Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
January 2005
Advanced Level Examination

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

Wednesday 26 January 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.

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

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

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^{γ} = 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. $= N \dfrac{\Delta\Phi}{\Delta t}$

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

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

Mechanical and Thermal Properties

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

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 $= 1.50 \times 10^{11}$ m

1 parsec = 206265 AU $= 3.08 \times 10^{16}$ m = 3.26 ly

1 light year $= 9.45 \times 10^{15}$ m

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

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

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

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

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

$v = Hd$

$P = \sigma A T^4$

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

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

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

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

SECTION A: NUCLEAR INSTABILITY

Answer **all** of this question

1 The high energy electron diffraction apparatus represented in **Figure 1** can be used to determine nuclear radii. The intensity of the electron beam received by the detector is measured at various diffraction angles, θ.

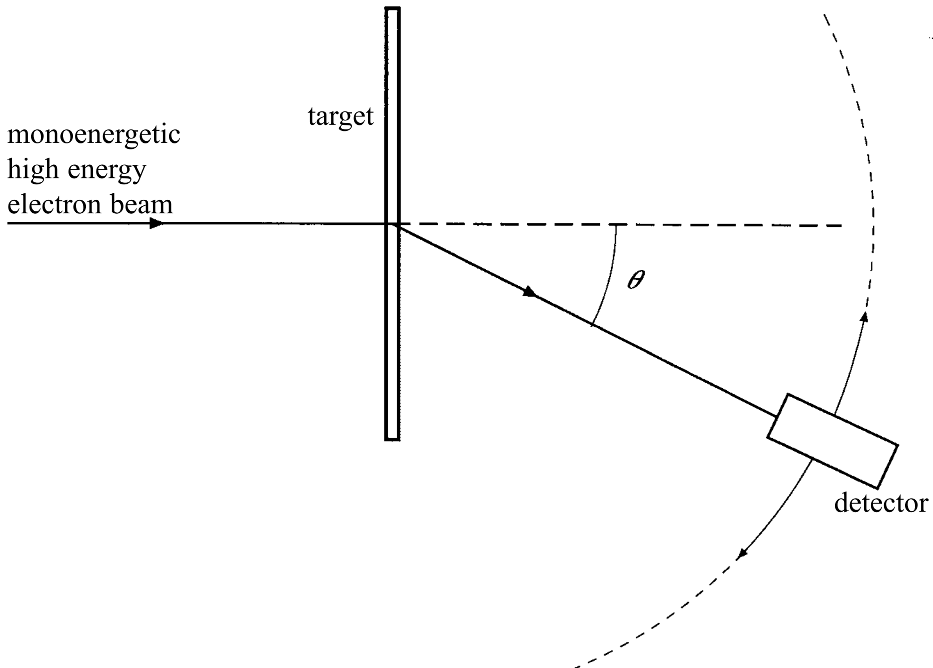
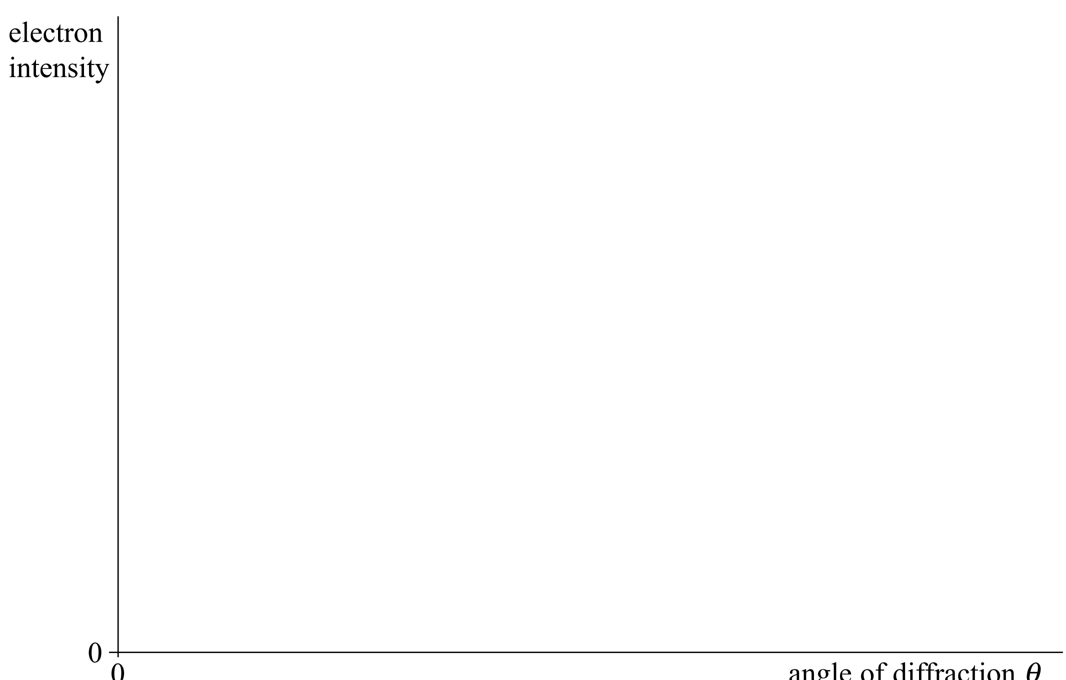


Figure 1

(a) Sketch on the axes below a graph of the results expected from such an electron diffraction experiment.



(2 marks)

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(b) (i) Use the data in the table to plot a straight line graph that confirms the relationship $R = r_0 A^{\frac{1}{3}}$.

element	**radius of nucleus, *R*** **10^{-15}m**	**nucleon number, *A***	
lead	6.66	208	
tin	5.49	120	
iron	4.35	56	
silicon	3.43	28	
carbon	2.66	12	

(ii) Estimate the value of r_0 from the graph.

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(5 marks)

(c) Discuss the merits of using high energy electrons to determine nuclear radii rather than using α particles.

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

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(3 marks)

10

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SECTION B : APPLIED PHYSICS

Answer **all** questions

2 **Figure 2** shows a 'firewheel' used at a firework display. Thrust produced by the captive rockets creates a torque which rotates the beam about a horizontal pivot at its centre. The shower of brilliant sparks in the exhaust gases of the rapidly orbiting rockets creates the illusion of a solid wheel.

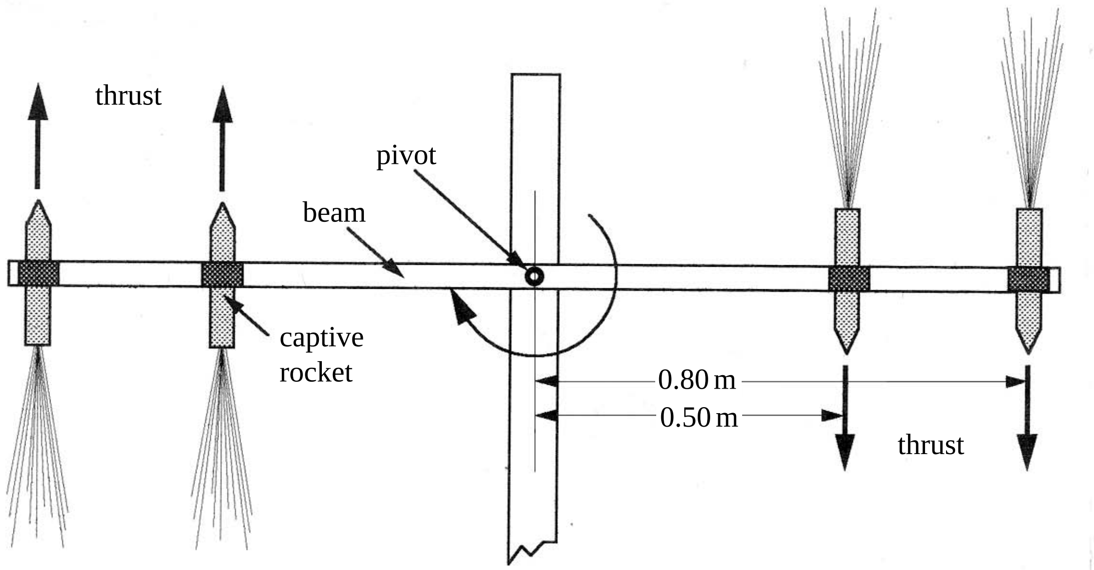

Figure 2

(a) The rockets are fixed symmetrically about the pivot at distances of 0.50 m and 0.80 m from the pivot. The initial mass of each rocket is 0.54 kg and the moment of inertia of the beam about the pivot is $0.14\,\text{kg m}^2$.
Show that the initial moment of inertia of the firewheel about the pivot is $1.10\,\text{kg m}^2$.

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(2 marks)

(b) The rockets are ignited simultaneously and each produces a constant thrust of 3.5 N. The frictional torque at the pivot is negligible. Calculate

(i) the total torque about the pivot when all the rockets are producing thrust,

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(ii) the initial angular acceleration of the firewheel,

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(iii) the time taken for the firewheel to make its first complete turn, starting from rest.

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(4 marks)

(c) The total thrust exerted by the rockets remains constant as the firewheel accelerates. Explain why, after a short time, the firewheel is rotating at a constant angular speed which is maintained until the rocket fuel is exhausted.

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(2 marks)

8

TURN OVER FOR THE NEXT QUESTION

3 In electrical resistance welding, two steel components are pressed together and a pulse of current passed through the junction between them. Local heating in the junction softens the metal and the components fuse together. One heavy-duty welding rig uses a rotating flywheel as the energy source for the welding operation. The flywheel drives a generator which sets up a current in the junction until the flywheel comes to rest.

(a) The flywheel is driven from rest up to its working angular speed by a motor which produces an output power of 15 kW for 3.0 minutes. The moment of inertia of the flywheel is $9.5\,\text{kg m}^2$. Assuming that frictional losses are negligible, show that the working angular speed of the flywheel is about $750\,\text{rad s}^{-1}$.

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(2 marks)

(b) When the flywheel reaches an angular speed of $750\,\text{rad s}^{-1}$, it is disconnected from the motor and connected to the generator. The energy stored in the flywheel is dissipated as heat in the junction between the steel components and the flywheel comes to rest in 4.5 s. Assuming that friction can be neglected, calculate

(i) the angular impulse acting on the flywheel during the welding operation,

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(ii) the average torque acting on the flywheel during the time it takes to come to rest.

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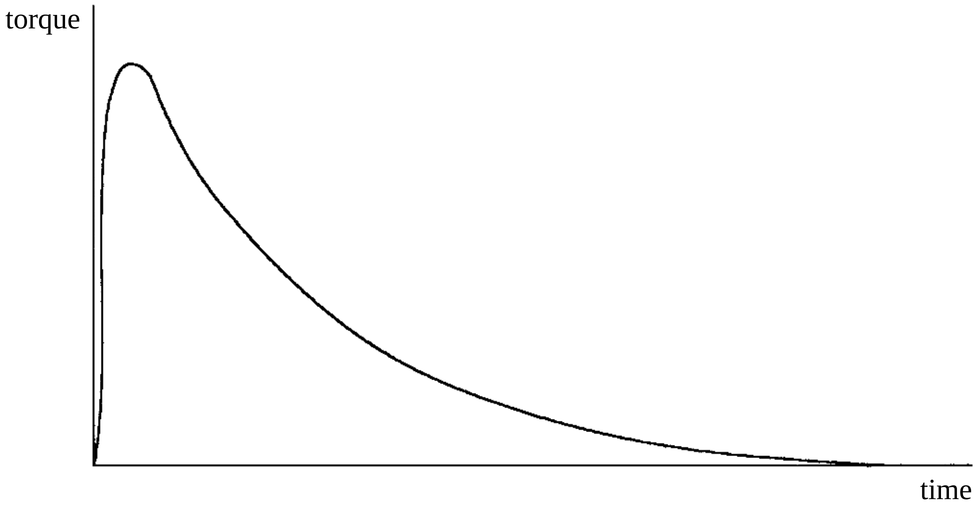
(2 marks)

(c) The torque is not constant during the retardation but is a maximum just after the current is established in the junction. The graph below shows the way that the torque varies with time during any welding operation.



Explain how you could use the graph, if the axes were fully calibrated, to estimate the average torque acting on the system during a welding operation.

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(3 marks)

7

TURN OVER FOR THE NEXT QUESTION

4 A spray can contains liquid paint with compressed gas in the space above it, as shown in **Figure 3**. Pressing down the cap opens a valve which allows the gas to expand, forcing paint through the nozzle. The cap is pressed until all the paint is expelled, leaving the can filled with gas at a pressure which is still greater than atmospheric.

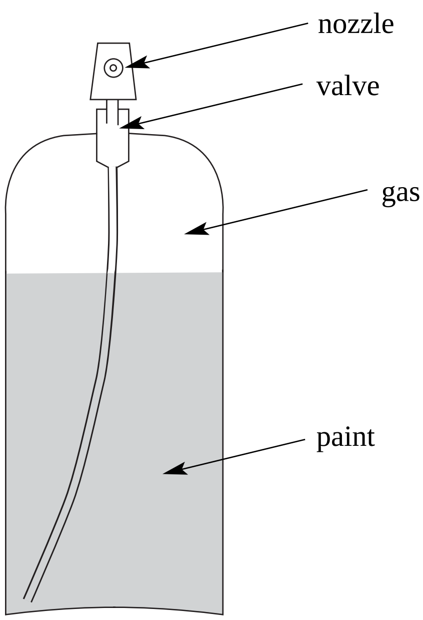

Figure 3

(a) The can has an internal volume of $6.6 \times 10^{-4}\,\text{m}^3$ and initially contains $5.0 \times 10^{-4}\,\text{m}^3$ of paint. The gas in the can is at an initial pressure of $7.8 \times 10^{5}\,\text{Pa}$. The pressure of the gas left in the can when all the paint has just been expelled is $1.9 \times 10^{5}\,\text{Pa}$. Show that the expansion of the gas was an approximately isothermal process.

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(2 marks)

(b) The cap is now pressed again to open the valve and is held down to allow the gas to expand rapidly into the air around the can. The atmospheric pressure is 9.8×10^4 Pa and the temperature of the gas at the start of the expansion is 22 °C.

(i) Explain why this expansion can be considered to be approximately adiabatic.

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(ii) Calculate the total volume that the gas would occupy if it were collected at atmospheric pressure immediately after the expansion.

γ for the gas = 1.4

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(3 marks)

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TURN OVER FOR THE NEXT QUESTION

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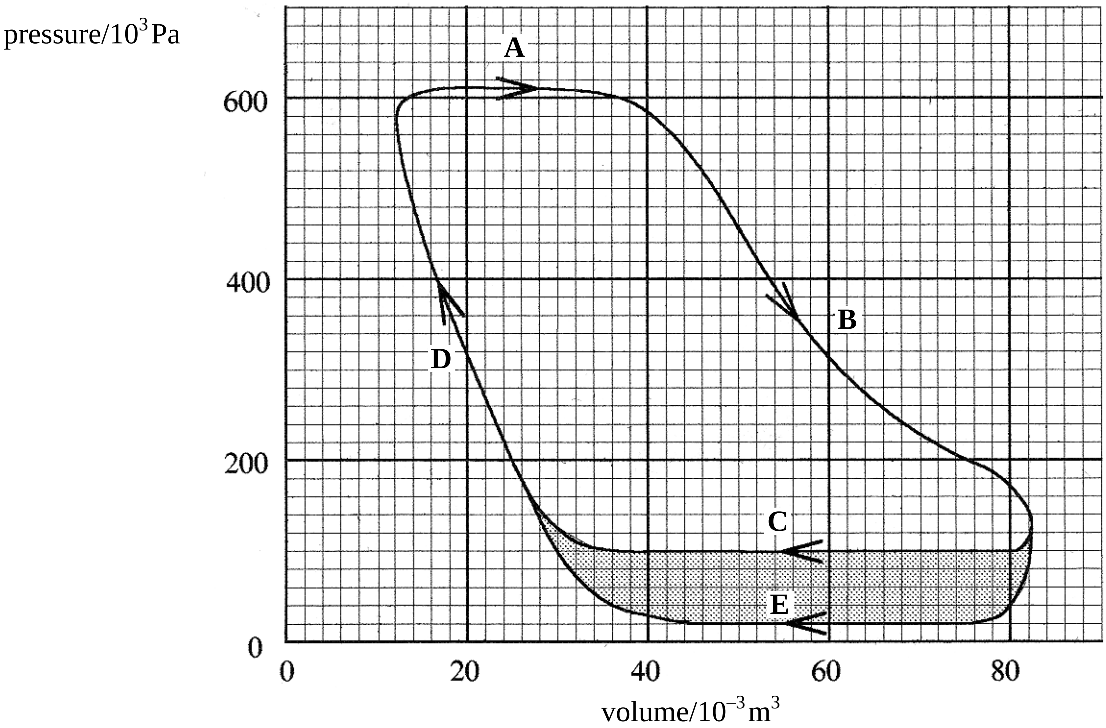
5 The line **ABCD** in the graph below is the indicator diagram for a single cylinder steam engine in which the exhaust steam is released directly into the atmosphere.



(a) (i) Calculate the work done by the engine during the cycle **ABCD**.

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(ii) Calculate the indicated output power of the engine when running at 3 cycles per second.

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(iii) To achieve this output power, fuel of calorific value 34 MJ kg^{-1} must be burnt at a rate of 2.4×10^{-2} kg s^{-1}. Calculate the thermal efficiency of the engine.

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(5 marks)

(b) The line **ABED** in the graph is the indicator diagram for the same engine after a modification has been made so that the exhaust steam is passed into a condenser, where it is converted to water. The hot water formed is returned to the boiler for reheating.

Without further calculation, compare the performance of the modified engine with that of the original engine when both engines are making the same number of cycles per second. In your comparison you should consider the fuel consumption of the engines, the mass of steam supplied to them, their power outputs and efficiencies.

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

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(3 marks)

8

QUALITY OF WRITTEN COMMUNICATION

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END OF QUESTIONS