Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

Leave blank

General Certificate of Education
June 2003
Advanced Level Examination

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

ASSESSMENT and QUALIFICATIONS ALLIANCE

Friday 20 June 2003 Afternoon 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

$v = u + at$

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

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

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

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

$P = Fv$

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

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

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

$I = \sum mr^2$

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

$\omega_2 = \omega_1 + \alpha t$

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

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

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

$T = I\alpha$

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^{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

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

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

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

$\Delta Q = ml$

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

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

Nuclear Physics and Turning Points in Physics

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

$force = Bev$

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

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

$work\ done = eV$

$F = 6\pi\eta rv$

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

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

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

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

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

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

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

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

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

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}

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

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

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

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

$v = Hd$

$P = \sigma AT^4$

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

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

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

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** parts of the question.

1 **Figure 1** shows a grid of neutron number against proton number. A nucleus $^{A}_{Z}X$ is marked.

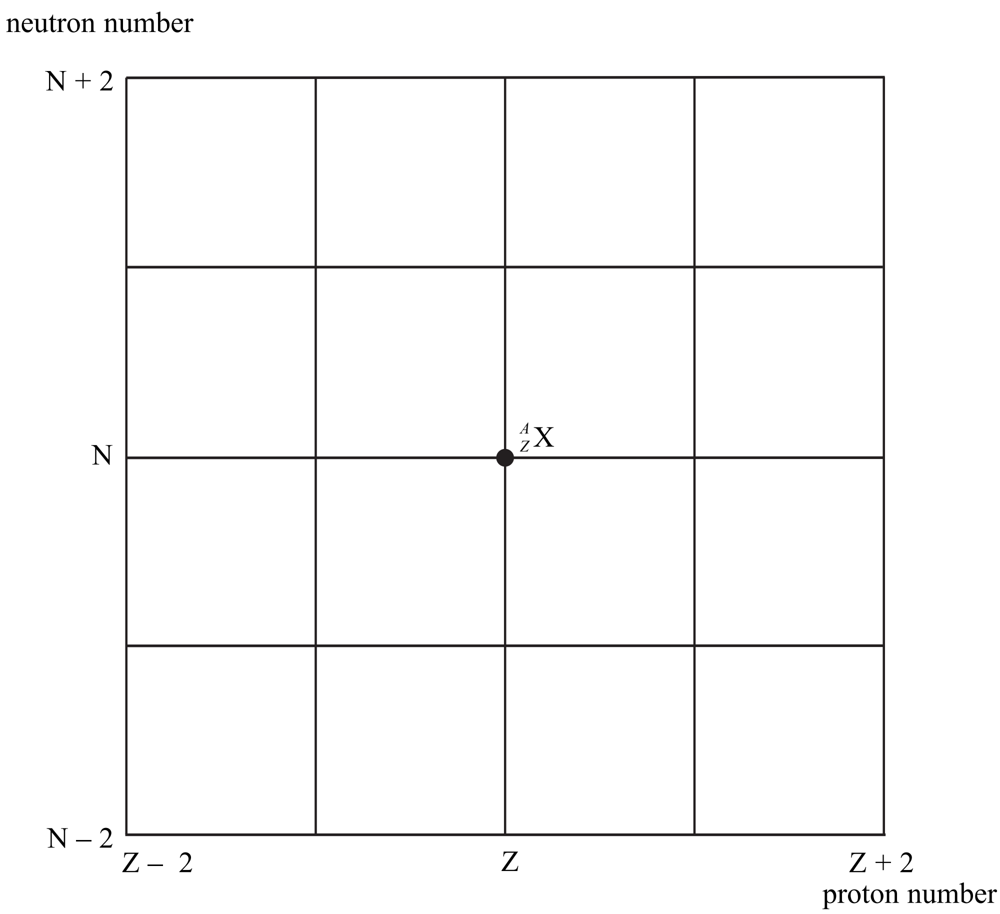


Figure 1

(a) Draw arrows on **Figure 1**, each starting on $^{A}_{Z}X$ and ending on a daughter nucleus after the following transitions:

(i) β^- emission (label this arrow A)
neutron emission (label this arrow B)
electron capture (label this arrow C).

(ii) Give the equation for electron capture by the nucleus $^{A}_{Z}X$.

....

(4 marks)

LEAVE MARGIN BLANK

(b) When $^{27}_{12}Mg$ decays to $^{27}_{13}Al$ by β^- decay, the daughter nucleus is produced in one of two possible excited states. These two states are shown in **Figure 2** together with their corresponding energies.

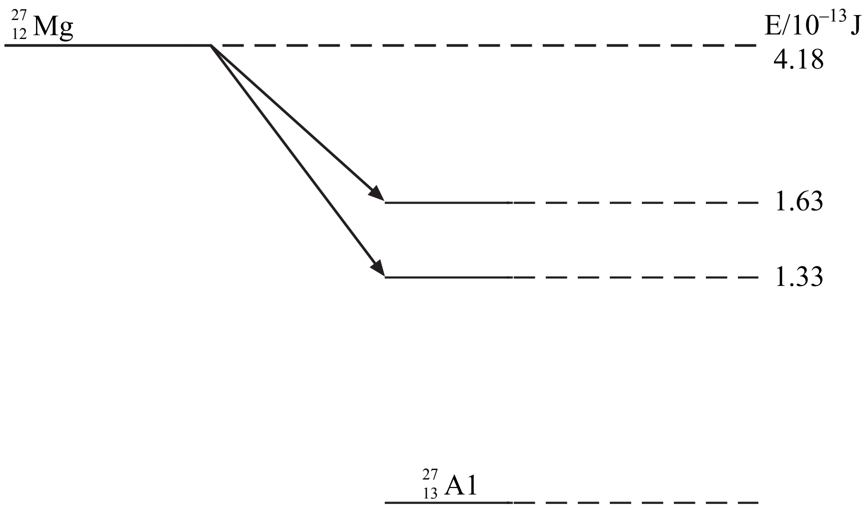


Figure 2

(i) Calculate the maximum possible kinetic energy, in J, which an emitted β^- particle can have.

....

....

(ii) The excited aluminium nuclei emit γ photons. Calculate each of the three possible γ photon energies in J.

....

....

....

(iii) Calculate the frequency of the most energetic γ photon emitted.

....

....

....

(3 marks)

LEAVE MARGIN BLANK

(c) (i) State and explain **two** precautions that should be taken when working with a sample of $^{27}_{12}Mg$ in a school laboratory.

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

....

....

....

....

....

....

....

....

(ii) Discuss which of the two types of radiation, β^- or γ, emitted from a sample of $^{27}_{12}Mg$ would be the more hazardous.

....

....

....

(3 marks)

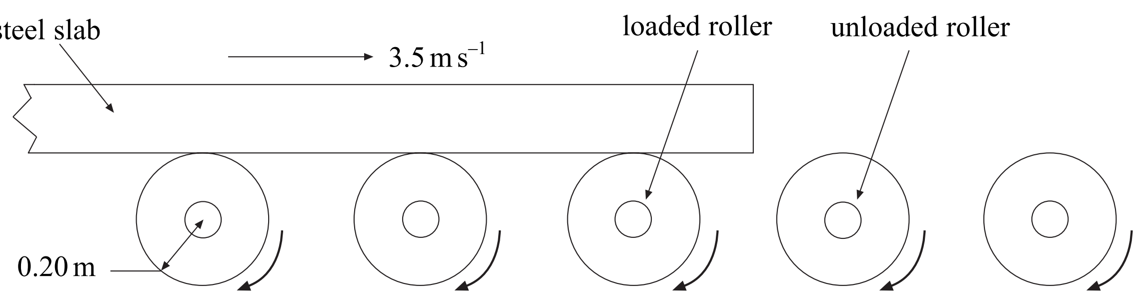
10

TURN OVER FOR THE NEXT QUESTION

SECTION B APPLIED PHYSICS

Answer **all** questions.

2 The diagram below shows a method used in a steel mill to transport steel slabs during the manufacture of steel beams. The slab rests on rollers of radius 0.20 m, each of which is driven by its own electric motor. In one operation, a slab moving at $3.5\,\mathrm{m\,s^{-1}}$ along the rollers must be brought to rest and its direction of motion reversed.



(a) Assuming that no sliding occurs between the surfaces of a loaded roller and the slab, calculate the angular speed of the roller when the slab is moving at a steady speed of $3.5\,\mathrm{m\,s^{-1}}$.

....

....

(1 mark)

(b) While the slab is moving at $3.5\,\mathrm{m\,s^{-1}}$, the motor driving each roller exerts a uniform torque for 4.6 s on its roller such that the direction of motion of the slab is reversed. At the end of this time, the slab is moving at $3.5\,\mathrm{m\,s^{-1}}$ in the opposite direction.

Calculate

(i) the angular acceleration of a roller during this reversal,

....

....

....

(ii) the uniform torque that its motor must exert to produce this angular acceleration in an unloaded roller. The moment of inertia of each unloaded roller system is $40\,\mathrm{kg\,m^2}$,

....

....

(iii) the angular impulse imparted when this torque acts on the system for 4.6 s,

....

....

(iv) the number of complete turns made by a loaded roller in bringing the slab momentarily to rest from a speed of 3.5 m s^{-1} before reversing its direction of motion.

....

....

....

....

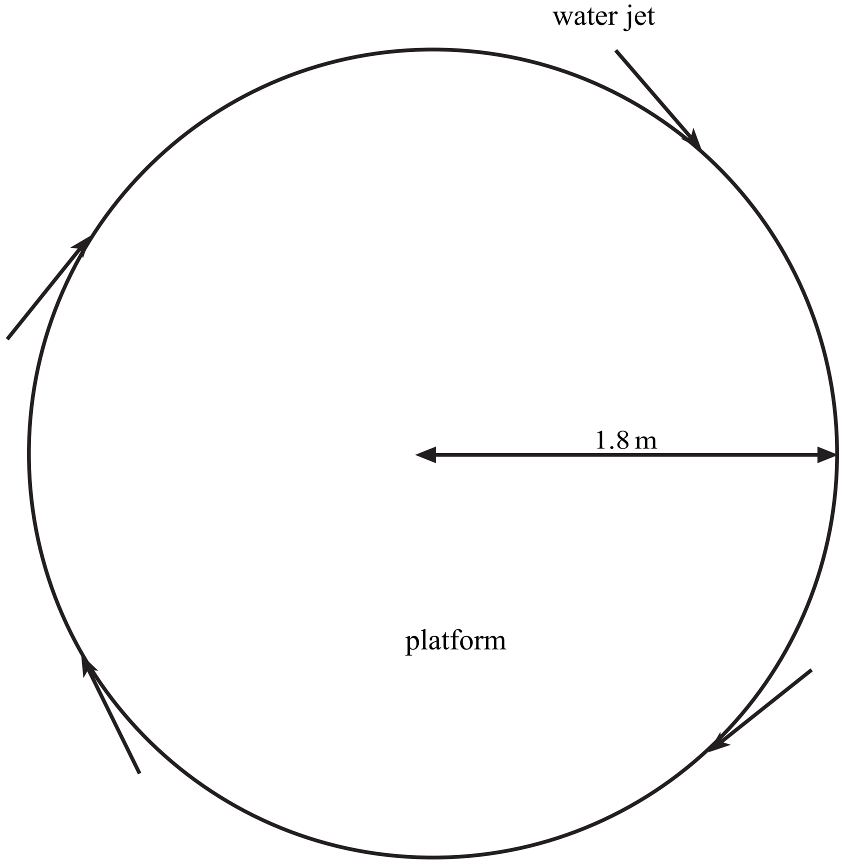
....

(6 marks)

7

TURN OVER FOR THE NEXT QUESTION

3 A rotating flower bed forms a novelty feature in the annual display of a horticultural society. The circular platform supporting the plants floats in a water tank and is caused to rotate by means of four water jets directed at the rim of the platform.



Each of the four jets exerts a tangential force of 0.60 N on the platform at a distance of 1.8 m from the axis of the rotation. The platform rotates at a steady angular speed, making one complete revolution in 110 s.

(a) Calculate

(i) the total torque exerted on the platform by the four jets,

....

....

(ii) the power dissipated by the frictional couple acting on the rotating platform, showing your reasoning.

....

....

....

....

(4 marks)

LEAVE MARGIN BLANK

(b) When the water jets are switched off, all the kinetic energy of the loaded platform is dissipated as heat by the frictional couple and the platform comes to rest from its normal steady speed in 12 s.

(i) The kinetic energy of the loaded platform when rotating at its normal steady speed is 1.5 J. Show that this value is consistent with your answer to part (a)(ii).

....

....

....

(ii) Calculate the moment of inertia of the loaded platform.

....

....

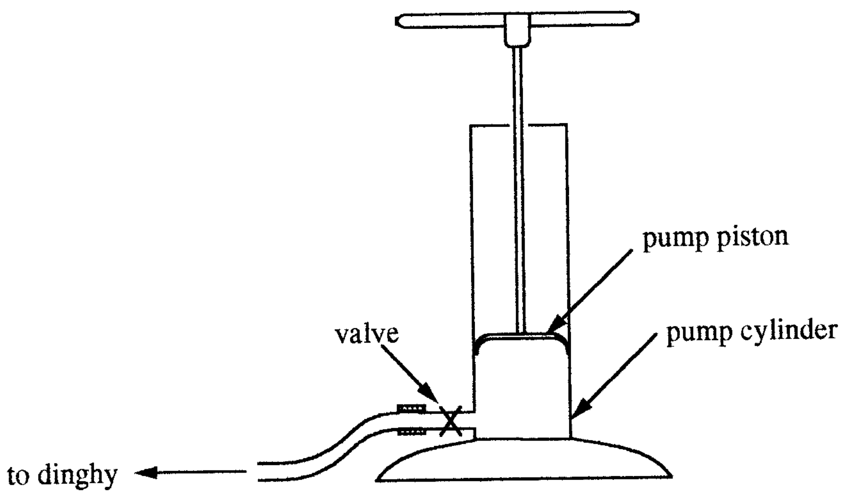
....

(3 marks)

7

TURN OVER FOR THE NEXT QUESTION

4 The diagram below shows a pump used to inflate a rubber dinghy. When the piston is pushed down, the pressure of air in the cylinder increases until it reaches the pressure of the air in the dinghy. At this pressure the valve opens and air flows at almost constant pressure into the dinghy.



(a) The pump is operated quickly so the compression of the air in the cylinder before the valve opens can be considered adiabatic.
At the start of a pump stroke, the pump cylinder contains 4.25×10^{-4} m^3 of air at a pressure of 1.01×10^5 Pa and a temperature of 23 °C. The pressure of air in the dinghy is 1.70×10^5 Pa.

Show that, when the valve is about to open, the volume of air in the pump is 2.93×10^{-4} m^3.

γ for air = 1.4

....

....

....

....

(2 marks)

(b) Calculate the temperature of the air in the pump when the valve is about to open.

....

....

....

....

(3 marks)

(c) State, explaining your reasons, whether the volume of air in the cylinder at the point when the valve opens would be less than, equal to or greater than $2.93 \times 10^{-4}\,m^3$ if the compression of the air had been carried out very slowly. You may find it helpful to sketch a pV diagram of the compression.

....

....

....

....

....

....

(3 marks)

—
8

TURN OVER FOR THE NEXT QUESTION

5 A single cylinder steam engine has an idealised indicator diagram as shown in **Figure 1**. Between **A** and **B** the cylinder is connected directly to a source of high pressure steam. Between **C** and **D** the cylinder is connected to the atmosphere.

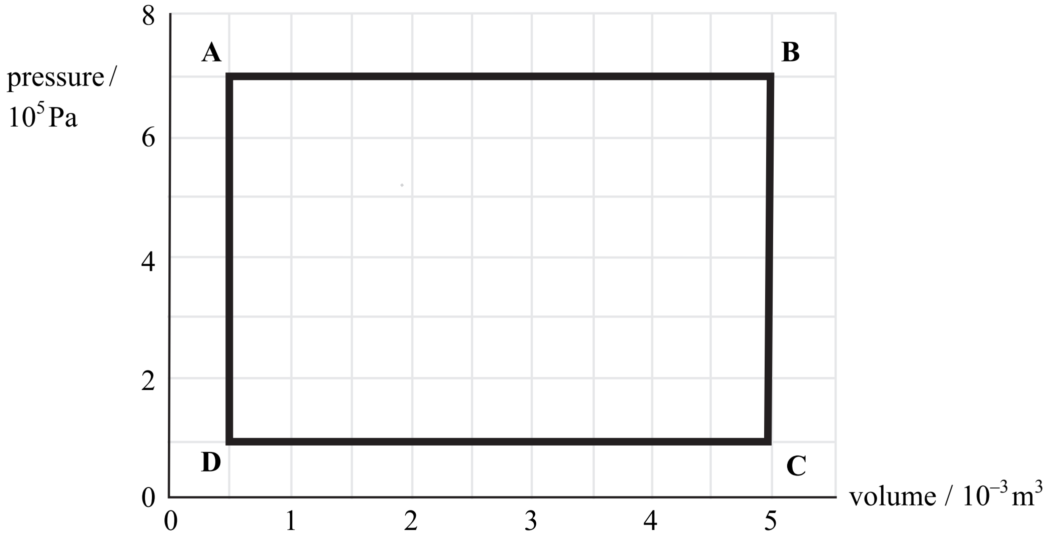


Figure 1

(a) Calculate the indicated power output of the engine when it is working at a rate such that one cycle takes 0.20 s.

....

....

....

....

(2 marks)

LEAVE MARGIN BLANK

(b) In a modified version of the engine, the steam input is cut off when the piston is part way along its stroke. The new indicator diagram is shown in **Figure 2**.

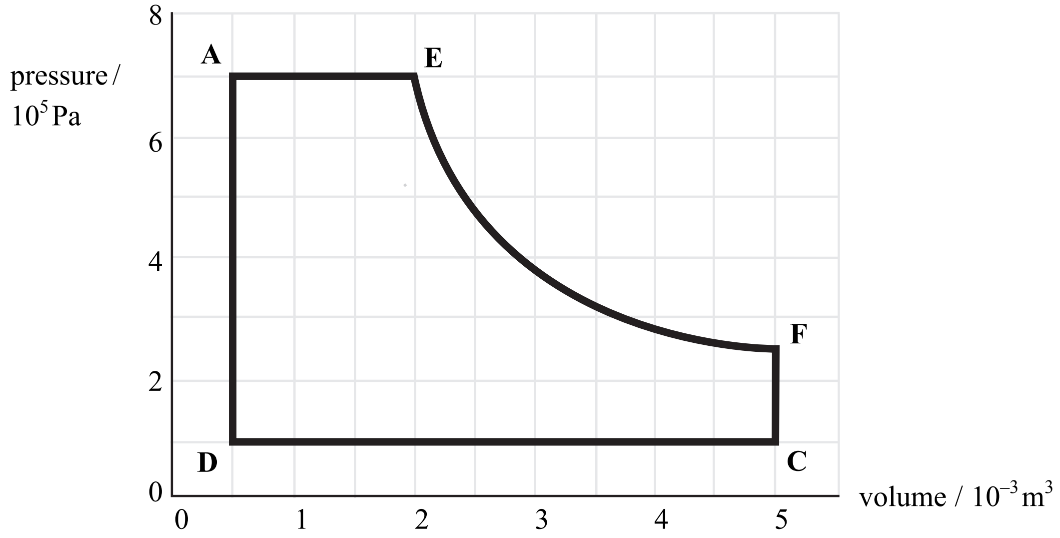


Figure 2

Use **Figures 1** and **2** to compare the performance of an engine based on the modified cycle 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 steam supplied to the engines, their power outputs and their efficiencies.

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

....

....

....

....

....

....

....

(4 marks)

6

QUALITY OF WRITTEN COMMUNICATION *(2 marks)*

2

END OF QUESTIONS