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Centre number

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Forename(s)

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A-level PHYSICS

Paper 3

Section B Engineering physics

Monday 3 June 2019

Afternoon

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
TOTAL	



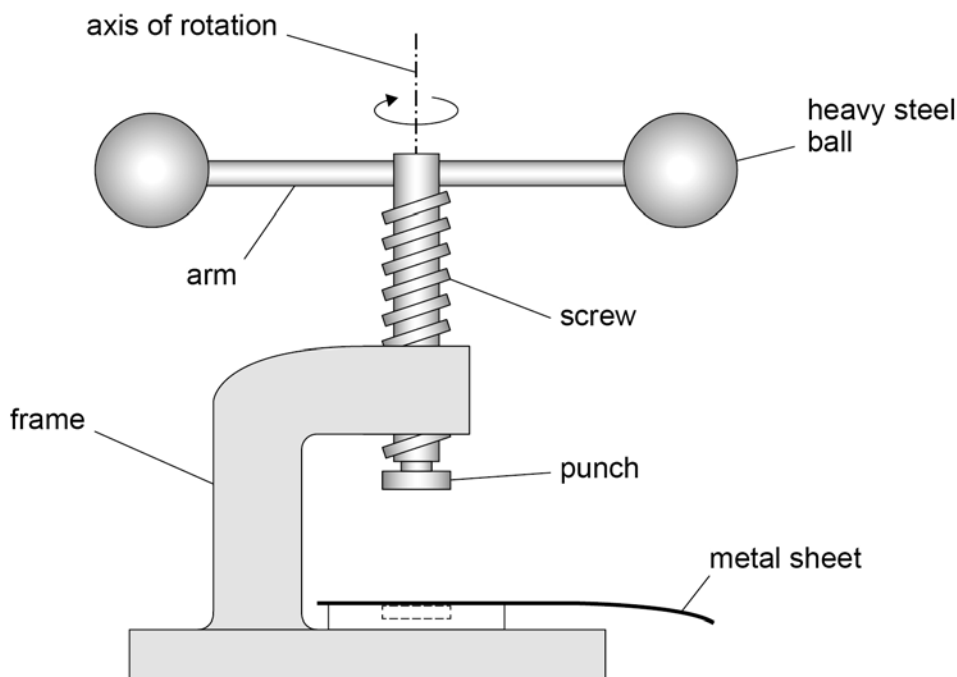
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Section B

Answer **all** questions in this section.

0 1

The fly-press shown in **Figure 1** is used by a jeweller to punch shapes out of a thin metal sheet.

Figure 1

The frame holds a screw and punch. Two arms are attached to the screw, each loaded with a heavy steel ball. The screw is driven downwards when the arms are rotated.

Kinetic energy is stored in the rotating parts: the balls, arms, screw and punch. This energy is used to punch the shape out of the metal sheet.

0 1 . 1

When the punch reaches the metal sheet, the rotational speed of the arms is 2.9 rev s^{-1} . At this speed the rotational kinetic energy of the rotating parts is 10.3 J .

Calculate the moment of inertia of the rotating parts about the axis of rotation.

[2 marks]

$$\omega = 2\pi \times 2.9 = 18.2 \text{ rad s}^{-1}$$

$$E_k = \frac{1}{2} I \omega^2, \text{ so } I = 2E_k \div \omega^2$$

$$I = (2 \times 10.3) \div 18.2^2$$

$$I = 6.2 \times 10^{-2} \text{ kg m}^2$$

moment of inertia = 6.2×10^{-2} kg m^2



0 1 . 2

The total mass of the screw, punch and arms is the same as the total mass of the two balls.

Explain why the moment of inertia of the screw, punch and arms about the axis of rotation is **much** smaller than the moment of inertia of the steel balls about the same axis.

[2 marks]

Moment of inertia depends on how the mass is distributed about the axis of rotation ($I = \Sigma mr^2$).

The mass of the screw, punch and arms is much closer to the axis than the steel balls, and I depends on r^2 , so I is much smaller (r is small and r^2 even smaller).

0 1 . 3

During the punching of the metal sheet, the rotating parts of the fly-press are brought uniformly to rest from an initial rotational speed of 2.9 rev s^{-1} in a time of 89 ms.

Determine

- the angular deceleration
- the angle turned through by the rotating parts.

[3 marks]

$$\omega_1 = 2\pi \times 2.9 = 18.2 \text{ rad s}^{-1}, \omega_2 = 0, t = 0.089 \text{ s}$$

$$\alpha = (\omega_2 - \omega_1) \div t = (0 - 2\pi \times 2.9) \div 0.089$$

$$\alpha = -205 \text{ rad s}^{-2}, \text{ so angular deceleration} = 205 \text{ rad s}^{-2}$$

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

$$\theta = \frac{1}{2} \times (18.2 + 0) \times 0.089$$

$$\theta = 0.81 \text{ rad}$$

angular deceleration = 205 rad s⁻²

angle = 0.81 rad

Question 1 continues on the next page

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0 1 . 4

For thicker or stiffer metal sheets the rotational kinetic energy at 2.9 rev s^{-1} is not enough to punch out the shape.

The distance from the axis of rotation to the centre of each ball is y .

The radius of each ball is R .

The stored energy can be increased by

either

- increasing y by 15% without changing R

or

- increasing R by 15% without changing y .

Deduce which of these would produce the greater increase in stored energy.

[3 marks]

$$E_k = \frac{1}{2} I \omega^2, \text{ so at the same } \omega, E_k \propto I$$

$$\text{For each ball } I = m y^2 \text{ (} I = 2m y^2 \text{ for both), and } m = \rho \times (4/3)\pi R^3$$

$$\text{so } I \propto y^2 \text{ and } I \propto R^3$$

$$\text{Increase } y \text{ by 15\%: new } I = 1.15^2 \times \text{original } I = 1.32 \times \text{original } I$$

$$\text{Increase } R \text{ by 15\%: new } I = 1.15^3 \times \text{original } I = 1.52 \times \text{original } I$$

$$\text{For the same 15\% increase, increasing } R \text{ increases } I \text{ by a factor of 1.52}$$

$$\text{but increasing } y \text{ only by 1.32.}$$

$$\text{Since } E_k = \frac{1}{2} I \omega^2, E_k \text{ increases by the same ratio as } I, \text{ so increasing}$$

$$R \text{ by 15\% gives the greater increase in stored energy.}$$



0 1 . 5

Which of the following is the SI unit for angular impulse?
Tick (✓) **one** box.

[1 mark]

 N m s^{-1} ☐ N s ☐ N m s ☒ $\text{kg m}^2 \text{s}^{-2}$ ☐

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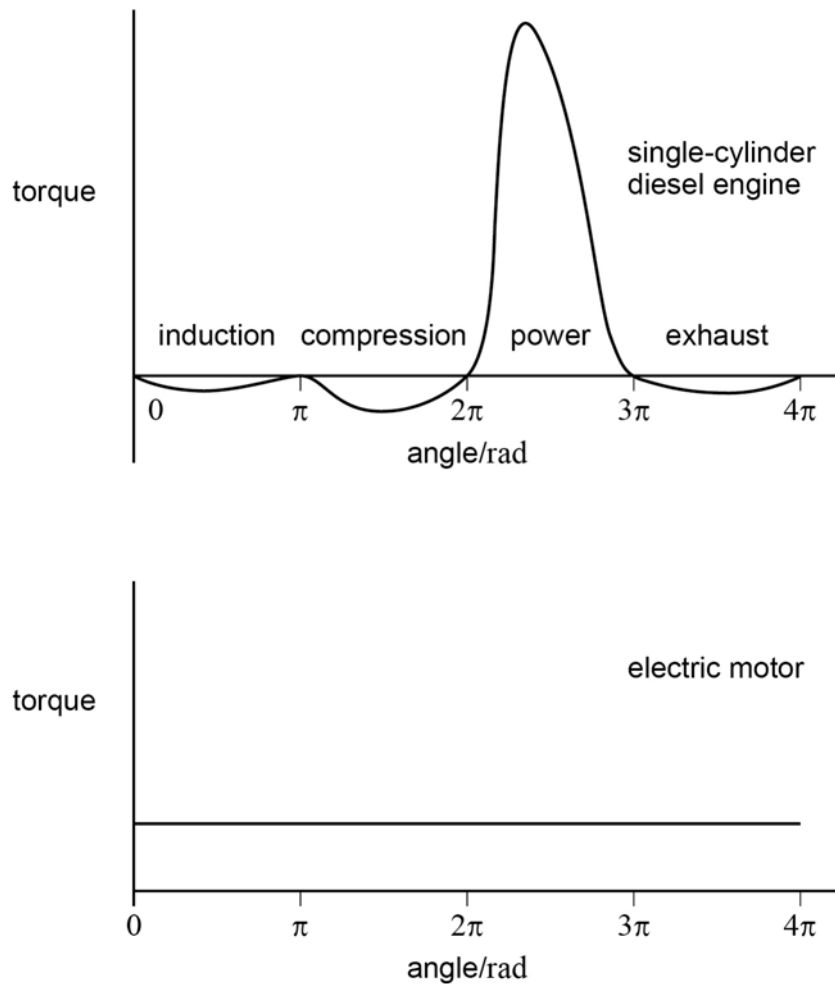


0 2

A turning moment diagram is a graph showing the variation of torque produced by an engine or motor with the angle of rotation of the output shaft.

Figure 2 shows the turning moment diagrams for a single-cylinder diesel engine and an electric motor that have the same output power.

Figure 2



0 2 . 1

State what is represented by the area between the curve and the angle axis for a turning moment diagram.

[1 mark]

The work done (by the torque).



0 2 . 2

The diesel engine or the electric motor may be used to drive a machine that has a low moment of inertia and that requires an almost constant torque.

Discuss why, to drive this machine, the diesel engine would need to be fitted with a flywheel.

In your answer you should explain

- why the electric motor does **not** require a flywheel
- why the torque of the diesel engine varies over one cycle, including why there are points where the torque is zero
- how the moment of inertia of the flywheel influences the motion of the output shaft of the diesel engine.

[6 marks]

The electric motor gives a constant torque throughout each revolution, so its output torque already matches the almost constant torque that the machine needs. Its motion is smooth, so it does not need a flywheel to smooth it.

In the diesel engine the torque comes from the force of the gas pressure on the piston, which varies over one cycle as the pressure in the cylinder changes. Torque = Fr , where the effective r (the perpendicular distance from the axis) changes as the crank rotates.

During the induction, compression and exhaust strokes work is done on the gas by the engine, so the torque is negative. Only the power (expansion) stroke gives a large positive torque.

The torque is zero when the connecting rod and crank are in line, at top and bottom dead centre, because the effective r is zero. This happens at crank angles that are multiples of π .

Without a flywheel, the varying torque of the diesel engine would give uneven, jerky motion of the low moment of inertia machine, and it could stall or slow down a lot between power strokes. The machine has a low moment of inertia so it cannot store energy itself to smooth the

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motion.

A flywheel acts as an energy store: it absorbs energy (speeds up slightly) during the power stroke and gives up energy (slows down slightly) during the other strokes, keeping the shaft turning through them.

The greater the moment of inertia of the flywheel, the smaller the change in angular speed for a given energy change, so the smoother the motion of the output shaft. However, a larger moment of inertia means the engine takes longer to speed up, slow down or stop.



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0 3

In an ideal heat-engine cycle a fixed mass of air is taken through the following four processes.

A → B isothermal compression from an initial pressure of 1.0×10^5 Pa and a volume of $9.0 \times 10^{-2} \text{ m}^3$ to a pressure of 2.2×10^5 Pa. The work done on the air is 7100 J.

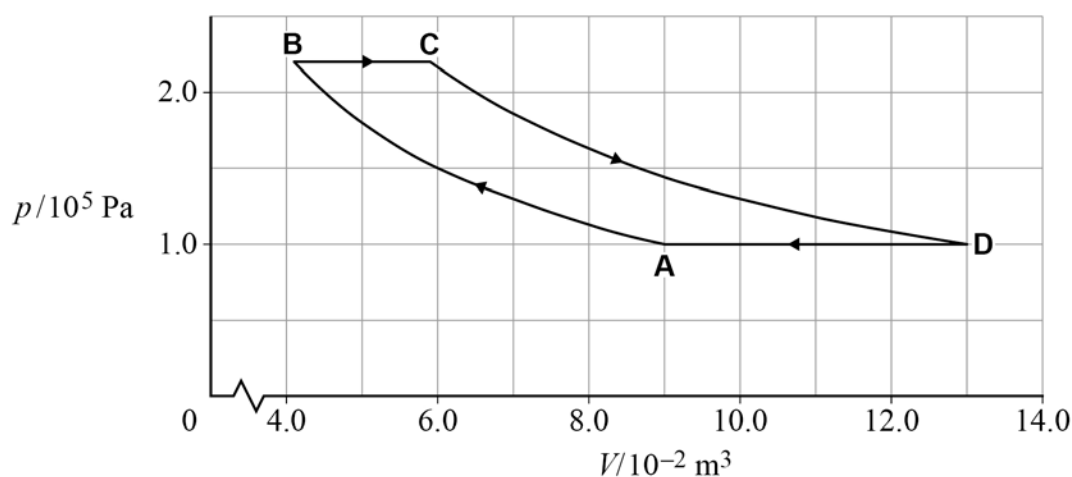
B → C increase in volume at constant pressure to a volume of $5.9 \times 10^{-2} \text{ m}^3$.

C → D isothermal expansion to a pressure of 1.0×10^5 Pa and a volume of $13 \times 10^{-2} \text{ m}^3$. The work done by the air is 10 300 J.

D → A reduction in volume at constant pressure to the original volume.

Figure 3 shows the cycle.

Figure 3



0 3

. 1

Show, by calculation, that the volume at **B** is $4.1 \times 10^{-2} \text{ m}^3$.

[1 mark]

Boyle's law (isothermal): $p_A V_A = p_B V_B$

$$V_B = p_A V_A \div p_B = (1.0 \times 10^5 \times 9.0 \times 10^{-2}) \div 2.2 \times 10^5$$

$$V_B = 4.09 \times 10^{-2} \text{ m}^3 \approx 4.1 \times 10^{-2} \text{ m}^3$$



0 3 . 2 The temperature of the air between **A** and **B** is 295 K.

Show that the temperature of the air at **C** is about 420 K.

[2 marks]

Constant pressure from B to C: $V_B \div T_B = V_C \div T_C$

$$T_C = T_B \times V_C \div V_B = 295 \times (5.9 \times 10^{-2}) \div (4.09 \times 10^{-2})$$

$$T_C = 426 \text{ K, which is about } 420 \text{ K}$$

0 3 . 3 An ideal engine based on this cycle uses a device called an economiser. The economiser stores **all** the energy transferred in the cooling process **D** $\rightarrow$ **A** and gives up **all** this energy to the air in process **B** $\rightarrow$ **C**. This means that an external source supplies energy to the air by heating only in process **C** $\rightarrow$ **D**.

Complete **Table 1** to show the values of work done W and energy transfer Q in each of the four processes.

Use the space below **Table 1** for any calculations.

Use a consistent sign convention.

[2 marks]

Table 1

Process	Work done W / J	Energy transfer Q / J
A $\rightarrow$ B	-7100	-7100
B $\rightarrow$ C	4000	<i>14 000</i>
C $\rightarrow$ D	10 300	10 300
D $\rightarrow$ A	<i>-4000</i>	-14 000

$$D \rightarrow A: W = p\Delta V = 1.0 \times 10^5 \times (9.0 - 13.0) \times 10^{-2} = -4000 \text{ J}$$

(work done on the air, so negative)

B $\rightarrow$ C: the economiser gives all 14 000 J from D $\rightarrow$ A back to the air, so $Q = +14\,000 \text{ J}$

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0 3 . 4

Explain why W is equal to Q in process **A** $\rightarrow$ **B** and in process **C** $\rightarrow$ **D**.

[2 marks]

The first law of thermodynamics applies: $Q = \Delta U + W$.

Both processes are isothermal, so the temperature is constant and the internal energy does not change: $\Delta U = 0$, so $Q = W$.

0 3 . 5

It is claimed that the efficiency of this engine cycle is the same as the maximum theoretical efficiency of a heat engine operating between the same temperatures.

Deduce whether this claim is true.

[3 marks]

Net work done per cycle = $-7100 + 4000 + 10\,300 - 4000 = 3200\text{ J}$

Energy supplied by heating (C $\rightarrow$ D only) = $10\,300\text{ J}$

$\eta = 3200 \div 10\,300 = 0.31$ (31%)

Maximum theoretical efficiency = $(T_H - T_C) \div T_H = (425 - 295) \div 425 = 0.31$ (31%).

The two efficiencies are the same (both 0.31), so the claim is true.



0 3 . 6

Discuss **one** problem that would be faced by an engineer designing a real engine based on this cycle.

[2 marks]

Isothermal processes are very difficult to achieve in a real engine: the engine would have to run very slowly so that heat can flow in or out to keep the temperature constant, or it would need perfectly conducting materials. Running slowly means the power output would be very small for the size of the engine.

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0 4

Tumble-dryers blow hot air over wet clothes that are moving in a rotating drum. Conventional tumble-dryers heat the air in the drum electrically; other dryers use a heat pump to heat the air.

0 4 . 1

A typical conventional tumble-dryer uses about 0.6 kW h per kg of clothes. A heat pump tumble-dryer uses about 0.25 kW h per kg.

Explain why the heat pump tumble-dryer uses less electrical energy than the conventional tumble-dryer to dry the same load.

[2 marks]

A heat pump takes energy (heat) from the cold space (the surroundings) and gives it to the hot space, as well as the electrical work done on it: $Q_H = W + Q_C$.

In the conventional dryer all the heat comes from electrical energy ($Q_H = W$), so for the same Q_H the heat pump needs less electrical energy ($W = Q_H - Q_C$): it gives more energy to the hot space per unit of electrical energy input.



0 4 . 2

The cold space of the heat pump is the room in which the tumble-dryer is placed. The hot space is the air in the tumble-dryer and is at a temperature of 160°C .

A heat pump tumble-dryer can be placed in a kitchen at a temperature of 20°C , or in a garage at around 5°C .

Deduce which place would result in lower running costs for the tumble-dryer. Support your answer with calculations.

[3 marks]

$$T_H = 160 + 273 = 433 \text{ K, kitchen } T_C = 20 + 273 = 293 \text{ K,}$$

$$\text{garage } T_C = 5 + 273 = 278 \text{ K}$$

$$\text{COP} = T_H \div (T_H - T_C)$$

$$\text{Kitchen: } \text{COP} = 433 \div (433 - 293) = 433 \div 140 = 3.1$$

$$\text{Garage: } \text{COP} = 433 \div (433 - 278) = 433 \div 155 = 2.8$$

The COP is greater in the kitchen (3.1) than in the garage (2.8),
because the cold space temperature is closer to the hot space
temperature.

A higher COP means less electrical energy input is needed for the same
heat Q_H given to the air in the dryer, so the kitchen at 20°C gives
lower running costs.

5

END OF QUESTIONS

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