Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2005
Advanced Level Examination

PHYSICS (SPECIFICATION A) PHA7/W
Unit 7 Nuclear Instability: Applied Physics Option

Thursday 16 June 2005 Morning Session

In addition to this paper you will require:
- a calculator;
- a pencil and a ruler.

Time allowed: 1 hour 15 minutes

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in the spaces provided. All working must be shown.
- Do all rough work in this book. Cross through any work you do not want marked.

Information
- The maximum mark for this paper is 40.
- Mark allocations are shown in brackets.
- The paper carries 10% of the total marks for Physics Advanced.
- A *Data Sheet* is provided on pages 3 and 4. You may wish to detach this perforated sheet at the start of the examination.
- You are expected to use a calculator where appropriate.
- In questions requiring description and explanation you will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate. The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

Data Sheet

- A perforated *Data Sheet* is provided as pages 3 and 4 of this question paper.
- This sheet may be useful for answering some of the questions in the examination.
- You may wish to detach this sheet before you begin work.

Data Sheet

Fundamental constants and values

Quantity	Symbol	Value	Units
speed of light in vacuo	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}	$F\ m^{-1}$
charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$N\ m^{2}\ kg^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$J\ K^{-1}\ mol^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	$J\ K^{-1}$
the Stefan constant	σ	5.67×10^{-8}	$W\ m^{-2}\ K^{-4}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4}u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	$C\ kg^{-1}$
proton rest mass (equivalent to 1.00728u)	m_p	1.67×10^{-27}	kg
proton charge/mass ratio	e/m_p	9.58×10^{7}	$C\ kg^{-1}$
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	$N\ kg^{-1}$
acceleration due to gravity	g	9.81	$m\ s^{-2}$
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

Fundamental particles

Class	Name	Symbol	Rest energy /MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^{\pm}$	0.510999
	muon	$\mu^{\pm}$	105.659
mesons	pion	$\pi^{\pm}$	139.576
		π^{0}	134.972
	kaon	$K^{\pm}$	493.821
		K^{0}	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1

Geometrical equations

arc length $= r\theta$

circumference of circle $= 2\pi r$

area of circle $= \pi r^2$

area of cylinder $= 2\pi rh$

volume of cylinder $= \pi r^2 h$

area of sphere $= 4\pi r^2$

volume of sphere $= \frac{4}{3}\pi r^3$

Mechanics and Applied Physics

$v = u + at$

$s = \left(\frac{u+v}{2}\right) t$

$s = ut + \frac{at^2}{2}$

$v^2 = u^2 + 2as$

$F = \frac{\Delta(mv)}{\Delta t}$

$P = Fv$

$efficiency = \frac{power\ output}{power\ input}$

$\omega = \frac{v}{r} = 2\pi f$

$a = \frac{v^2}{r} = r\omega^2$

$I = \sum mr^2$

$E_k = \frac{1}{2} I\omega^2$

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

$T = I\alpha$

angular momentum $= I\omega$

$W = T\theta$

$P = T\omega$

angular impulse = change of angular momentum $= Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$pV^{\gamma} =$ constant

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power as (area of p – V loop) × (no. of cycles/s) × (no. of cylinders)

friction power = indicated power – brake power

$efficiency = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$

maximum possible efficiency $= \frac{T_H - T_C}{T_H}$

Fields, Waves, Quantum Phenomena

$g = \frac{F}{m}$

$g = -\frac{GM}{r^2}$

$g = -\frac{\Delta V}{\Delta x}$

$V = -\frac{GM}{r}$

$a = -(2\pi f)^2 x$

$v = \pm 2\pi f\sqrt{A^2 - x^2}$

$x = A\cos 2\pi ft$

$T = 2\pi\sqrt{\frac{m}{k}}$

$T = 2\pi\sqrt{\frac{l}{g}}$

$\lambda = \frac{\omega s}{D}$

$d\sin\theta = n\lambda$

$\theta \approx \frac{\lambda}{D}$

${}_1n_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2}$

${}_1n_2 = \frac{n_2}{n_1}$

$\sin\theta_c = \frac{1}{n}$

$E = hf$

$hf = \phi + E_k$

$hf = E_1 - E_2$

$\lambda = \frac{h}{p} = \frac{h}{mv}$

$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

Electricity

$\epsilon = \frac{E}{Q}$

$\epsilon = I(R + r)$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$

$R_T = R_1 + R_2 + R_3 + \cdots$

$P = I^2 R$

$E = \frac{F}{Q} = \frac{V}{d}$

$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

$E = \frac{1}{2}QV$

$F = BIl$

$F = BQv$

$Q = Q_0 e^{-t/RC}$

$\Phi = BA$

Turn over ▶

magnitude of induced e.m.f. $= N\frac{\Delta\Phi}{\Delta t}$

$I_{rms} = \frac{I_0}{\sqrt{2}}$

$V_{rms} = \frac{V_0}{\sqrt{2}}$

Mechanical and Thermal Properties

the Young modulus $= \frac{tensile\ stress}{tensile\ strain} = \frac{F}{A}\frac{l}{e}$

energy stored $= \frac{1}{2}Fe$

$\Delta Q = mc\,\Delta\theta$

$\Delta Q = ml$

$pV = \frac{1}{3}Nm\overline{c^2}$

$\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT = \frac{3RT}{2N_A}$

Nuclear Physics and Turning Points in Physics

force $= \frac{eV_p}{d}$

force $= Bev$

radius of curvature $= \frac{mv}{Be}$

$\frac{eV}{d} = mg$

work done $= eV$

$F = 6\pi\eta rv$

$I = k\frac{I_0}{x^2}$

$\frac{\Delta N}{\Delta t} = -\lambda N$

$\lambda = \frac{h}{\sqrt{2meV}}$

$N = N_0 e^{-\lambda t}$

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

$R = r_0 A^{\frac{1}{3}}$

$E = mc^2 = \frac{m_0c^2}{\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}}$

$l = l_0\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}$

$t = \frac{t_0}{\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}}$

Astrophysics and Medical Physics

Body	*Mass*/kg	*Mean radius*/m
Sun	2.00×10^{30}	7.00×10^{8}
Earth	6.00×10^{24}	6.40×10^{6}

1 astronomical unit = 1.50×10^{11} m

1 parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

1 light year = 9.45×10^{15} m

Hubble constant (H) = 65 km s^{-1} Mpc^{-1}

$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

$M = \frac{f_o}{f_e}$

$m - M = 5\log\frac{d}{10}$

$\lambda_{max}T$ = constant = 0.0029 m K

$v = Hd$

$P = \sigma AT^4$

$\frac{\Delta f}{f} = \frac{v}{c}$

$\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$

$R_s \approx \frac{2GM}{c^2}$

Medical Physics

power $= \frac{1}{f}$

$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ and $m = \frac{v}{u}$

intensity level $= 10\log\frac{I}{I_0}$

$I = I_0 e^{-\mu x}$

$\mu_m = \frac{\mu}{\rho}$

Electronics

Resistors

Preferred values for resistors (E24)
Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms
and multiples that are ten times greater

$Z = \frac{V_{rms}}{I_{rms}}$

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$

$C_T = C_1 + C_2 + C_3 + \cdots$

$X_C = \frac{1}{2\pi fC}$

Alternating Currents

$f = \frac{1}{T}$

Operational amplifier

$G = \frac{V_{out}}{V_{in}}$ voltage gain

$G = -\frac{R_f}{R_1}$ inverting

$G = 1 + \frac{R_f}{R_1}$ non-inverting

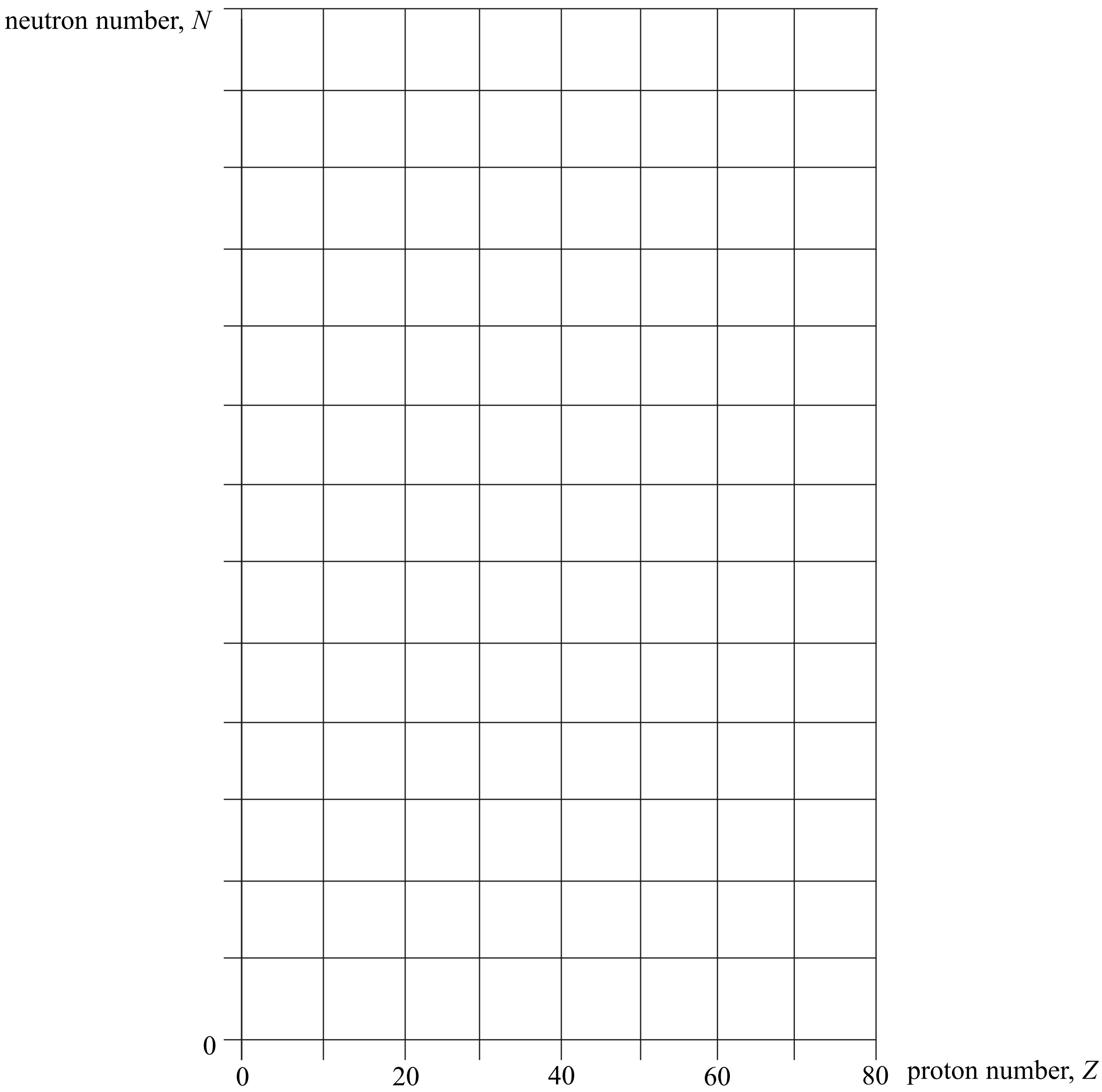
$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$ summing

TURN OVER FOR THE FIRST QUESTION

SECTION A: NUCLEAR INSTABILITY

Answer **all** parts of the question.

1 (a) Sketch, using the axes provided, a graph of neutron number, N, against proton number, Z, for stable nuclei over the range $Z = 0$ to $Z = 80$. Show suitable numerical values on the N axis.



(2 marks)

(b) On the graph indicate, for each of the following, a possible position of a nuclide that may decay by

(i) α emission, labelling the position with **W**,

(ii) β^- emission, labelling the position with **X**,

(iii) β^+ emission, labelling the position with **Y**.

(3 marks)

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(c) The isotope $^{222}_{86}Rn$ decays sequentially by emitting α particles and β^- particles, eventually forming the isotope $^{206}_{82}Pb$. Four α particles are emitted in the sequence.

Calculate the number of β^- particles in the sequence.

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(2 marks)

(d) A particular nuclide is described as proton-rich. Discuss **two** ways in which the nuclide may decay.

You may be awarded marks for the quality of written communication in your answer.

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(3 marks)

10

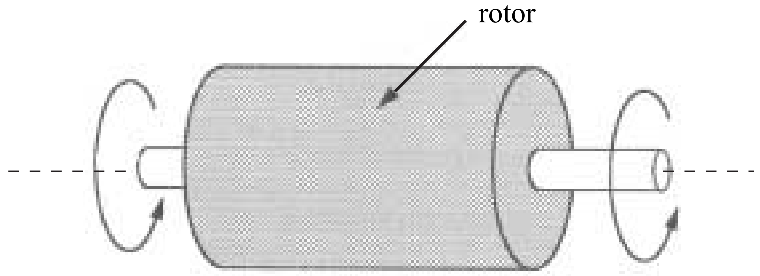
TURN OVER FOR SECTION B

LEAVE MARGIN BLANK

SECTION B: APPLIED PHYSICS

Answer **all** questions.

2 'Low inertia' motors are used in applications requiring rapid changes of speed and direction of rotation. These motors are designed so that the rotor has a very low moment of inertia about its axis of rotation.



(a) (i) Explain why a low moment of inertia is desirable when the speed and direction of rotation must be changed quickly.

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(ii) State, giving a reason in each case, **two** features of rotor design which would lead to a low moment of inertia about the axis of rotation.

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(4 marks)

LEAVE MARGIN BLANK

(b) In one application, a rotor of moment of inertia $4.4 \times 10^{-5}\,\mathrm{kg\,m^2}$ about its axis of rotation is required to reverse direction from an angular speed of $120\,\mathrm{rad\,s^{-1}}$ to the same speed in the opposite direction in a time of 50 ms. Assuming that the torque acting is constant throughout the change, calculate

(i) the angular acceleration of the rotor,

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(ii) the torque needed to achieve this acceleration,

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(iii) the angular impulse given to the rotor during the time the torque is acting,

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(iv) the angle turned through by the rotor in coming to rest momentarily before reversing direction.

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(4 marks)

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8

Turn over

LEAVE MARGIN BLANK

3 An early form of four-stroke gas engine stores kinetic energy in a large flywheel driven by the crankshaft. The engine is started from rest with its load disconnected and produces a torque which accelerates the flywheel to its off-load running speed of 110 rev min^{-1}.

(a) The flywheel has a moment of inertia of 150 kg m^2 and takes 15 s to accelerate from rest to an angular speed of 110 rev min^{-1}.

(i) Show that the rotational kinetic energy stored in the flywheel at this speed is approximately 10 kJ.

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(ii) Calculate the average useful power output of the engine during the acceleration.

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(iii) Use your answer to part (ii) to calculate the average net torque acting on the flywheel during the acceleration.

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(5 marks)

(b) When the engine is running at 110 rev min^{-1} off-load, the gas supply to the engine is suddenly cut off and the flywheel continues to rotate for a further 35 complete turns before coming to rest. Calculate the average retarding torque acting on the flywheel.

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(2 marks)

7

TURN OVER FOR THE NEXT QUESTION

4 In the pneumatic tool shown in **Figure 1**, preheated air enters the cylinder via the inlet valve at a pressure of 2.0×10^6 Pa and a temperature of 77 °C. The pressure and temperature remain constant while the inlet valve is open, and the piston is forced down the cylinder.
When the volume of air contained in the cylinder between the inlet valve and the piston is 3.5×10^{-4} m^3 the inlet valve closes and the air expands to a final volume of 6.2×10^{-4} m^3. **Figure 2** shows the *p-V* diagram for this stroke of the piston. Details of the return stroke are not needed in this question.

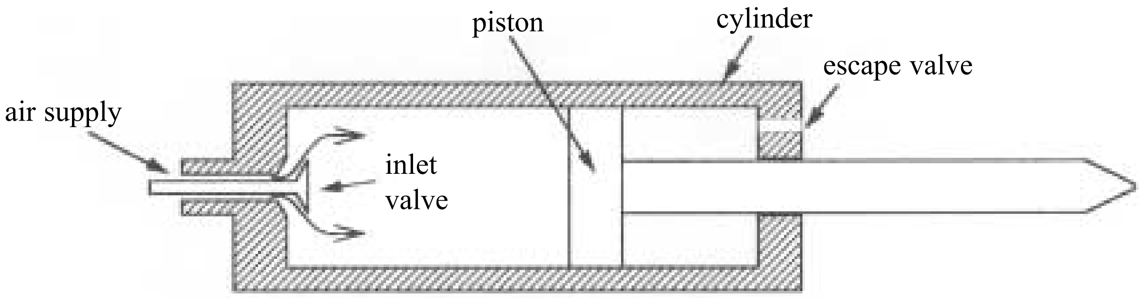

Figure 1

(a) Using the values of pressure and volume from **Figure 2**, show that the expansion of the air between points **B** and **C** is approximately adiabatic.
γ for air = 1.4

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(1 mark)

(b) Calculate the amount of air in the cylinder, in moles, when the inlet valve closes.

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(2 marks)

(c) Calculate the temperature of the air at the end of the outward stroke, corresponding to the point marked **C** in **Figure 2**.

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(1 mark)

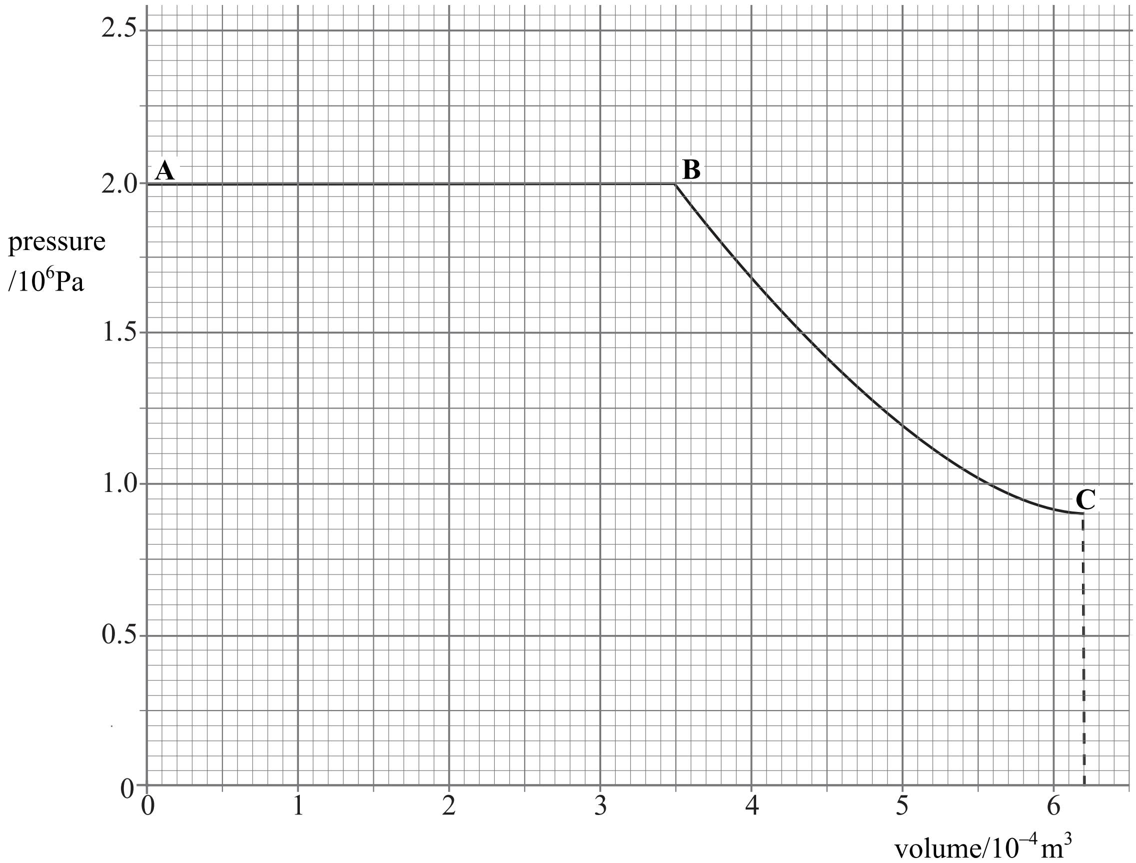

Figure 2

(d) Calculate the total work done by the air during the outward stroke of the piston, between points **A** and **C** in **Figure 2**.

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(2 marks)

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6

Turn over ▸

LEAVE MARGIN BLANK

5 An inventor has designed a gas engine for a small combined heat and power plant which will operate between temperatures of 1400 K and 360 K. The inventor makes two claims about the performance of the engine:

claim 1 When the engine consumes gas of calorific value 36 MJ kg^{-1} at a rate of 9.6 kg h^{-1}, it will deliver a useful mechanical output power of 80 kW.

claim 2 At the same time, the engine will also provide energy at the rate of at least 20 kW for heating purposes.

(a) Show that the input power to the engine is approximately 100 kW.

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(2 marks)

(b) Calculate the maximum possible efficiency of any heat engine which operates between temperatures of 1400 K and 360 K.

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(1 mark)

(c) Using the result of your calculation in part (b) and any other necessary calculations, explain whether either or both of the inventor's claims are justified.

You may be awarded marks for the quality of written communication in your answer.

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(4 marks)

7

QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

2

END OF QUESTIONS

THERE ARE NO QUESTIONS PRINTED ON THIS PAGE

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