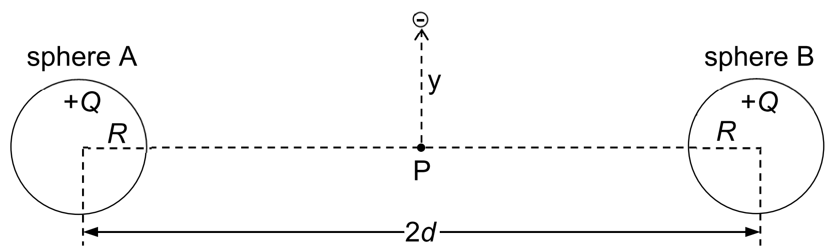

Fig. 3.4

[1]

2. Derive an expression, in terms of Q, d, y, elementary charge e and the permittivity of free space ε_0, for the resultant force F_R acting vertically on the electron when the displacement of the electron from its equilibrium position is y.

Explain your working.

[2]

3. For very small displacements, it can be shown from the expression derived in **(b)(ii)2.** that the acceleration a of the electron at displacement y is given by

$$a = -\frac{Qe}{2\pi\varepsilon_0 m_e d^3} y$$

where m_e is the mass of the electron.

Describe and explain the subsequent motion of the electron after it is released.

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....

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.... [2]

4 Fig. 4.1 shows an electron with constant speed *v* moving in a region of uniform magnetic field of flux density 2.8×10^{-5} T. The direction of the magnetic field is perpendicular to the plane of to the paper. The electron follows a clockwise circular path in the plane of the paper.

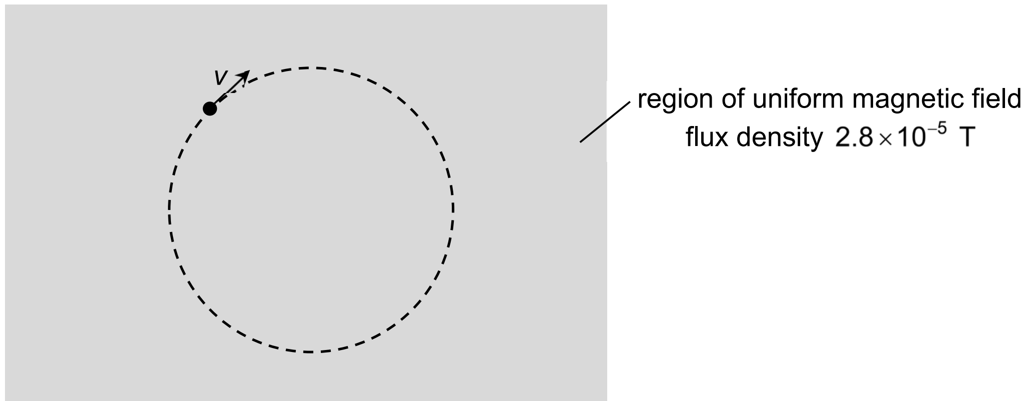

Fig. 4.1

(a) (i) Explain why the path of the electron in the magnetic field is circular.

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.... [2]

(ii) Determine the frequency of revolution *f* of the electron.

f = ... Hz [2]

(b) A second electron, with twice the kinetic energy of the first electron in **(a)**, is injected in the same direction into the same magnetic field. The second electron also follows a circular path in the magnetic field.

Comparing the circular motion of the first and second electron, state and explain whether there are differences in each of the following quantities:

(i) radius of circular path,

....

....

....

.... [2]

(ii) period of revolution,

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....

.... [1]

(iii) work done on the electron in one revolution.

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.... [1]

(c) A uniform electric field is now applied together with the magnetic field. The direction of the electric field is in the same direction as the magnetic field in Fig. 4.1.

Describe and explain the subsequent motion of the electron.

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.... [2]

5 Fig. 5.1 shows two uniform magnetic fields P and Q next to each other. The fields do not affect each other.

Field P, with magnetic flux density 0.1 T, is pointing into the page. Field Q, of magnetic flux density 0.2 T, is pointing out of the page. The length of each magnetic field is 3.0 cm.

A small square coil with sides of length 1.0 cm moves at a constant velocity of 1.0 cm s^{-1} across the two fields, entering through field P and finally exiting through field Q.

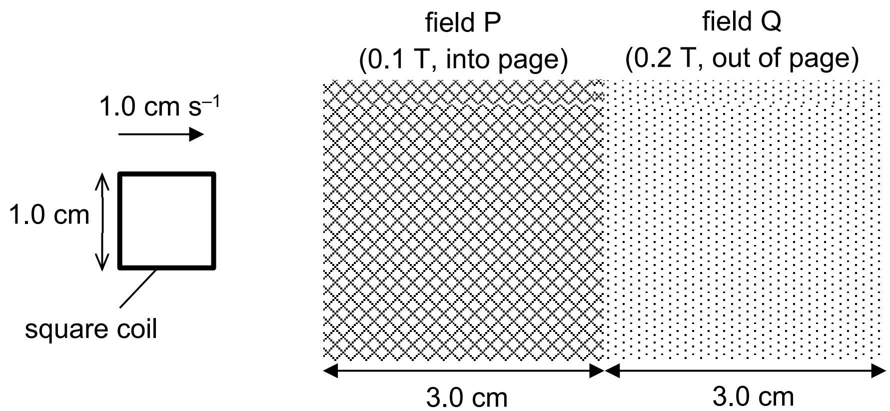

Fig. 5.1

(a) On Fig. 5.2, draw the variation with time t of the magnetic flux Φ through the square coil from the moment the coil enters field P ($t = 0$) to the moment it completely exits field Q.

Include appropriate values on the axes.

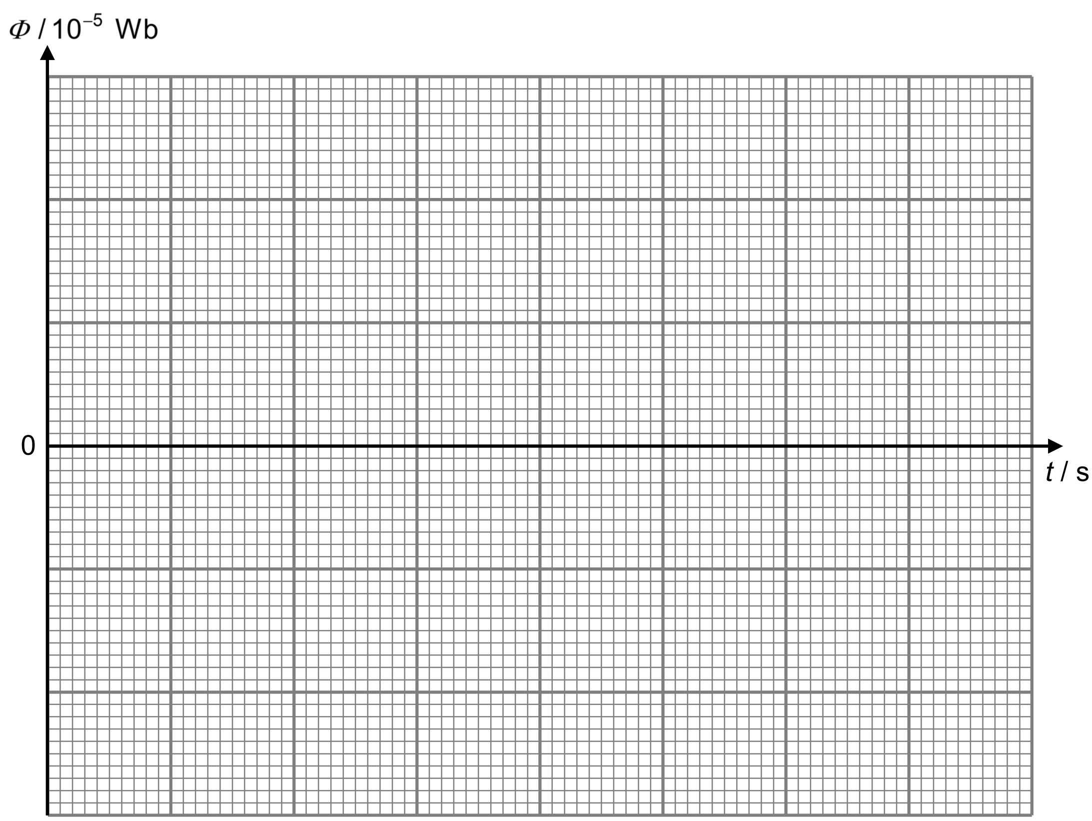

Fig. 5.2

[3]

(b) Using the laws of electromagnetic induction, explain why work needs to be done by an external force on the square coil to move it through the magnetic fields at a constant velocity.

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.... [3]

(c) Determine the magnitude of the maximum e.m.f. induced in the square coil.

e.m.f. = ... V [2]

6 **(a)** With reference to the photoelectric effect, explain why the existence of a threshold frequency provides evidence for the particulate nature of electromagnetic radiation.

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.... [3]

(b) Light of frequency f and wavelength λ is incident on a metal surface with work function energy Φ . Electrons are emitted from the surface with maximum kinetic energy E_{max} .

The variation of $E_{max}\lambda$ with λ from 100 nm to 1000 nm is shown in Fig. 6.1.

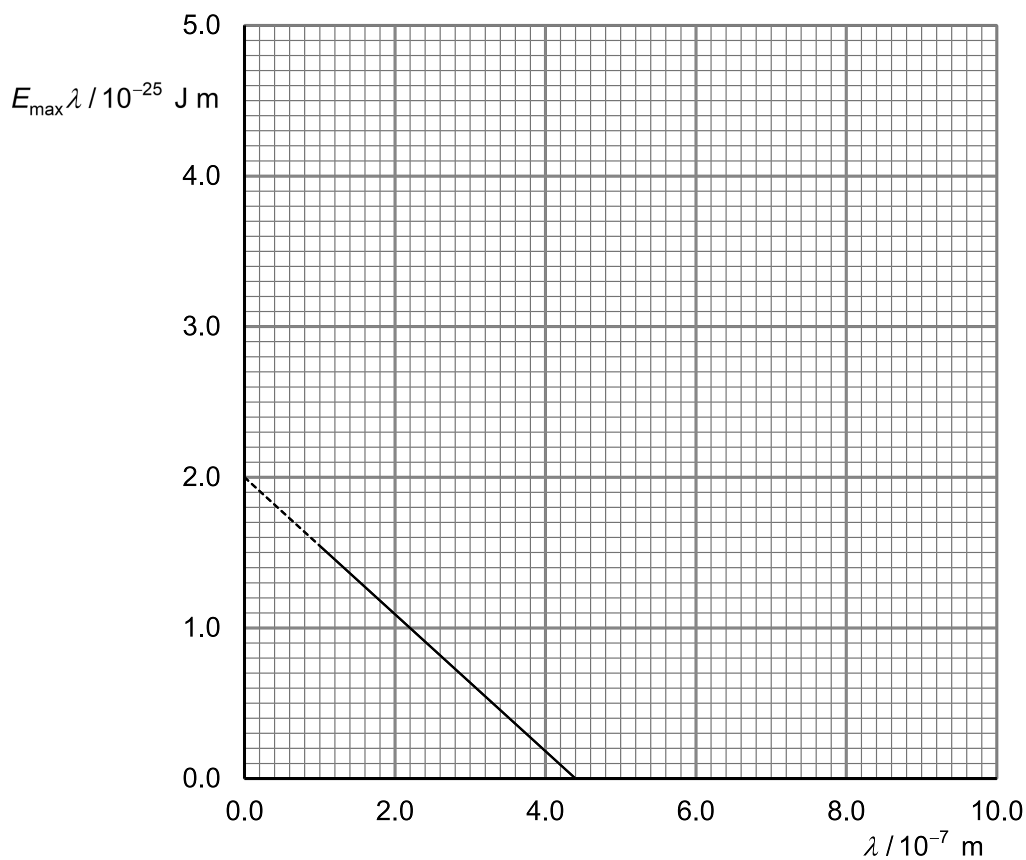

Fig. 6.1

(i) Use Fig. 6.1 to determine Φ . Explain your working.

Φ = ... J [2]

(ii) For $\lambda = 2.0 \times 10^{-7}$ m, use Fig. 6.1 to determine

1. the stopping potential,

stopping potential = ... V [3]

2. the de Broglie wavelength of the electron with maximum kinetic energy.

wavelength = ... m [2]

(c) The metal is now replaced with another metal with twice the work function energy.

On Fig. 6.1, draw a line to show the variation of $E_{max}\lambda$ with λ for this new metal.

[2]

End of Paper 3 Section A