

Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

For Examiner's Use

General Certificate of Education
June 2007
Advanced Level Examination



ASSESSMENT and
QUALIFICATIONS
ALLIANCE

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

PHA7/W

Thursday 14 June 2007 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 to be marked.

Information

- The maximum mark for this paper is 40.
- Two of these marks will be awarded for using good English, organising information clearly and using specialist vocabulary where appropriate.
- 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.
- Questions 1(a) and 5(b) should be answered in continuous prose. In these questions you will be marked on your ability to use good English, to organise information clearly and to use specialist vocabulary where appropriate.

For Examiner's Use			
Question	Mark	Question	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				Mechanics and Applied Physics		Fields, Waves, Quantum Phenomena	
Quantity	Symbol	Value	Units				
speed of light in vacuo	c	3.00×10^8	m s^{-1}	$v = u + at$		$g = \frac{F}{m}$	
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}	$s = \left(\frac{u+v}{2}\right)t$		$g = -\frac{GM}{r^2}$	
permittivity of free space	ϵ_0	8.85×10^{-12}	F m^{-1}	$s = ut + \frac{at^2}{2}$		$g = -\frac{\Delta V}{\Delta x}$	
charge of electron	e	1.60×10^{-19}	C	$v^2 = u^2 + 2as$		$V = -\frac{GM}{r}$	
the Planck constant	h	6.63×10^{-34}	J s	$F = \frac{\Delta(mv)}{\Delta t}$		$a = -(2\pi f)^2 x$	
gravitational constant	G	6.67×10^{-11}	$\text{N m}^2 \text{kg}^{-2}$	$P = Fv$		$v = \pm 2\pi f \sqrt{A^2 - x^2}$	
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}	$\text{efficiency} = \frac{\text{power output}}{\text{power input}}$		$x = A \cos 2\pi ft$	
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$	$\omega = \frac{v}{r} = 2\pi f$		$T = 2\pi \sqrt{\frac{m}{k}}$	
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}	$a = \frac{v^2}{r} = r\omega^2$		$T = 2\pi \sqrt{\frac{L}{g}}$	
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$	$I = \sum mr^2$		$\lambda = \frac{\omega s}{D}$	
the Wien constant	a	2.90×10^{-3}	m K	$E_k = \frac{1}{2} I\omega^2$		$d \sin \theta = n\lambda$	
electron rest mass	m_e	9.11×10^{-31}	kg	$\omega_2 = \omega_1 + \alpha t$		$\theta \approx \frac{\lambda}{D}$	
(equivalent to $5.5 \times 10^{-4}u$)				$\theta = \omega_1 t + \frac{1}{2} \alpha t^2$		$n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$	
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}	$\omega_2^2 = \omega_1^2 + 2\alpha\theta$		$n_2 = \frac{n_2}{n_1}$	
proton rest mass	m_p	1.67×10^{-27}	kg	$\theta = \frac{1}{2} (\omega_1 + \omega_2)t$		$\sin \theta_c = \frac{1}{n}$	
(equivalent to 1.00728u)				$T = I\alpha$		$E = hf$	
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}	$\text{angular momentum} = I\omega$		$hf = \phi + E_k$	
neutron rest mass	m_n	1.67×10^{-27}	kg	$W = T\theta$		$hf = E_1 - E_2$	
(equivalent to 1.00867u)				$P = T\omega$		$\lambda = \frac{h}{p} = \frac{h}{mv}$	
gravitational field strength	g	9.81	N kg^{-1}	$\text{angular impulse} = \text{change of angular momentum} = Tt$		$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$	
acceleration due to gravity	g	9.81	m s^{-2}	$\Delta Q = \Delta U + \Delta W$		Electricity	
atomic mass unit	u	1.661×10^{-27}	kg	$\Delta W = p\Delta V$		$\epsilon = \frac{E}{Q}$	
(1u is equivalent to 931.3 MeV)				$pV^\gamma = \text{constant}$		$\epsilon = I(R + r)$	
Fundamental particles				$\text{work done per cycle} = \text{area of loop}$		$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$	
Class	Name	Symbol	Rest energy	$\text{input power} = \text{calorific value} \times \text{fuel flow rate}$		$R_T = R_1 + R_2 + R_3 + \dots$	
			/MeV	$\text{indicated power as (area of } p-V \text{ loop)} \times (\text{no. of cycles/s}) \times (\text{no. of cylinders})$		$P = I^2 R$	
photon	photon	γ	0	$\text{friction power} = \text{indicated power} - \text{brake power}$		$E = \frac{F}{Q} = \frac{V}{d}$	
lepton	neutrino	ν_e	0	$\text{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$		$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$	
		ν_μ	0	$\text{maximum possible efficiency} = \frac{T_H - T_C}{T_H}$		$E = \frac{1}{2} QV$	
	electron	e^\pm	0.510999			$F = BIl$	
	muon	μ^\pm	105.659			$F = BQv$	
mesons	pion	π^\pm	139.576			$Q = Q_0 e^{-t/RC}$	
		π^0	134.972			$Q = \frac{Q_0}{BA}$	
	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 = πr^2							
area of cylinder = $2\pi rh$							
volume of cylinder = $\pi r^2 h$							
area of sphere = $4\pi r^2$							
volume of sphere = $\frac{4}{3}\pi r^3$							

$$\text{magnitude of induced emf} = N \frac{\Delta\Phi}{\Delta t}$$

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

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

Mechanical and Thermal Properties

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

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

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

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

Nuclear Physics and Turning Points in Physics

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

$$\text{force} = Bev$$

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

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

$$\text{work done} = eV$$

$$F = 6\pi\eta rv$$

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

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

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

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

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

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

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

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

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

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

$$1 \text{ astronomical unit} = 1.50 \times 10^{11} \text{ m}$$

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

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

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

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

Medical Physics

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

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

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

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

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

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

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

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

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

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

Alternating Currents

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

Operational amplifier

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

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

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

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

Turn over for the first question

SECTION A: NUCLEAR INSTABILITY

Answer **all** of this question.

- 1 (a) X and Y are two different β emitting sources. Initially they contain the same number of unstable nuclei. Both sources have their emissions recorded over a period of time. The *decay constant* of source X is greater than that of Y. State what is meant by decay constant and describe **two** differences in the recordings from the two sources.

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

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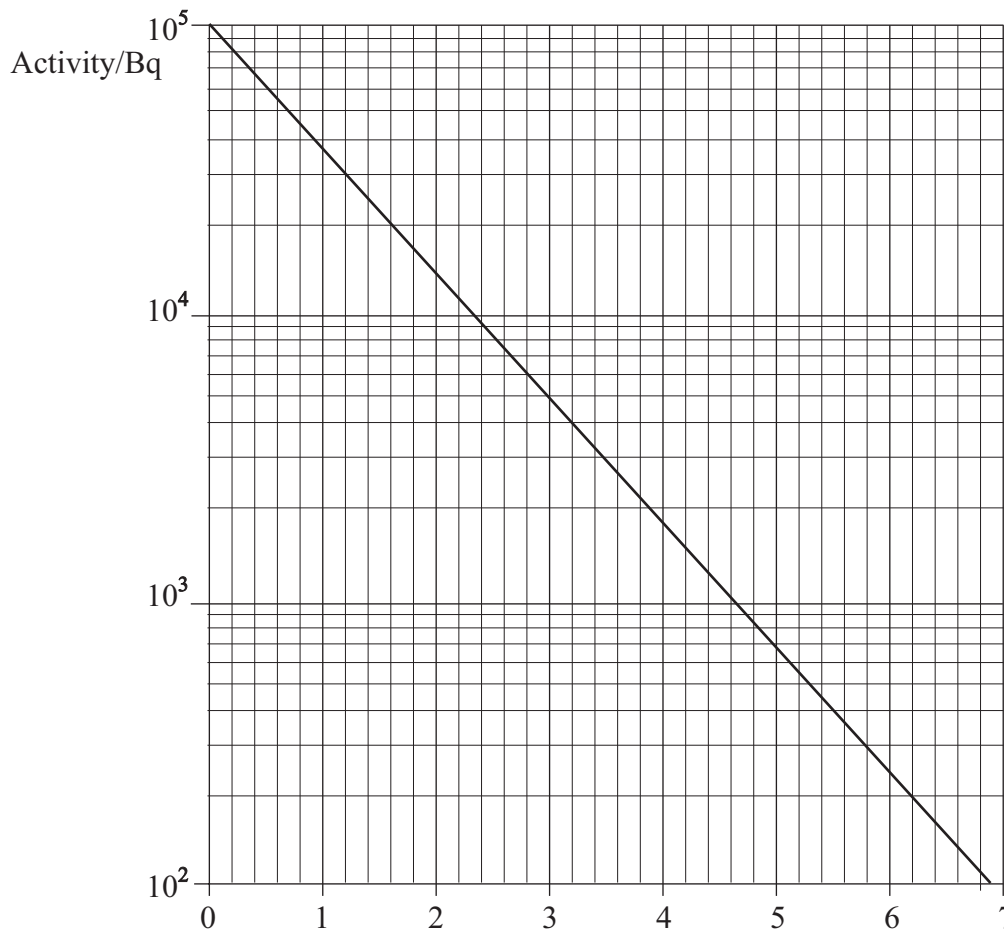
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(3 marks)

- (b) The activity of a sample of radioactive iodine, $^{131}_{53}\text{I}$, is presented in the following graph.



- (i) Show that the decay constant of $^{131}_{53}\text{I}$ is about $1 \times 10^{-6} \text{ s}^{-1}$.

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- (ii) Calculate the half-life of $^{131}_{53}\text{I}$ in days.

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- (iii) Calculate the initial number of $^{131}_{53}\text{I}$ atoms in the sample.

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(7 marks)

Turn over for the next question

10

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SECTION B: APPLIED PHYSICSAnswer **all** questions.

2 Wood chips are burned in a power plant to produce steam that drives turbine generators to generate electricity. Fast-growing trees are specially grown for this purpose. The power plant has an efficiency of 24 %.

- (a) Calculate the energy input to the power plant to give a daily electrical energy output of 1.30×10^{11} J.

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(1 mark)

- (b) The calorific value of the wood chips is 10.4 MJ kg^{-1} . Calculate the daily mass of wood chips required.

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(1 mark)

- (c) The maximum temperature of the steam is 420°C and the minimum temperature is 10°C .

- (i) Calculate the maximum theoretical efficiency of a heat engine operating between these temperatures.

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- (ii) State **one** reason why in practice the power plant has a lower efficiency than your answer to part (c)(i).

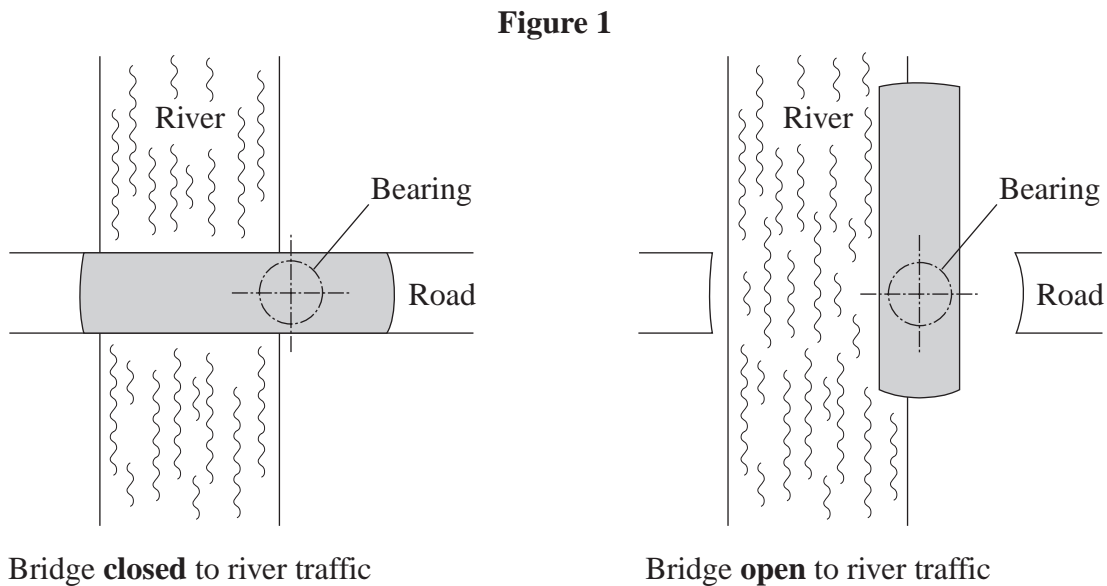
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- (iii) State **one** advantage of wood grown for fuel instead of oil or coal to produce steam for the power plant, even though the wood-fuelled power plant may be less efficient.

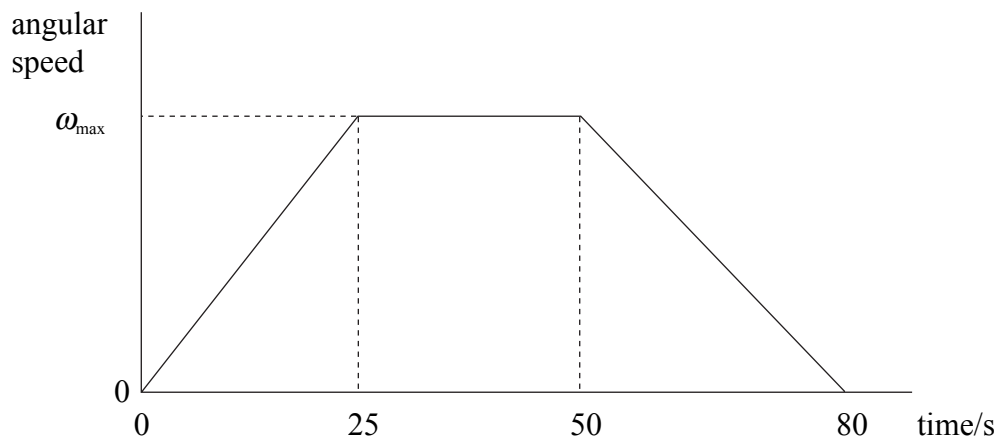
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(4 marks)

- 3 A swing bridge carries road traffic over a river. To allow movement of river boats, the bridge opens by turning through an angle of 90° in a time of 80 seconds. **Figure 1** shows plan views of the bridge in closed and open positions.



The graph below shows the variation of angular speed of the bridge from fully closed to fully open. The bridge accelerates, moves at constant angular speed and then decelerates to a standstill.



(a) (i) Show that the maximum angular speed, ω_{\max} , of the bridge is 0.030 rad s^{-1} .

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(ii) Calculate the angular acceleration of the bridge in the first 25 s.

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(3 marks)

(b) The moment of inertia of the bridge about its axis of rotation is $9.1 \times 10^8 \text{ kg m}^2$.
When the bridge is moving, a constant frictional torque of $3.5 \times 10^5 \text{ N m}$ acts to oppose its motion.

Calculate

(i) the torque that must be applied by the driving motor of the bridge to give the bridge the angular acceleration calculated in part (a)(ii),

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(ii) the power output of the driving motor to keep the bridge moving at constant angular speed between 25 s and 50 s,

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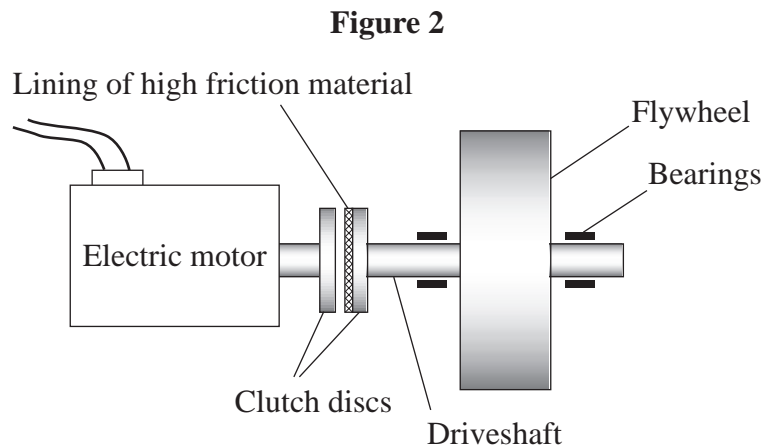
(iii) the maximum kinetic energy of the bridge.

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(4 marks)



- 4 **Figure 2** shows a friction clutch which enables an electric motor to be easily connected to and disconnected from a flywheel. When the motor needs to be connected to the flywheel the discs are forced into contact and slipping occurs for a short time until the motor and flywheel rotate at a common angular speed. The clutch is then said to be engaged.



- (a) The flywheel is initially stationary and the motor is rotating at $1500 \text{ rev min}^{-1}$. The rotating parts (the rotor and clutch disc) of the electric motor have a moment of inertia of 0.56 kg m^2 .
Calculate the angular momentum of the motor.

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(2 marks)

- (b) The motor is now connected by means of the clutch to the flywheel. The moment of inertia of the flywheel and driveshaft is 0.94 kg m^2 .
- (i) Explain why the speed of the motor falls as the clutch engages.

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- (ii) Calculate the common angular speed of the motor and flywheel immediately after the clutch is engaged.

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- (iii) Calculate the angular impulse on the flywheel as the clutch engages.

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(5 marks)

7

Turn over for the next question

- 5 (a) The p - V diagram in **Figure 3** shows the theoretical cycle for a petrol engine in which a fixed mass of air is taken through the following four processes:

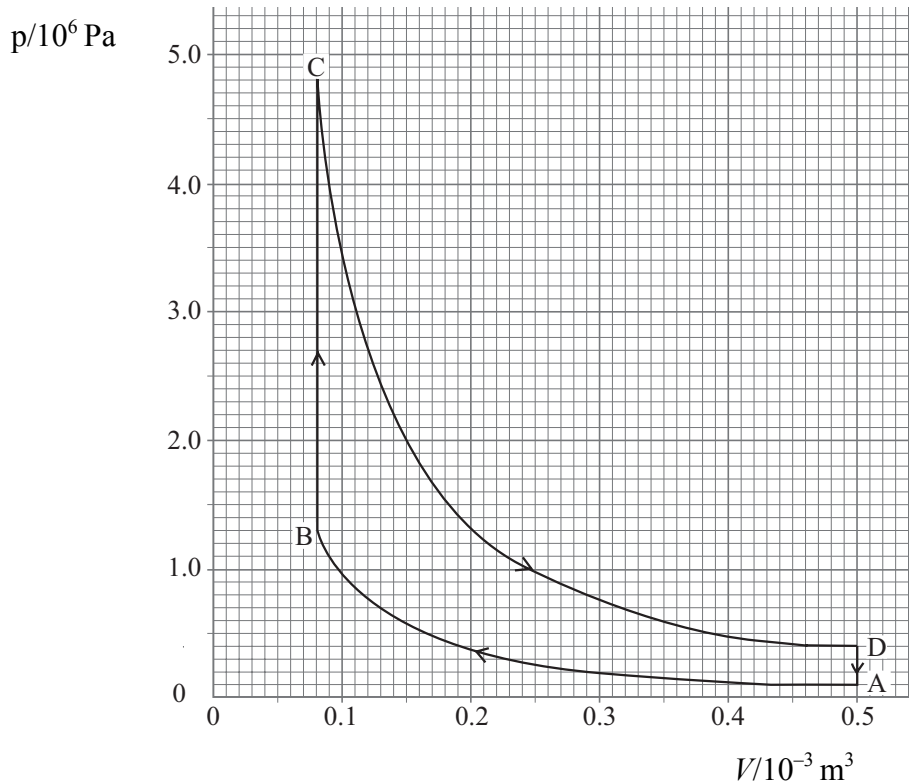
A \rightarrow B adiabatic compression from an initial temperature of 293 K

B \rightarrow C addition of 700 J of energy at constant volume

C \rightarrow D adiabatic expansion

D \rightarrow A reduction in pressure at constant volume.

Figure 3



- (i) Apply the first law of thermodynamics to determine the change in internal energy of the air in process B \rightarrow C.

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- (ii) Show that 0.021 mol of air are taken through the cycle.

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(iii) Determine the work output of the cycle.

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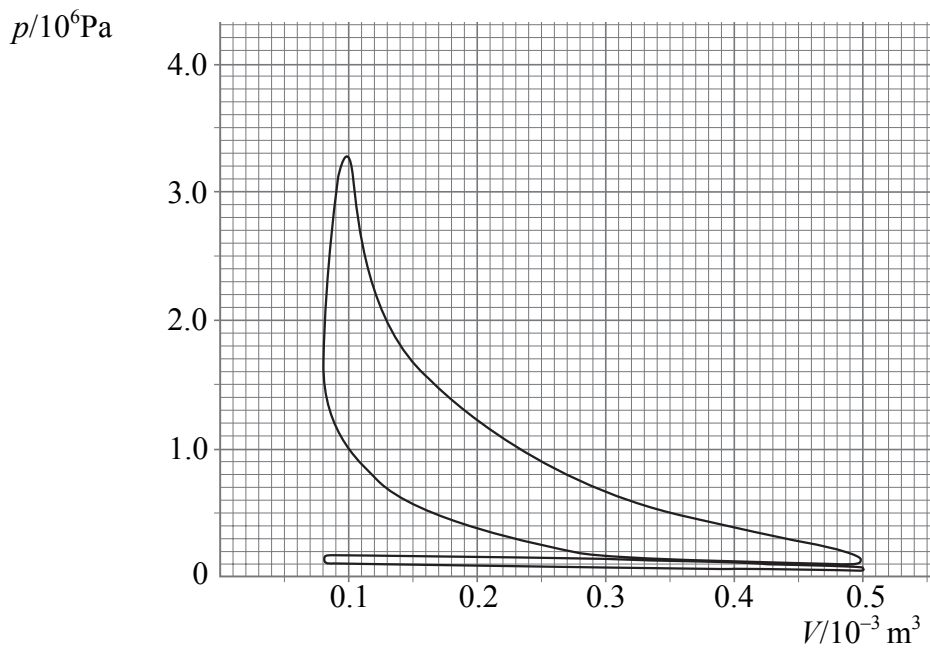
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(6 marks)

(b) **Figure 4** shows the p - V diagram taken from a real four-stroke petrol engine having the same maximum and minimum volumes as the cycle shown in **Figure 3**.

Figure 4



Explain **two** differences between the theoretical and real cycles (as illustrated by **Figures 3 and 4**).

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

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(2 marks)

Quality of Written Communication (2 marks)

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