| Surname | | Other Names | |
|---|---|---|---|
| Centre Number | | Candidate Number | |
| Candidate Signature | | | |

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General Certificate of Education
January 2004
Advanced Level Examination

ASSESSMENT and QUALIFICATIONS ALLIANCE

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

Monday 26 January 2004 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 | | | |
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| 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 | $c$ | $3.00 \times 10^{8}$ | $m\ s^{-1}$ |
| permeability of free space | $\mu_0$ | $4\pi \times 10^{-7}$ | $H\ m^{-1}$ |
| permittivity of free space | $\varepsilon_0$ | $8.85 \times 10^{-12}$ | $F\ m^{-1}$ |
| charge of electron | $e$ | $1.60 \times 10^{-19}$ | C |
| the Planck constant | $h$ | $6.63 \times 10^{-34}$ | J s |
| gravitational constant | $G$ | $6.67 \times 10^{-11}$ | $N\ m^{2}\ kg^{-2}$ |
| the Avogadro constant | $N_A$ | $6.02 \times 10^{23}$ | $mol^{-1}$ |
| molar gas constant | $R$ | 8.31 | $J\ K^{-1}\ mol^{-1}$ |
| the Boltzmann constant | $k$ | $1.38 \times 10^{-23}$ | $J\ K^{-1}$ |
| the Stefan constant | $\sigma$ | $5.67 \times 10^{-8}$ | $W\ m^{-2}\ K^{-4}$ |
| the Wien constant | $\alpha$ | $2.90 \times 10^{-3}$ | m K |
| electron rest mass (equivalent to $5.5 \times 10^{-4}$u) | $m_e$ | $9.11 \times 10^{-31}$ | kg |
| electron charge/mass ratio | $e/m_e$ | $1.76 \times 10^{11}$ | $C\ kg^{-1}$ |
| proton rest mass (equivalent to 1.00728u) | $m_p$ | $1.67 \times 10^{-27}$ | kg |
| proton charge/mass ratio | $e/m_p$ | $9.58 \times 10^{7}$ | $C\ kg^{-1}$ |
| neutron rest mass (equivalent to 1.00867u) | $m_n$ | $1.67 \times 10^{-27}$ | 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 | $1.661 \times 10^{-27}$ | kg |

## Fundamental particles

| Class | Name | Symbol | Rest energy /MeV |
|---|---|---|---|
| photon | photon | $\gamma$ | 0 |
| lepton | neutrino | $\nu_e$ | 0 |
| | | $\nu_\mu$ | 0 |
| | electron | $e^{\pm}$ | 0.510999 |
| | muon | $\mu^{\pm}$ | 105.659 |
| mesons | pion | $\pi^{\pm}$ | 139.576 |
| | | $\pi^{0}$ | 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* $= Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$pV^{\gamma}$ = 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

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

$\epsilon = I(R + r)$

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

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

$P = I^2 R$

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

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

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

$F = BIl$

$F = BQv$

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

$\Phi = BA$

Turn over ▶

**Data Sheet**



*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* $= \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F}{A}\frac{l}{e}$

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

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

$\Delta Q = ml$

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

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

## 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* $= eV$

$F = 6\pi\eta rv$

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

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

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

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

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

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

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

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

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

## Astrophysics and Medical Physics

| *Body* | *Mass*/kg | *Mean radius*/m |
|---|---|---|
| Sun | $2.00 \times 10^{30}$ | $7.00 \times 10^{8}$ |
| Earth | $6.00 \times 10^{24}$ | $6.40 \times 10^{6}$ |

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$^{-1}$

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

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

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

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

$v = Hd$

$P = \sigma AT^4$

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

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

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

## Medical Physics

*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

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

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

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

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

## Alternating Currents

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

## Operational amplifier

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

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

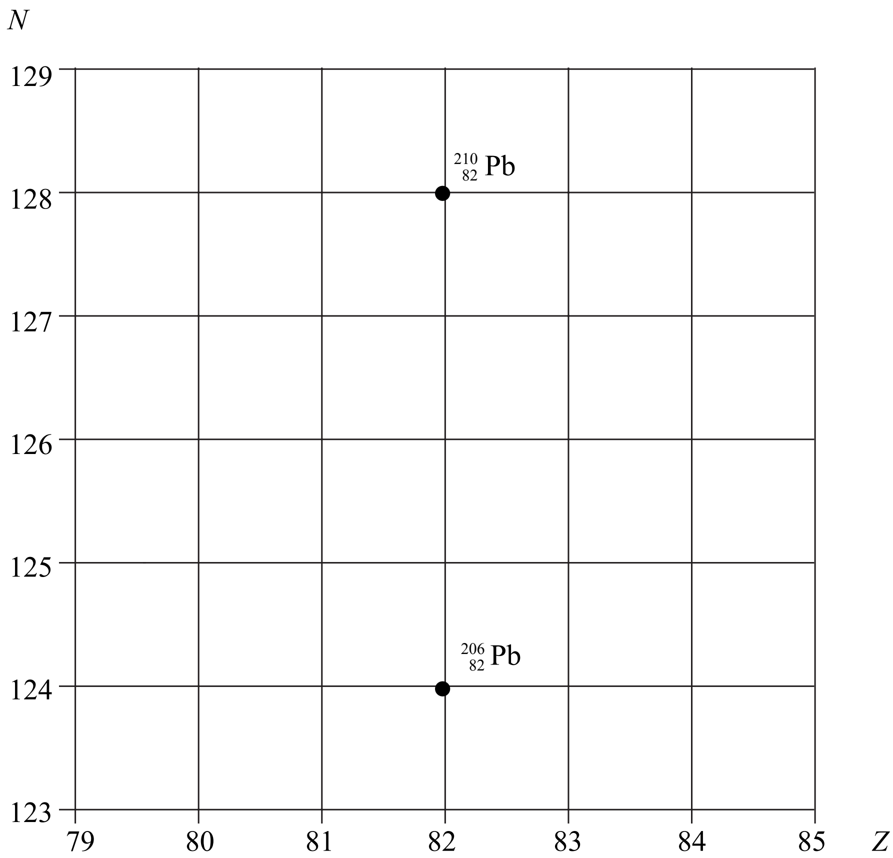
$G = 1 + \frac{R_f}{R_1}$ non-inverting

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

## SECTION A: NUCLEAR INSTABILITY

Answer **all** of this question

**1** (a) The lead nuclide $^{210}_{82}Pb$ is unstable and decays in three stages through $\alpha$ and $\beta$ emissions to a different lead nuclide $^{206}_{82}Pb$. The position of these lead nuclides on a grid of neutron number, *N*, against proton number, *Z*, is shown below.




On the grid draw **three** arrows to represent one possible decay route.
Label each arrow with the decay taking place. *(3 marks)*

(b) The copper nuclide $^{64}_{29}Cu$ may decay by positron emission or by electron capture to form a nickel (Ni) nuclide.
Complete the two equations that represent these two possible modes of decay.

positron emission $^{64}_{29}Cu$

electron capture $^{64}_{29}Cu$

*(4 marks)*

LEAVE MARGIN BLANK

(c) The nucleus of an atom may be investigated by scattering experiments in which radiation or particles bombard the nucleus.

Name **one** type of radiation or particle that may be used in this investigation and describe the main physical principle of the scattering process.

State the information which can be obtained from the results of this scattering.

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

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*(3 marks)*

$\overline{\phantom{10}}$
*10*

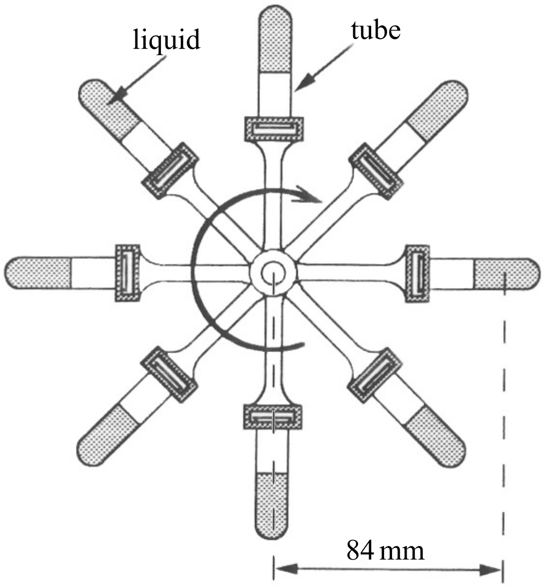
**TURN OVER FOR THE NEXT QUESTION**

**Turn over ▶**

**SECTION B: APPLIED PHYSICS**

Answer **all** questions.

**2** The diagram shows an overhead view of the load carrier of a spinning centrifuge, used to separate solid particles from the liquid in which they are suspended.




(a) When the centrifuge is operated with empty tubes, it reaches its working angular speed of $1100\,\mathrm{rad\,s^{-1}}$ in a time of 4.2 s, starting from rest. The moment of inertia of this system is $7.6 \times 10^{-4}\,\mathrm{kg\,m^2}$. Calculate

(i) the angular acceleration of the system,

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(ii) the torque required to produce this angular acceleration.

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*(2 marks)*

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(b) In normal operation, each of the eight tubes contains $3.0 \times 10^{-3}$ kg of liquid, whose centre of mass, when spinning, is 84 mm from the axis of rotation. The torque produced by the motor is the same as when the tubes are empty.

Show that this system takes approximately 5 s to reach its working speed of 1100 rad $s^{-1}$, starting from rest.

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*(3 marks)*

(c) The normal operating cycle of the centrifuge takes a total time of 1 min. The centrifuge accelerates uniformly during the first 5.0 s to a speed of 1100 rad $s^{-1}$, after which the speed remains constant until the final 6.0 s of the cycle, during which it is brought to rest uniformly. Calculate the angle turned by a tube during one complete operating cycle.

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*(3 marks)*

*8*

**TURN OVER FOR THE NEXT QUESTION**

**3** An electric motor drives a machine which stamps out washers from a metal sheet. The motor is coupled to a flywheel of moment of inertia 38 $\text{kg m}^2$, which is accelerated until it is rotating at 480 $\text{rev min}^{-1}$. The motor drive to the flywheel is then disconnected and some of the kinetic energy of the flywheel is used to do work in the stamping operation.

(a) (i) Calculate the angular speed of the flywheel, in $\text{rad s}^{-1}$, when it is rotating at 480 $\text{rev min}^{-1}$.

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(ii) Show that the rotational kinetic energy of the flywheel when it is rotating at this speed is 48 kJ.

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*(2 marks)*

(b) During the stamping operation, the punch is in contact with the metal sheet for 150 ms. The kinetic energy of the flywheel is reduced by 12 kJ during this time. Calculate

(i) the angular speed of the flywheel immediately after the stamping,

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(ii) the angular impulse acting on the flywheel during the stamping,

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(iii) the mean retarding torque acting on the flywheel during the stamping.

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*(3 marks)*

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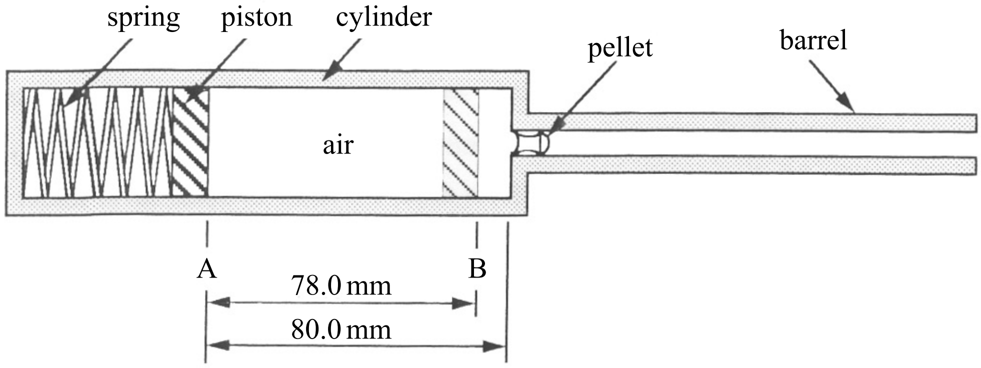
**4** The diagram shows the mechanism of an air gun. The energy needed to propel the pellet is stored in a spring which is held in compression by a trigger. Pulling the trigger releases the spring, which pushes the piston rapidly along the cylinder from A to B. This compresses the air behind the pellet, exerting a force on it and causing it to accelerate along the barrel.




When the piston is at A, the air in the cylinder is at a pressure of 103 kPa and a temperature of 291 K. After the spring is released, the pellet remains in place until the piston reaches B.

(a) (i) The internal cross-sectional area of the cylinder is $1.77 \times 10^{-4}\,\text{m}^2$. Calculate the quantity of air, in moles, contained in the cylinder.

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(ii) Estimate the pressure of the air in the cylinder when the piston has just reached B.
$\gamma$ for air = 1.4

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(iii) Estimate the temperature of the air in the cylinder when the piston has just reached B.

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*(6 marks)*

**Turn over ▸**

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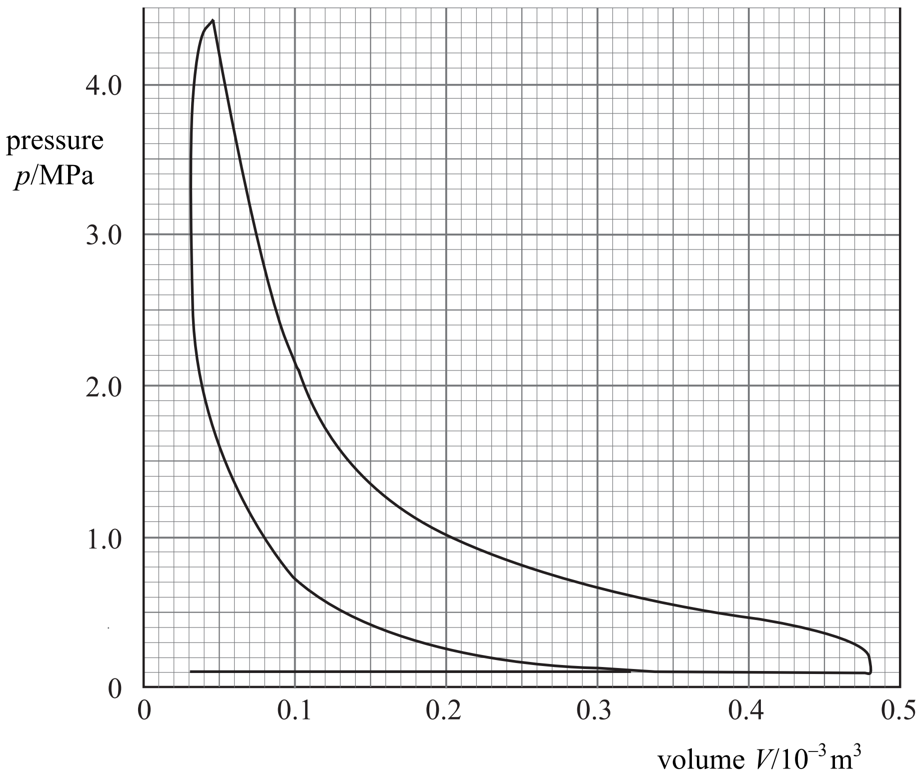
**5** The indicator diagram below is for a single-cylinder, four-stroke internal combustion engine. The measurements were made during a test in which a constant load was applied to the engine output shaft, which was rotating at a steady 2400 rev min$^{-1}$. During the test, fuel with a calorific value of 42.9 MJ kg$^{-1}$ was supplied at a rate of $4.45 \times 10^{-4}$ kg s$^{-1}$.




(a) Calculate the input power to the engine.

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*(1 mark)*

(b) (i) Show that the indicated work output per cycle is about 350 J.

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(ii) Calculate the indicated output power of the engine.

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*(5 marks)*

(c) The actual output power of the engine was measured as 6.3 kW.

(i) Explain why this value is not the same as the indicated output power of the engine.

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

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(ii) Calculate the overall efficiency of the engine under the conditions of the test.

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*(3 marks)*

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*9*

**QUALITY OF WRITTEN COMMUNICATION** *(2 marks)*

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*2*

**END OF QUESTIONS**