Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2004
Advanced Level Examination

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

Thursday 17 June 2004 Morning Session

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

Time allowed: 1 hour 15 minutes

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

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.

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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}	$\mathrm{m\ s^{-1}}$
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 $= 4\pi r^2$

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

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

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. $= N \frac{\Delta\Phi}{\Delta t}$

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

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

Mechanical and Thermal Properties

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

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

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

$\Delta Q = ml$

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

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

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 $= eV$

$F = 6\pi\eta r v$

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

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

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

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

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

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

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

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

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

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

$v = Hd$

$P = \sigma A T^4$

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

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

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

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

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

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

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

$X_C = \frac{1}{2\pi f C}$

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

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SECTION A: NUCLEAR INSTABILITY

Answer **all** parts of the question.

1 (a) A radioactive source gives an initial count rate of 110 counts per second. After 10 minutes the count rate is 84 counts per second.

background radiation = 3 counts per second

(i) Give **three** origins of the radiation that contributes to this background radiation.

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2 ....

3 ....

(ii) Calculate the decay constant of the radioactive source in s^{-1}.

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(iii) Calculate the number of radioactive nuclei in the initial sample assuming that the detector counts all the radiation emitted from the source.

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(7 marks)

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(b) Discuss the dangers of exposing the human body to a source of α radiation. In particular compare the dangers when the α source is held outside, but in contact with the body, with those when the source is placed inside the body.

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

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(3 marks)

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10

TURN OVER FOR THE NEXT QUESTION

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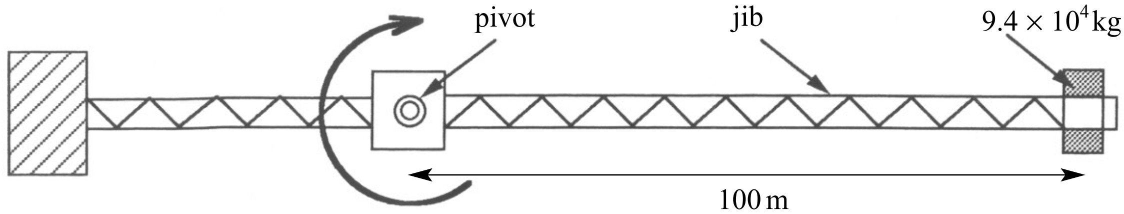
SECTION B: APPLIED PHYSICS

Answer **all** questions.

2 The diagram shows an overhead view of the jib of a tower crane carrying its maximum permitted load of 9.4×10^4 kg at a distance of 100 m from the pivot of the jib. The manufacturer states that, under these conditions, at least 2.5 minutes must be allowed for one complete turn of the jib at constant speed.



(a) The moment of inertia of the unloaded jib about the pivot is 5.3×10^8 kg m^2.

(i) Calculate the moment of inertia of the jib when carrying its maximum load, as shown in the diagram.

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(ii) Calculate the maximum permitted angular speed of the jib, in rad s^{-1}.

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(iii) Show that the rotational kinetic energy of the jib when rotating at this angular speed is 1.3×10^6 J.

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(3 marks)

(b) When the jib is at maximum loading, the motor used to rotate it accelerates the jib from rest to its maximum permitted angular speed in 25 s. Assuming that frictional forces can be neglected, calculate the output power of the motor.

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(1 mark)

(c) When frictional forces in the bearing are taken into account and the jib is rotating at its maximum permitted speed, the motor must produce an output power of 3.0 kW to do work against the frictional torque. Calculate

(i) the frictional torque in the bearings,

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(ii) the total work done against friction in making one turn.

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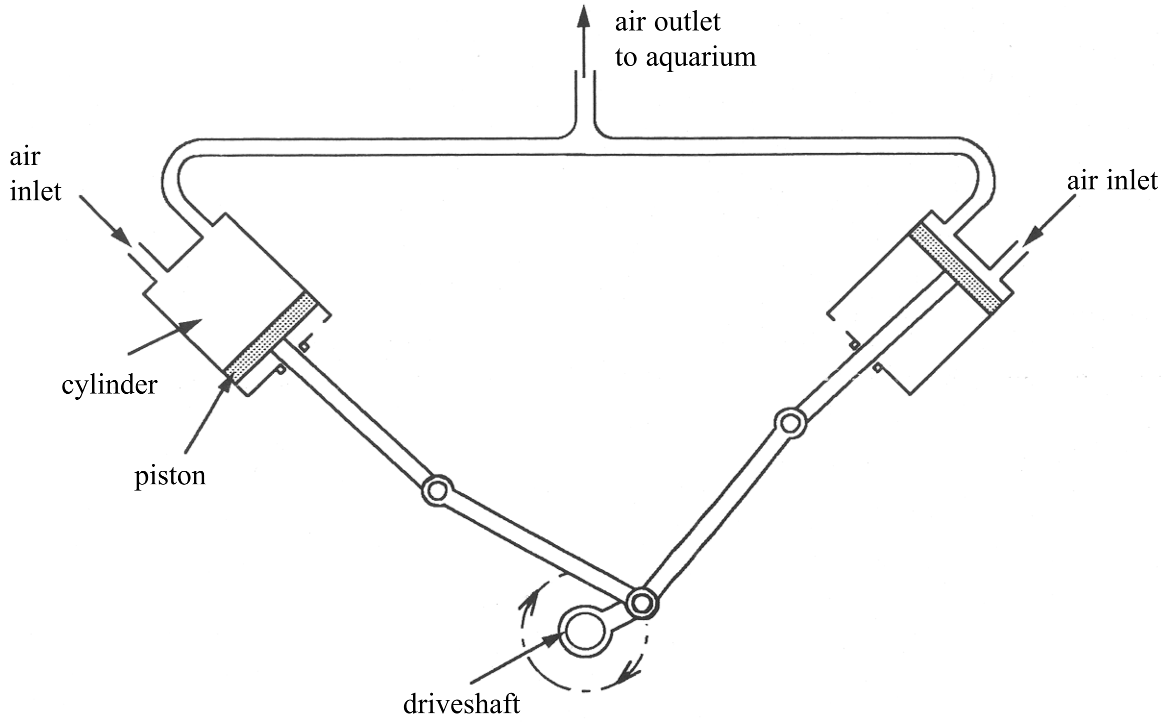
(2 marks)

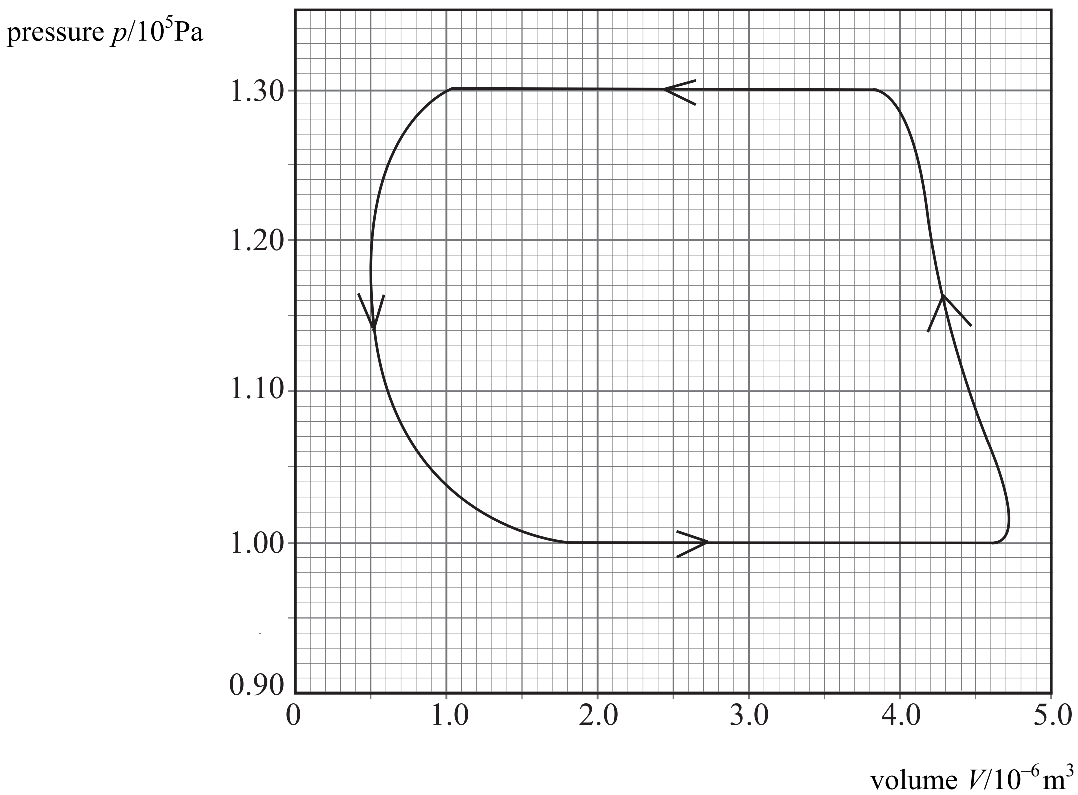
6

TURN OVER FOR THE NEXT QUESTION

Turn over

3 A small, two-cylinder pump shown in the diagram is used for aerating water in an aquarium. The two cylinders are identical and each has a piston driven by a rotating driveshaft so that both cylinders pump air to the aquarium during one rotation of the driveshaft. The inlet and outlet valves controlling the airflow are not shown.





Air at a pressure of 1.00×10^5 Pa is drawn into the cylinders, is compressed and exhausted to an underwater outlet in the aquarium, where it is released as a stream of bubbles. The graph shows the p-V diagram for one cycle of one cylinder.

(a) Use the graph to determine the outlet pressure of the air from the pump.

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(1 mark)

(b) Estimate

(i) the net work done on the air in one cylinder during one revolution of the driveshaft,

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(ii) the power input to the pump if the driveshaft rotates at 360 rev min^{-1}.

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(6 marks)

(c) Give **one** reason why the motor driving the pump would need to have a greater power than your answer to part (b) (ii).

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(1 mark)

8

Turn over ▸

4 (a) The first law of thermodynamics can be represented by $\Delta Q = \Delta U + \Delta W$.

State and explain, with reference to the equation, **two** ways in which the internal energy of a gas can be decreased.

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

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(3 marks)

(b) A volume of $20\,m^3$ of exhaust gas from a diesel engine leaves the exhaust pipe at a pressure of 1.0×10^5 Pa. The gas is cooled by the surrounding atmosphere, which is also at a pressure of 1.0×10^5 Pa, and, as a result, the exhaust gas contracts to half its volume.

(i) Calculate the work done by the atmosphere on the gas during this contraction.

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(ii) 4.9 MJ of heat is transferred to the atmosphere during cooling. Using the first law of thermodynamics, calculate the change in internal energy of the gas.

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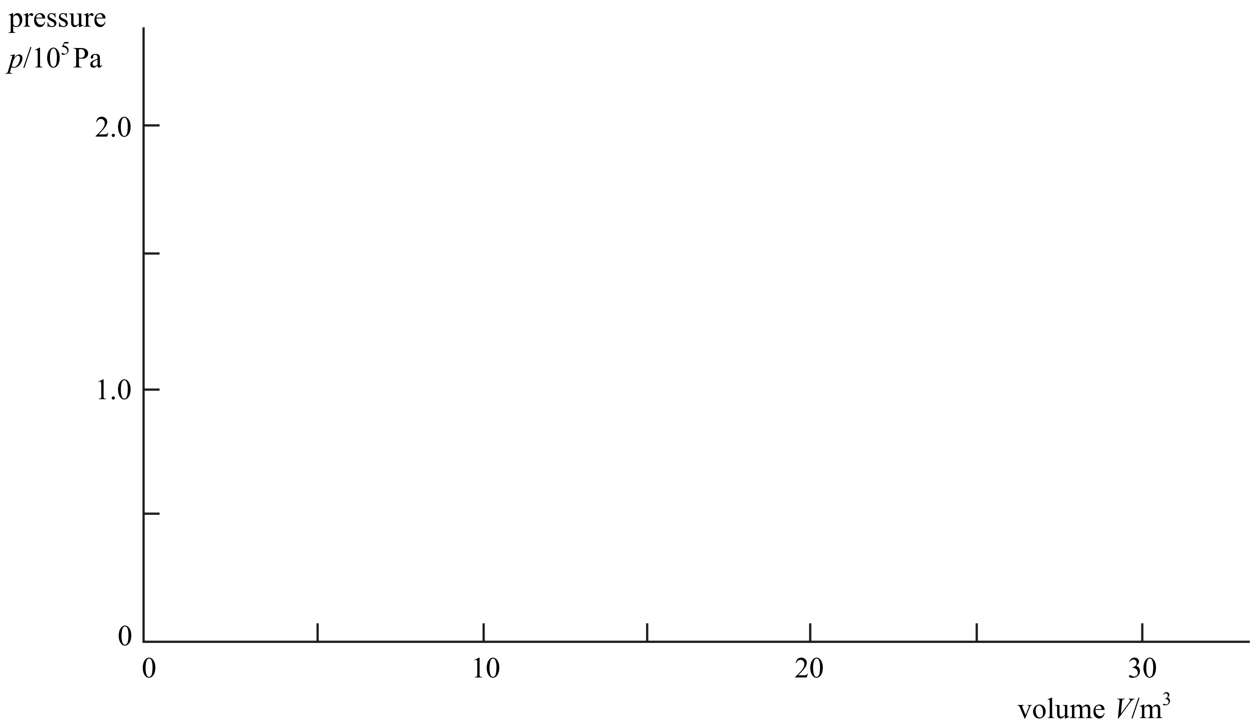
(iii) Use the axes below to represent this process as a *p*-*V* diagram, showing the direction of the process.



(5 marks)

8

TURN OVER FOR THE NEXT QUESTION

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5 After replacing a tyre on a car wheel, the wheel must be 'balanced' before refitting on the car to prevent excessive vibration. The wheel is balanced using a wheel-balancing machine which measures the characteristics of the wheel as it rotates at steady speed. One such machine has a cycle of operation in which the wheel is accelerated uniformly from rest to an angular speed of 35 rad s^{-1} during the first 1.7 s. It is kept at constant speed while measurements are made and finally braked uniformly to rest in the last 3.0 s. The complete cycle takes 12 s.

(a) Calculate

(i) the angular acceleration of the wheel during the first part of the cycle,

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(ii) the torque needed to produce this acceleration in a wheel which has a moment of inertia of 0.85 kg m^2,

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(iii) the angular impulse applied to this wheel during the first part of the cycle.

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(3 marks)

(b) Show that the wheel makes approximately 54 turns during one cycle of operation.

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(3 marks)

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6

QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

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2

END OF QUESTIONS

THERE ARE NO QUESTIONS PRINTED ON THIS PAGE

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