Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2006
Advanced Level Examination

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

Thursday 15 June 2006 9.00 am to 10.15 am

For this paper you must have:
- 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.
- Answer the questions in the spaces provided.
- Show all your working.
- 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. This includes up to 2 marks for the Quality of Written Communication.
- The marks for questions are shown in brackets.
- 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.
- You are reminded of the need for good English and clear presentation in your answers. Questions indicated on the paper should be answered in continuous prose. Quality of Written Communication will be assessed in these answers.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1) →			
Total (Column 2) →			
Quality of Written Communication			
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}	$\mathrm{m\,s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\,m^{-1}}$
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}	$\mathrm{N\,m^{2}\,kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\,K^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\,K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
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}	$\mathrm{C\,kg^{-1}}$
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}	$\mathrm{C\,kg^{-1}}$
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	$\mathrm{N\,kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\,s^{-2}}$
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 $= 4\pi r^2$

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

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

$\epsilon = I(R + r)$

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

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

$P = I^2 R$

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

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

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

$F = BIl$

$F = BQv$

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

Data Sheet

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

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

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

Mechanical and Thermal Properties

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

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

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

$\Delta Q = ml$

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

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

Nuclear Physics and Turning Points in Physics

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

force $= Bev$

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

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

work done $= eV$

$F = 6\pi\eta rv$

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

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

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

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

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

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

$E = mc^2 = \dfrac{m_0 c^2}{\left(1 - \dfrac{v^2}{c^2}\right)^{\frac{1}{2}}}$

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

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

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}

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

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

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

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

$v = Hd$

$P = \sigma A T^4$

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

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

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

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

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

Turn over for the first question

SECTION A: NUCLEAR INSTABILITY

Answer **all** of this question.

1 (a) Calculate the radius of the $^{238}_{92}U$ nucleus.

$r_0 = 1.3 \times 10^{-15}$ m

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(2 marks)

(b) At a distance of 30 mm from a point source of γ rays the corrected count rate is C. Calculate the distance from the source at which the corrected count rate is $0.10\,C$, assuming that there is no absorption.

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(2 marks)

(c) The activity of a source of β particles falls to 85% of its initial value in 52 s. Calculate the decay constant of the source.

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(3 marks)

(d) Explain why the isotope of technetium, $^{99}Tc_m$, is often chosen as a suitable source of radiation for use in medical diagnosis.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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(3 marks)

10

Turn over for the next question

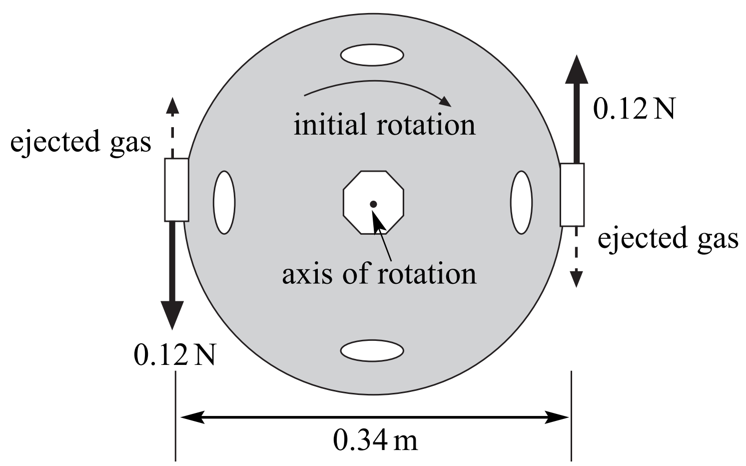
SECTION B: APPLIED PHYSICS

Answer **all** questions.

2 **Figure 1** shows a remote-control camera used in space for inspecting space stations. The camera can be moved into position and rotated by firing 'thrusters' which eject xenon gas at high speed. The camera is spherical with a diameter of 0.34 m.

In use, the camera develops a spin about its axis of rotation. In order to bring it to rest, the thrusters on opposite ends of a diameter are fired, as shown in **Figure 1**.

Figure 1



(a) When fired, each thruster provides a constant force of 0.12 N.

(i) Calculate the torque on the camera provided by the thrusters.

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(ii) The moment of inertia of the camera about its axis of rotation is 0.17 kg m^2. Show that the angular deceleration of the camera whilst the thrusters are firing is 0.24 rad s^{-2}.

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(3 marks)

(b) The initial rotational speed of the camera is 0.92 rad s^{-1}.

Calculate

(i) the time for which the thrusters have to be fired to bring the camera to rest,

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(ii) the angle turned through by the camera whilst the thrusters are firing.
Express your answer in degrees.

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(3 marks)

6

Turn over for the next question

3 Flywheels store energy very efficiently and are being considered as an alternative to battery power.

(a) A flywheel for an energy storage system has a moment of inertia of 0.60 kg m^2 and a maximum safe angular speed of 22 000 rev min^{-1}.

Show that the energy stored in the flywheel when rotating at its maximum safe speed is 1.6 MJ.

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(2 marks)

(b) In a test the flywheel was taken up to maximum safe speed and then allowed to run freely until it came to rest. The average power dissipated in overcoming friction was 8.7 W.

Calculate

(i) the time taken for the flywheel to come to rest from its maximum speed,

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(ii) the average frictional torque acting on the flywheel.

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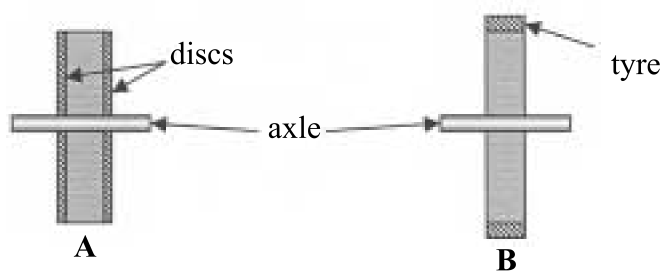
(2 marks)

(c) The energy storage capacity of the flywheel can be improved by adding solid discs to the flywheel as shown in cross-section in **A** in **Figure 2**, or by adding a hoop or tyre to the rim of the flywheel as shown in **B** in **Figure 2**. The same mass of material is added in each case. State, with reasons, which arrangement stores the more energy when rotating at a given angular speed.

Figure 2



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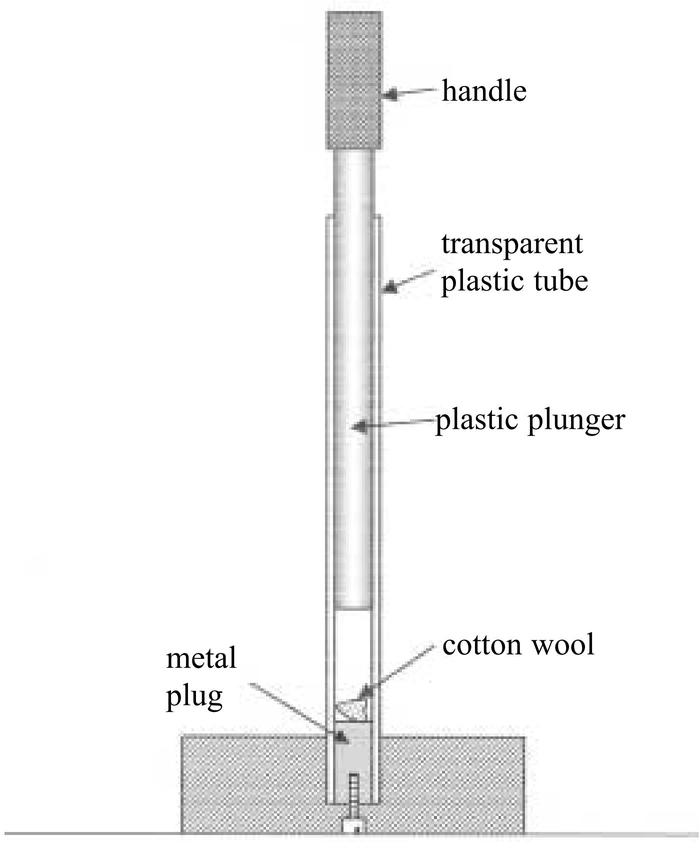
(2 marks)

6

Turn over for the next question

4 **Figure 3** shows a device for demonstrating an effect of adiabatic compression. A small pad of dry cotton wool is placed on the metal plug at the lower end of a long transparent plastic tube. The plunger is pushed quickly down the tube compressing the air in the tube. When the plunger nears the bottom the cotton wool is seen to ignite in a small tongue of flame.

Figure 3



(a) With the plunger at the top of the tube the air inside the tube has a volume of 1.2×10^{-5} m^3 and is at atmospheric pressure of 1.0×10^5 Pa.
When the plunger has been pushed down the tube to its lowest point, the volume of air in the tube is 3.1×10^{-7} m^3. Assuming the compression of the air to be adiabatic, show that the pressure of air in the tube is 1.7×10^7 Pa.

γ for air = 1.4

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(2 marks)

(b) The temperature of the air before the compression is 290 K.

Calculate

(i) the number of moles of air in the tube,

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(ii) the temperature of the air at the end of the compression.

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(4 marks)

(c) Use the first law of thermodynamics to explain why the cotton wool will not ignite if the plunger is pushed down the tube very slowly.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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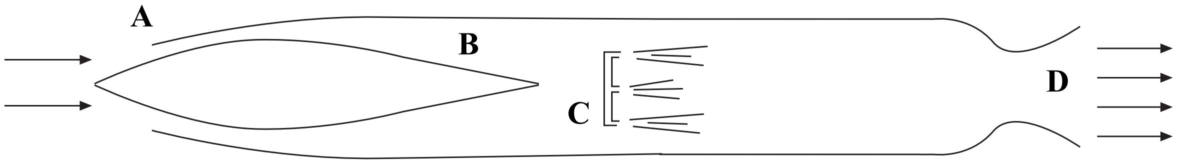
(3 marks)

9

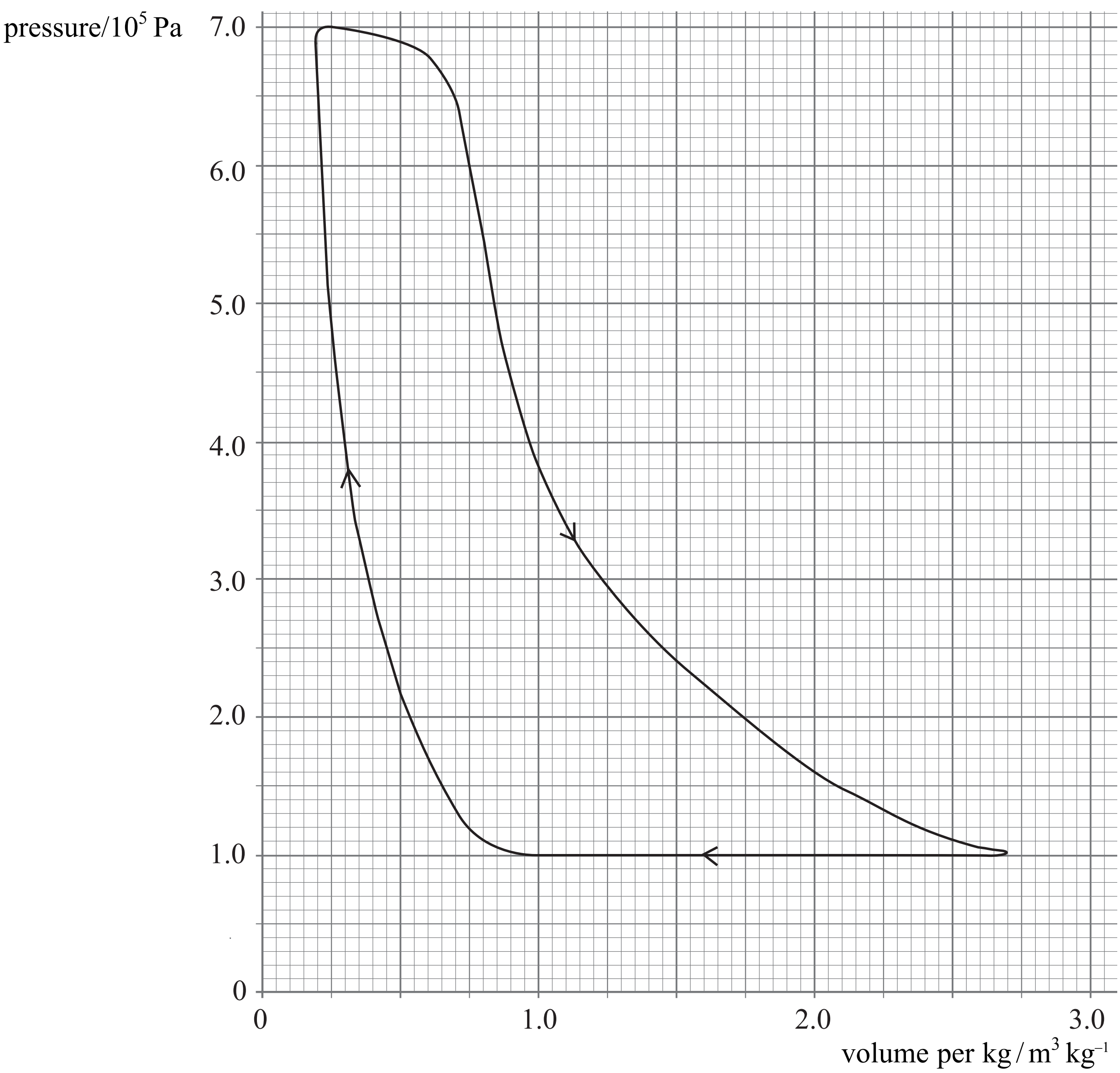
5 The ram jet engine was used as a cheap and efficient propulsion unit for high speed guided missiles. **Figure 4** shows a section through this engine.

Figure 4



When moving at high speed, air enters the nose at **A** and its pressure increases up to region **B**. At **C**, fuel is injected directly into the air stream where it is ignited, and the burning gases are exhausted at high speed through the nozzle at **D**. This provides the thrust.

The graph shows the pressure-volume diagram for 1.0 kg of air passing through the engine. Note that the volume axis has units of $m^3 kg^{-1}$ i.e. the volume for every kg of air that passes through the engine.



(a) (i) Use the graph to show that the work done for every kg of air that passes through the engine is about 500 kJ.

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(ii) The mass flow rate of the air through the engine is 9.9 kg s^{-1}. Determine the work done in one second in the engine. This is the equivalent of the indicated power of the engine.

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(iii) Because of the high speed of the air in the engine, there is significant frictional heating amounting to a power loss of 430 kW. Determine the power output of the engine (available for thrust).

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(5 marks)

(b) The engine consumes fuel at the rate of 0.30 kg per second. The calorific value of the fuel is 44 MJ kg^{-1}. Calculate

(i) the input power to the engine,

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(ii) the overall efficiency of the engine.

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(2 marks)

7

Quality of Written Communication *(2 marks)*

2

END OF QUESTIONS

There are no questions printed on this page