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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Engineering physics (3.11)

A Level Physics (7408) · Section 3.11

40 questions · 315 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

40 questions · 315 marks · 2 sub-topics



SUB-TOPIC 3.11.1

ROTATIONAL DYNAMICS

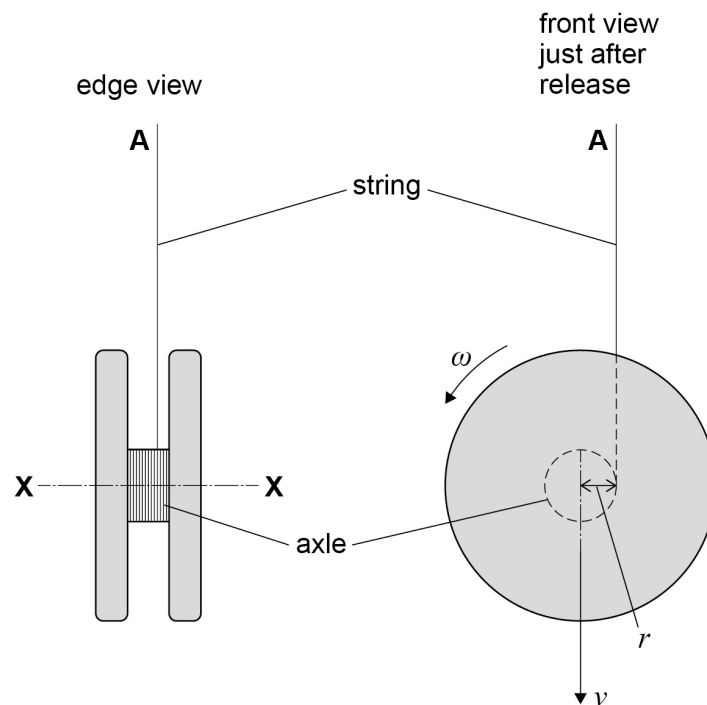
Sub-topic 3.11.1 · 18 questions · 150 marks · lowest tariff first



0 2

Figure 2 shows a yo-yo made of two discs separated by a cylindrical axle. Thin string is wrapped tightly around the axle.

Figure 2



Initially both the free end **A** of the string and the yo-yo are held stationary.

With **A** remaining stationary, the yo-yo is now released so that it falls vertically. As the yo-yo falls, the string unwinds from the axle so that the yo-yo spins about its centre of mass.

The linear velocity v of the centre of mass of the falling yo-yo is related to the angular velocity ω by $v = r\omega$ where r is the radius of the axle.

Question 2 continues on the next page



0 2 . 1

The yo-yo accelerates uniformly as it falls from rest. The string remains taut and has negligible thickness.

mass of yo-yo = 9.2×10^{-2} kg

radius of axle = 5.0×10^{-3} m

moment of inertia of yo-yo about axis **X-X** = 8.6×10^{-5} kg m²

When the yo-yo has fallen a distance of 0.50 m, its linear velocity is V .

Calculate V by considering the energy transfers that occur during the fall.

[3 marks]

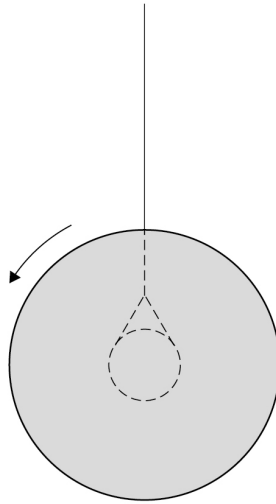
$V =$ _____ m s⁻¹



0	2	2
---	---	---

The yo-yo falls further until all the string is unwound. The yo-yo then 'sleeps'. This means the yo-yo continues to rotate in a loose loop of string as shown in **Figure 3**.

Figure 3



The string applies a constant frictional torque of $8.3 \times 10^{-4} \text{ N m}$ to the axle. The angular velocity of the yo-yo at the start of the sleep is 145 rad s^{-1} .

Determine, in rad, the total angle turned through by the yo-yo during the first 10 s of sleeping.

[3 marks]

angle = _____ rad

0 2 . 1 State **one** function of a flywheel.

[1 mark]

Question 2 continues on the next page

0 2 . 2 A student does an experiment to determine the frictional torque acting at the bearings of a steel flywheel. The flywheel has a radius of 0.075 m and is perfectly balanced.

The student places a small magnet of mass 0.020 kg at point **A** on the circumference of the flywheel on a horizontal line through the axis of rotation as shown in **Figure 2a**. The student releases the flywheel. The flywheel first comes to rest when it has moved through an angle of 3.00 rad (172°), with the magnet now in position **B** as shown in **Figure 2b**.

Figure 2a

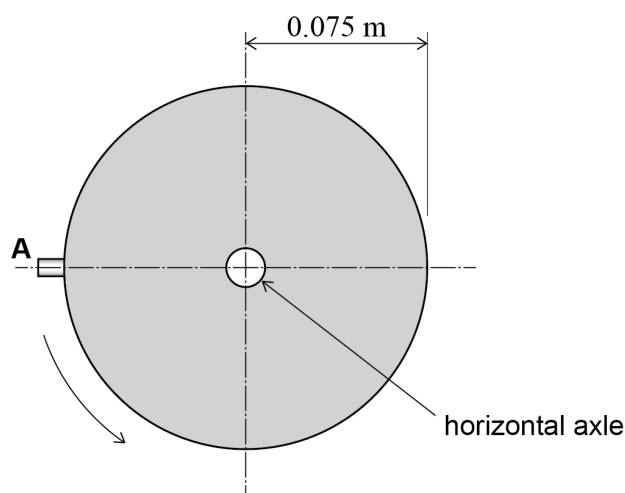
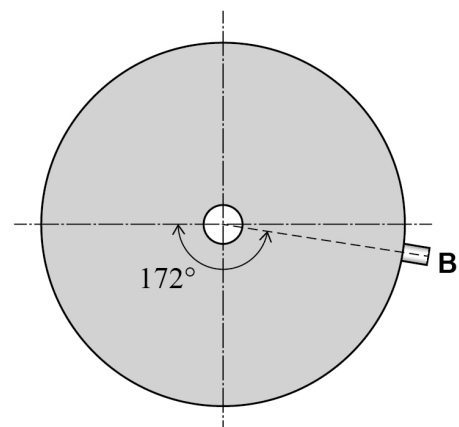


Figure 2b



The loss in gravitational potential energy of the magnet equals the work done against the frictional torque acting at the bearings.

Show that the frictional torque is about $7 \times 10^{-4} \text{ N m}$

[3 marks]

0 2 . 3 The student goes on to determine the moment of inertia of the flywheel.

The magnet is removed and the flywheel is made to spin. Measurements show that the flywheel makes 573 rotations as its angular speed reduces uniformly from 25.0 rad s^{-1} to zero. Assume the frictional torque at the bearings is constant and the same as in question **02.2**.

Determine the moment of inertia of the flywheel about its axis of rotation.

[3 marks]

moment of inertia = _____ kg m^2

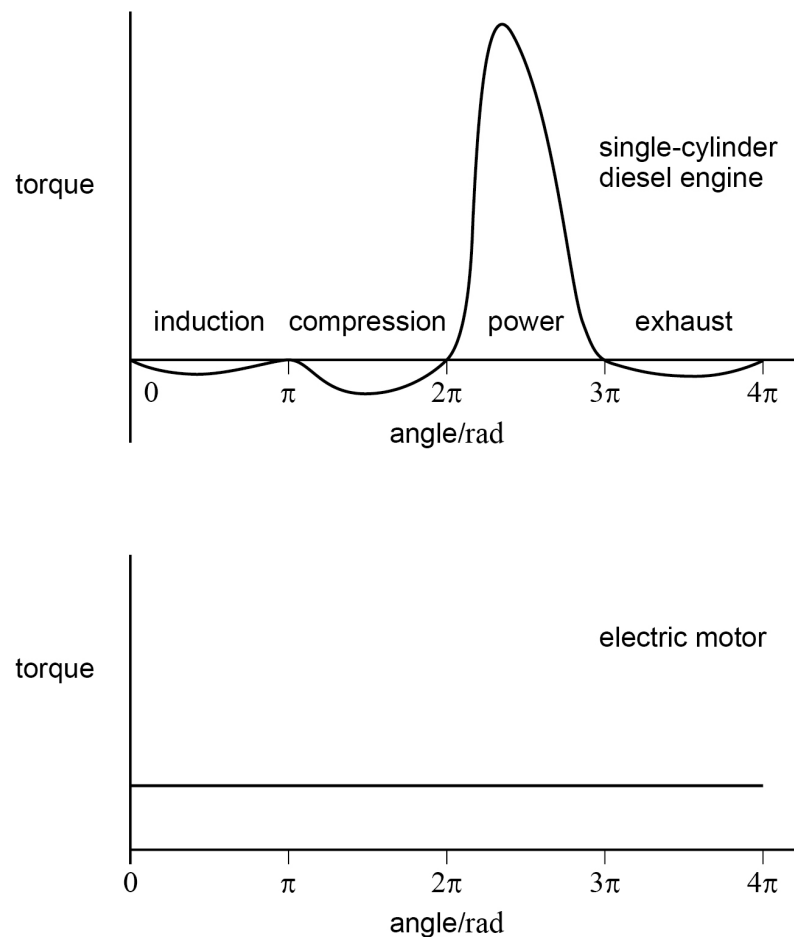


0 2

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]

02.1

State the condition necessary so that the law of conservation of angular momentum applies to a rotating system.

[1 mark]

A clutch is used to connect two rotating shafts together so that they rotate at the same speed.

02.2

Figure 3 shows two shafts, **A** and **B**, rotating freely about the same axis. **Table 1** gives information about the two shafts.

Figure 3

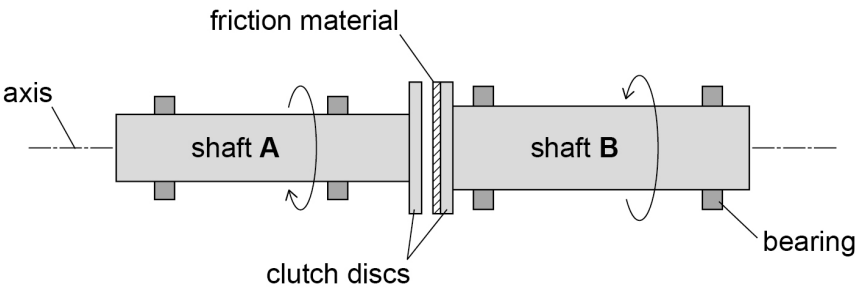


Table 1

	Shaft A	Shaft B
Angular speed / rad s ⁻¹	95	45
Moment of inertia / kg m ²	7.2	11.5
Direction of rotation	Clockwise looking from left	Anticlockwise looking from left

The two shafts are connected by forcing the clutch discs together.
Friction acts between the discs and slipping occurs for a short time until both shafts rotate at a common angular speed.
The clutch is now said to be engaged.

Show that the common angular speed of the two shafts immediately after the clutch is engaged is about 9 rad s^{-1} .

State whether the direction of the common angular speed is clockwise or anticlockwise when viewed from the left.

[3 marks]

direction when viewed from the left = _____

Question 2 continues on the next page



0 2 . 3

Table 2 gives information about two clutches, **C** and **D**.
C and **D** provide different constant frictional torques during slipping at the clutch discs.

Table 2

Clutch	Frictional torque during slipping / N m
C	600
D	320

The slipping time is to be kept between 1.0 s and 2.0 s with the same initial conditions shown in **Table 1**, and the same final common angular speed.

Deduce whether either or both clutches allow this.

[3 marks]

0 1 . 1

One equation used in translational dynamics is:

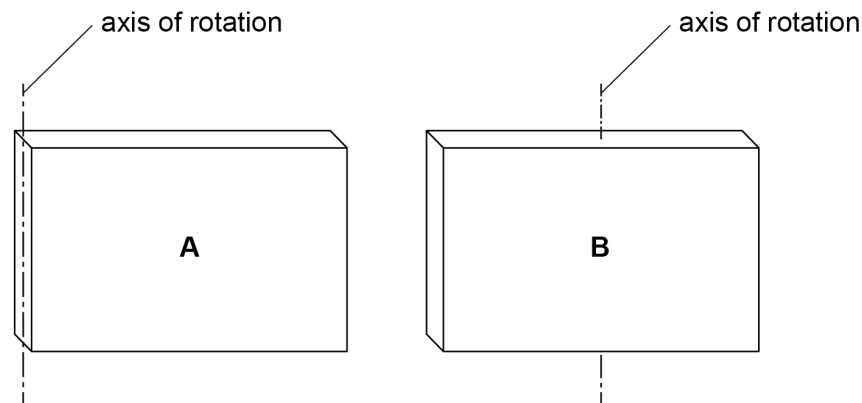
$$\text{force} = \text{mass} \times \text{acceleration}$$

State **in words** the equivalent equation used in rotational dynamics.

[2 marks]

Figure 1 shows two identical uniform plates **A** and **B**. The axis of rotation of each plate is shown.

Figure 1

**0 1 . 2**

State and explain which plate has the greater moment of inertia about its axis of rotation.

[2 marks]

An electric motor drives a machine that punches out plates from a long strip of sheet metal. The motor runs continuously and is fitted with a flywheel. **Figure 2** shows how the angular velocity ω of the flywheel varies with time t .

Figure 2

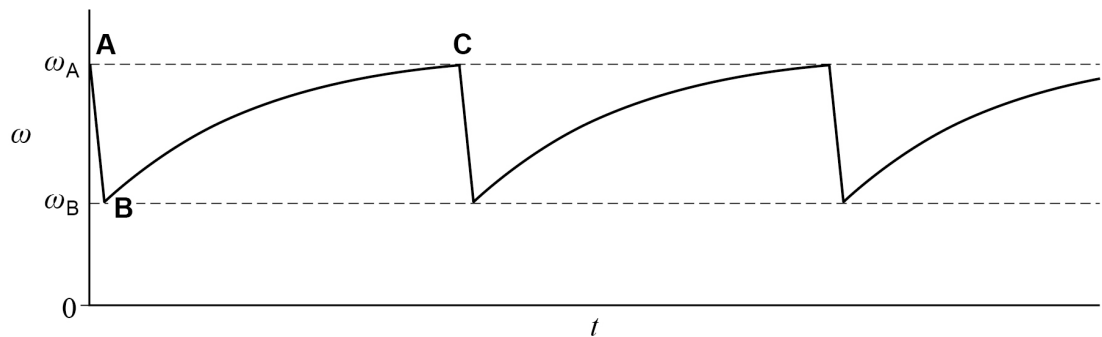


Table 1 describes the sequence for the machine after it has been brought up to speed ω_A .

Table 1

A	The punching operation starts.
A to B	The flywheel transfers some of its energy during the punching operation.
B to C	The flywheel is again brought up to speed ω_A by the motor.
C	The next punching operation starts.

0 1 . 3 A new flywheel with a greater moment of inertia is fitted in place of the original flywheel. The motor torque is constant and the same as before.

Sketch on **Figure 2** a graph showing how the angular velocity varies with time for the machine fitted with the new flywheel.

Assume that:

- the punching operation starts at the same angular speed ω_A
- the same quantity of energy is transferred when punching the metal sheet.

[2 marks]

Question 1 continues on the next page

0 1 . 4 Explain **one** difference between your graph and the original graph.

[1 mark]



0 2 . 1 The moment of inertia I of any rolling object about its axis of rotation is given by

$$I = Amr^2$$

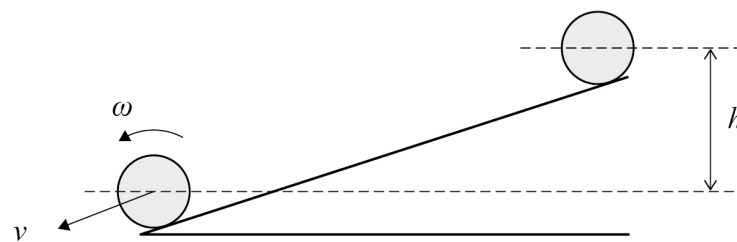
where A is a constant that depends on the shape of the object

m is the mass of the object

r is the radius of the object.

Figure 4 shows an object that starts from rest and rolls down a slope without slipping.

Figure 4



The object falls a vertical distance h . It then has a linear velocity v and angular velocity ω .

For a rolling object the linear velocity v of the centre of mass is related to the angular velocity ω by $v = r\omega$.

Show, by considering the energy transfers that occur, that

$$v = \sqrt{\frac{2gh}{1+A}}$$

[3 marks]

Question 2 continues on the next page

Table 1 gives the moments of inertia of a solid sphere **P**, a hollow sphere **Q**, a solid cylinder **R** and a hollow cylinder **S** about their axes of rotation.

P, **Q**, **R** and **S** have the same mass m and outer radius r .

Table 1

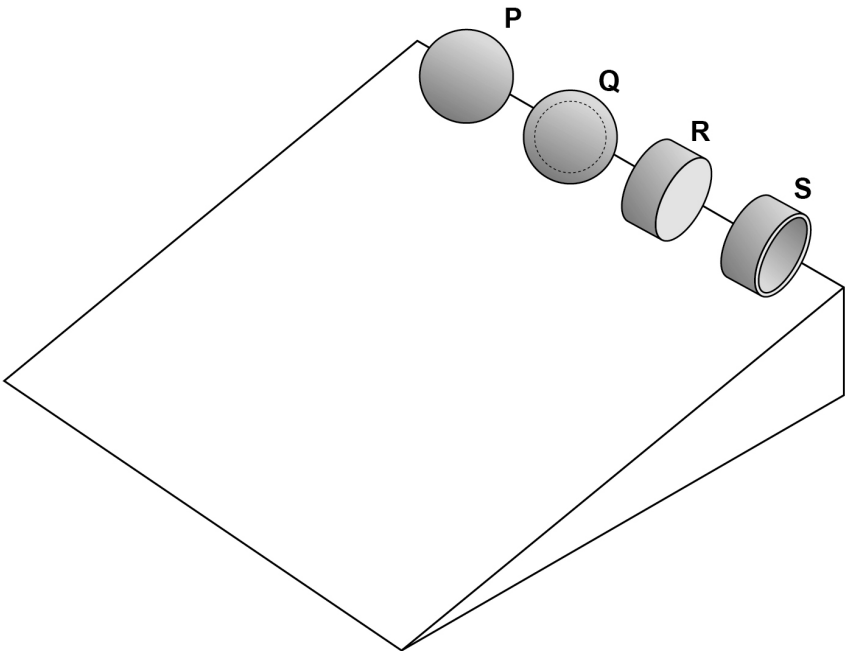
Object		Moment of inertia
solid sphere P		$\frac{2}{5}mr^2$
hollow sphere Q		$\frac{2}{3}mr^2$
solid cylinder R		$\frac{1}{2}mr^2$
hollow cylinder S		mr^2

02.2 Explain why the hollow sphere **Q** has a greater moment of inertia about its axis of rotation than the solid sphere **P**.

[1 mark]

02.3 **Figure 5** shows all four objects at rest at the top of a slope. They are released at the same time and roll down the slope without slipping.

Figure 5



Deduce the order in which the objects reach the bottom of the slope.

[3 marks]

0 1 . 1

There is an analogy between quantities in rotational and translational dynamics.

Complete **Table 1**, stating in words the quantities in rotational dynamics that are analogous to force and mass in translational dynamics.

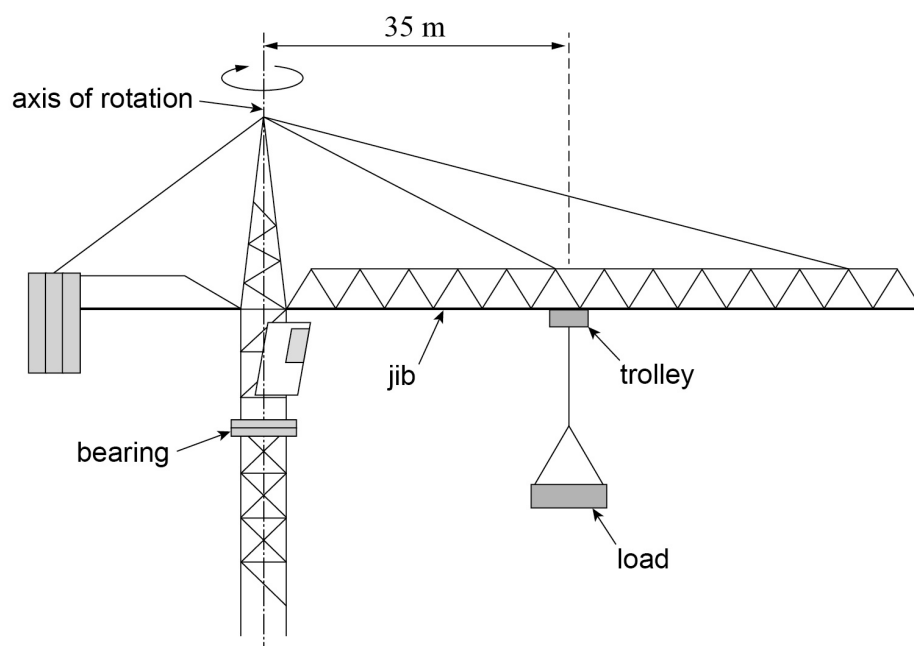
[2 marks]

Table 1

Translational dynamics	Rotational dynamics
force	
mass	

Figure 1 shows a side view of the jib of a tower crane. The load is supported by a trolley which can move along the jib. The jib consists of all the parts of the crane above the bearing, but excluding the trolley and load.

Figure 1



The moment of inertia of the jib about the axis of rotation = $2.6 \times 10^7 \text{ kg m}^2$

Mass of trolley and load = $2.2 \times 10^3 \text{ kg}$

0	1	.	2
---	---	---	---

The load is at a distance of 35 m from the axis of rotation.

Show that the total moment of inertia of the jib, and the trolley and load, about the axis of rotation is about $3 \times 10^7 \text{ kg m}^2$.

[1 mark]

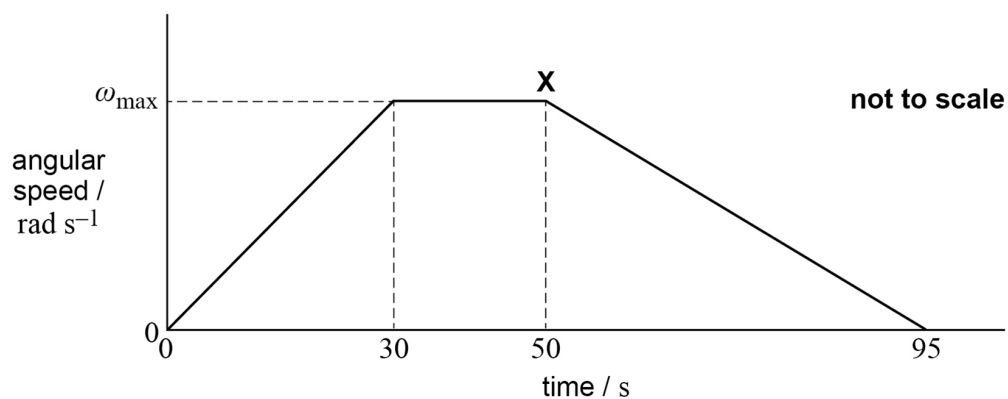
Question 1 continues on the next page



0 1 . 3

Figure 2 shows the variation of angular speed of the jib as it turns through an angle of 4.7 rad (270°) in a total time of 95 s. The trolley and load remain at a distance of 35 m from the axis.

Figure 2



Calculate the maximum angular speed ω_{max} of the jib.

[2 marks]

maximum angular speed = _____ rad s^{-1}



0	1	.	4
---	---	---	---

At time **X** in **Figure 2** the motor that is driving the jib is disengaged. A constant braking torque is then applied to bring the jib to a standstill from its maximum angular speed.

The crane driver repeats the movement of the jib with the same load at 35 m from the axis of rotation. Up to time **X** the motion is the same as before. From time **X** the trolley is driven at a steady speed away from the axis as the jib continues to rotate until the jib comes to a standstill.

Assume the braking torque remains the same as before.

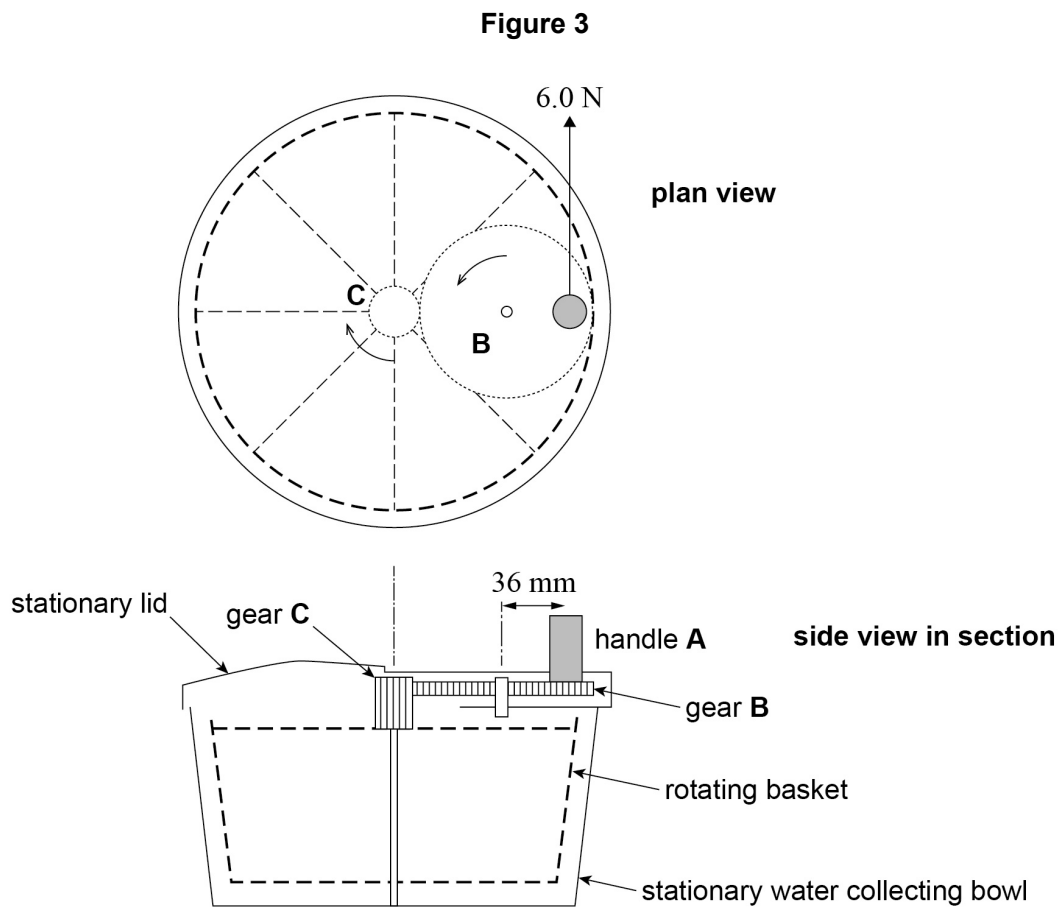
Discuss how the motion of the trolley affects the time taken for the jib to come to a standstill.

[3 marks]



0 2

Figure 3 shows the basic principle of operation of a hand-operated salad spinner used to dry washed salads.



The salad is placed in the basket and the lid is attached.

When handle **A** is turned the basket and its contents spin rapidly. Water on the salad is driven through holes in the basket into the stationary water collecting bowl. The pivot for gear **B** is fixed to the lid. This pivot and the lid do not move. When gear **B** rotates, gear **C** also rotates but at a greater angular speed. Gear **C** is fixed to the basket and rotates it.

A force of 6.0 N is applied to handle **A** as shown. Handle **A** is at a radius of 36 mm from its centre of rotation.

0	2	.	1
---	---	---	---

Calculate the input torque.

[1 mark]

torque = _____ N m

0	2	.	2
---	---	---	---

Gear **C** rotates four times for every one revolution of gear **B**.Deduce whether it is possible for the torque on gear **C** to be greater than one quarter of the input torque.

[2 marks]

0	2	.	3
---	---	---	---

It takes 2.1 s for the empty basket to reach an angular speed of 76 rad s^{-1} .
The torque on gear **C** is a constant 0.054 N m during this time. Frictional losses are negligible.

Calculate the moment of inertia of the basket about its axis of rotation.

[2 marks]

moment of inertia = _____ kg m^2

Question 2 continues on the next page



0	2	.	4
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The gears are made from polymer (plastic). An early version of this salad spinner suffered from damaged gear teeth.

Explain with reference to angular impulse why a great force is put on the gear teeth if the user tries to stop the loaded basket too quickly using the handle.

[3 marks]



0	1	.	1
---	---	---	---

State what is meant by the moment of inertia of an object about an axis.

[1 mark]

0	1	.	2
---	---	---	---

A student does an experiment using the apparatus shown in **Figure 1**.

Figure 1



A solid disc pulley of mass M and radius R is supported in bearings which have negligible friction.

A string of negligible mass is wrapped around the circumference of the pulley. A load of mass $0.5M$ is fixed to the free end of the string. The string does not slip on the pulley.

The moment of inertia of the pulley about the axis of rotation is $0.5MR^2$.

The student holds the pulley stationary.

When the student releases the pulley, the load accelerates downwards uniformly and is at a velocity v after moving a distance h .

Show that the acceleration of the load is $0.5g$.

[4 marks]

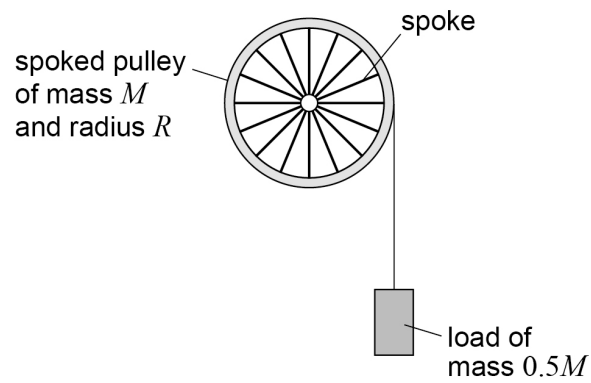
Question 1 continues on the next page



0 1 . 3

The student repeats the experiment using a spoked pulley of the same mass and radius, as shown in **Figure 2**.

Figure 2



Compare the acceleration of the load in this experiment with its acceleration in the previous experiment.

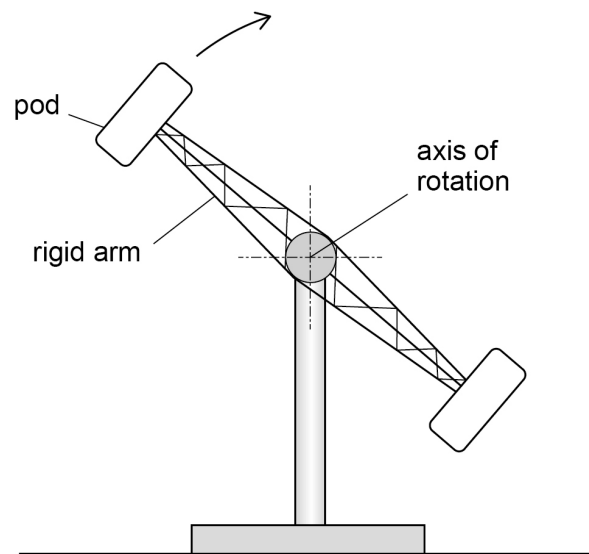
A calculation is **not** required.

[3 marks]

0	1
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Figure 1 shows a fairground ride.

Figure 1

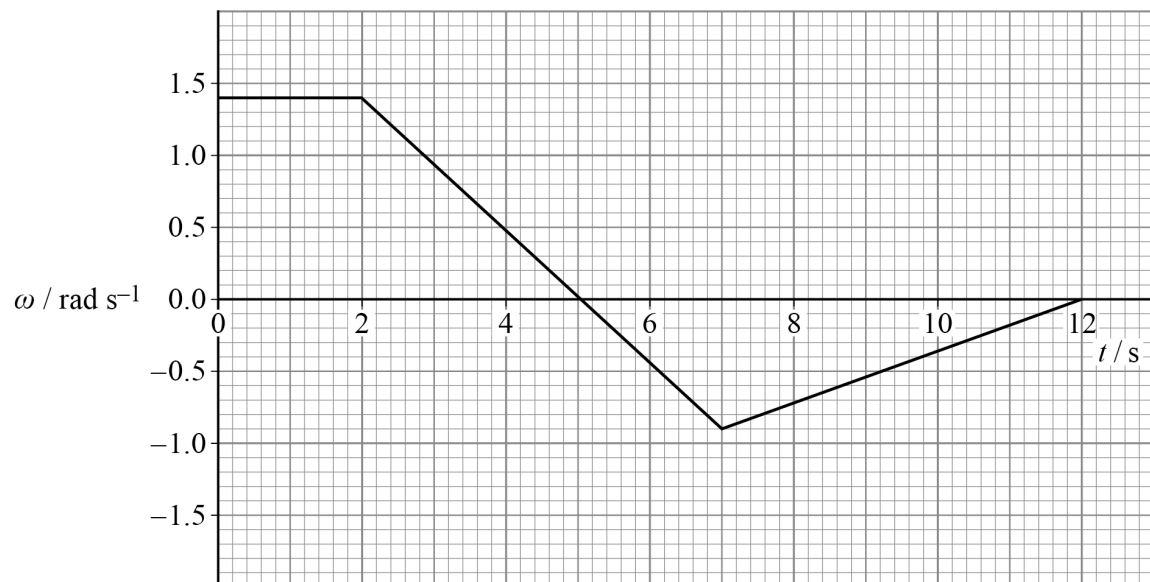


The ride consists of a rotor that rotates in a vertical circle about a horizontal axis. The rotor has two rigid arms. A pod containing passengers is attached to each arm. The rotor is perfectly balanced. The direction of rotation of the rotor is reversed at times during the ride.

Question 1 continues on the next page

Figure 2 shows the variation of the angular velocity ω of the rotor with time t during a 12 s period.

Figure 2



0 1 . 1 Determine the mean angular velocity of the rotor during the 12 s period.

[2 marks]

mean angular velocity = _____ rad s^{-1}

The moment of inertia of the rotor about its axis of rotation is $2.1 \times 10^4 \text{ kg m}^2$.
A constant frictional torque of 390 N m acts at the bearings of the rotor.

0 1 . 2

Calculate the power output of the driving mechanism during the first 2 s shown in **Figure 2**.

[1 mark]

power output = _____ W

0 1 . 3

Calculate the maximum torque applied by the driving mechanism to the rotor during the 12 s period.

[3 marks]

maximum torque = _____ N m

0 1 . 4

Calculate the magnitude of the angular impulse on the rotor between $t = 2.0 \text{ s}$ and $t = 7.0 \text{ s}$.

[1 mark]

angular impulse = _____ N m s

Question 1 continues on the next page



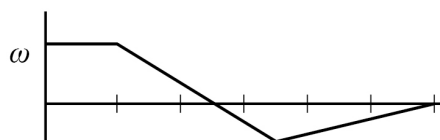
0	1	5
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Which graph best shows the variation of the torque T applied to the rotor for the 12 s period?

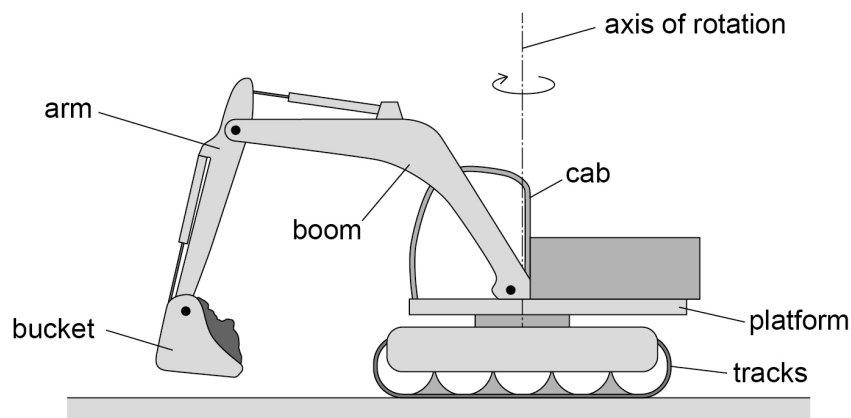
Tick (✓) **one** box.

A copy of **Figure 2** is provided to help you.

[1 mark]



copy of **Figure 2**

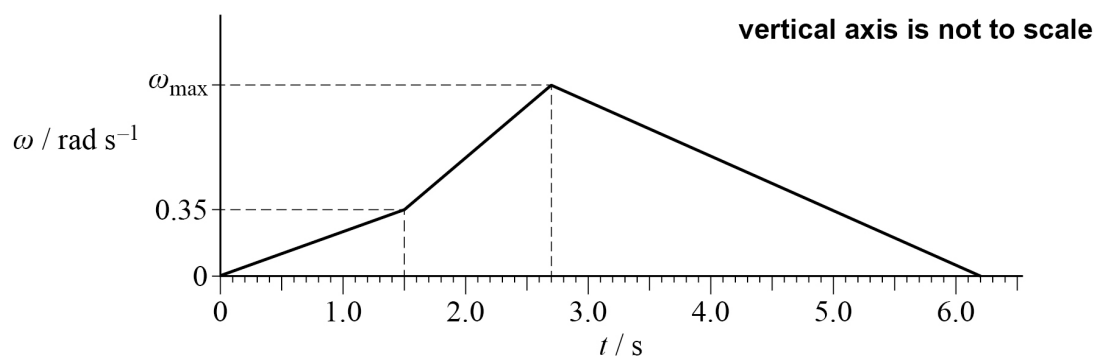
0 2**Figure 3** shows an excavator.**Figure 3**

The bucket position can be changed by moving the boom and arm and by rotating the platform about the vertical axis of rotation.
For the purposes of this question, assume that the excavator tracks do not move.

Question 2 continues on the next page

The bucket is moved to a new position by rotating the platform about the axis of rotation.

Figure 4 shows the variation in angular velocity ω with time t for the rotation of the platform about the vertical axis.

Figure 4**0 2 . 1**

The total angular displacement of the platform is 2.52 rad during the movement of the bucket.

Show that ω_{max} is about 0.9 rad s^{-1} .

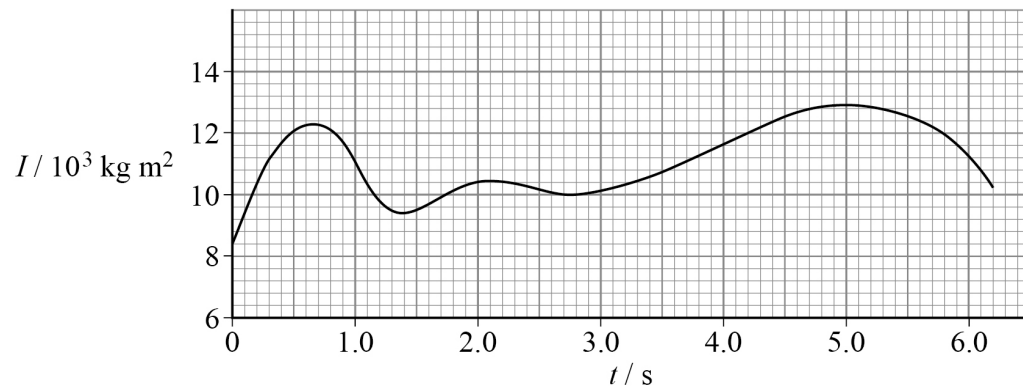
[3 marks]

At the same time as the platform is rotating, the bucket is moved up and down, and away from and towards the cab.

The moment of inertia of the rotating parts of the excavator about the axis of rotation is I .

Figure 5 shows how I varies with t for the same time period as **Figure 4**.

Figure 5



0 2 . 2

Torque must be applied to the platform to change its angular velocity and to overcome friction at the platform bearing.

Show that the torque applied to the platform is at a maximum at time $t = 2.1$ s.

[3 marks]

Question 2 continues on the next page

0	2	.	3
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Deduce whether the maximum power applied to the platform occurs at the same time of 2.1 s.

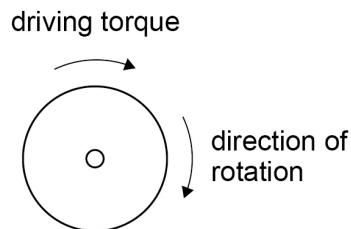
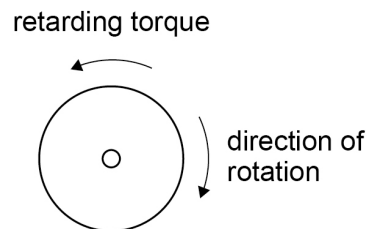
[2 marks]



0 1

The rotating part of an electric motor is called the rotor.

Figure 1 shows an end view of a rotor turning clockwise due to a driving torque from the motor. In this question, the clockwise direction is treated as positive.

Figure 1**Figure 2**

The rotor can be brought to rest rapidly by reversing the electrical supply connections to the motor. **Figure 2** shows the rotor at time $t = 0$ when the supply connections are reversed.

The rotor then slows down due to a constant anticlockwise retarding torque so that it stops at time $t = t_1$.

The angular velocity of the rotor at $t = 0$ is 98.0 rad s^{-1} clockwise.

The applied torque on the rotor at $t = 0$ is anticlockwise.

The applied torque produces a constant angular acceleration of -303 rad s^{-2} .

Friction torque is negligible.

0 1 . 1

Determine t_1 .

[2 marks]

$t_1 =$ _____ s

The electrical supply remains connected and the rotor now accelerates uniformly anticlockwise with an acceleration of magnitude 303 rad s^{-2} .

At a later time $t = t_2$, the angular velocity of the rotor is -120 rad s^{-1} .

0 1 . 2

Determine the number of anticlockwise revolutions made by the rotor between t_1 and t_2 .

[2 marks]

number of revolutions = _____

0 1 . 3

The moment of inertia of the rotor about the axis of rotation is $9.60 \times 10^{-2} \text{ kg m}^2$.

Calculate the angular impulse on the rotor between $t = 0$ and t_2 .

[1 mark]

angular impulse = _____ N m s

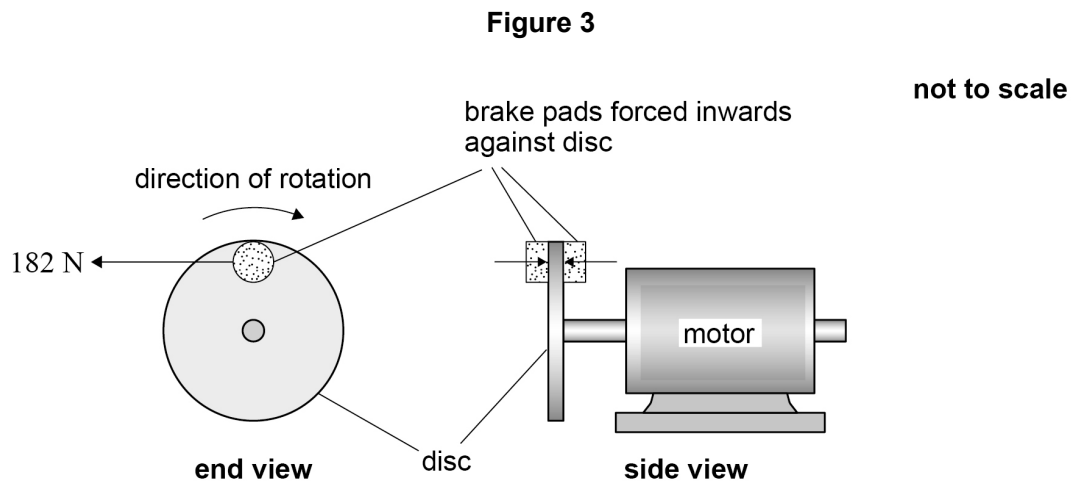
Question 1 continues on the next page



0 1 . 4

Another way of quickly stopping the motor is to use a disc brake. The motor is brought to rest by switching off the power supply and then forcing two brake pads against the disc.

Figure 3 shows the two brake pads each applying a constant retarding force of 182 N to the disc.



moment of inertia of rotor and disc about the axis of rotation = 0.101 kg m^2

diameter of disc = 0.160 m

diameter of pad = 22 mm

Compare the angular deceleration produced by the disc brake system with the angular deceleration produced by reversing the electrical connections.

[3 marks]

0	1	.	1
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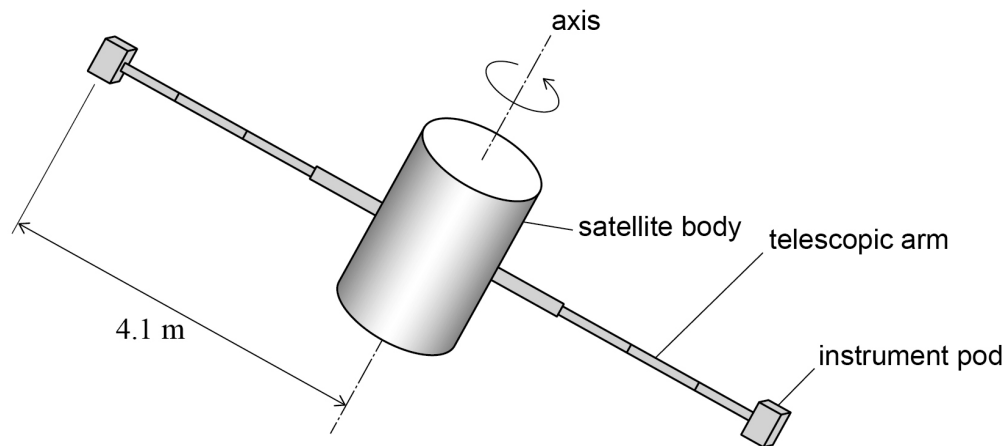
State the law of conservation of angular momentum.

[1 mark]

0 1 . 2

Figure 1 shows an orbiting satellite fitted with two small instrument pods attached to the ends of telescopic arms. The arms can be extended or retracted by a motor in the body of the satellite.

Figure 1



With the telescopic arms fully extended, the centre of mass of each instrument pod is at a radius of 4.1 m from the axis of rotation.

moment of inertia of satellite body about axis = 71 kg m^2

mass of each instrument pod = 5.0 kg

The mass of the telescopic arms is negligible.

Show that the total moment of inertia of the satellite with the arms fully extended is 240 kg m^2

[2 marks]

Question 1 continues on the next page

0 1 . 3

The satellite is initially rotating slowly about its axis with the arms fully extended. The arms are slowly retracted so that the instrument pods move closer to the body of the satellite.

State and explain the change in the angular speed of the satellite as the arms are retracted.

[3 marks]

0 1 . 4

The satellite is initially rotating at 1.3 rad s^{-1} with the telescopic arms fully extended. When fully retracted the instrument pods are at a radius of 0.74 m from the axis. The satellite contains sensitive equipment that may be damaged if the rotational speed exceeds 4.2 rad s^{-1}

Deduce whether the arms can be retracted fully without the satellite exceeding its maximum permitted angular speed.

[3 marks]

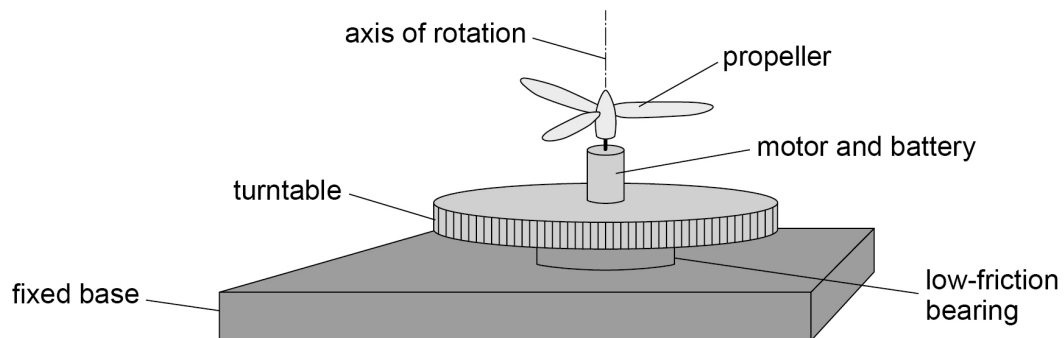
0 1

A heavy turntable is mounted on a fixed base. The turntable can rotate freely on a low-friction bearing.

0 1 . 1

Figure 1 shows a propeller unit fixed to the centre of the turntable. The propeller unit consists of a motor-driven propeller and a battery. The propeller and the turntable have a common axis of rotation.

Figure 1



At first, the turntable and the propeller are at rest.
The propeller motor is switched on and the propeller quickly reaches a high final angular speed.
The propeller rotates clockwise when viewed from above.

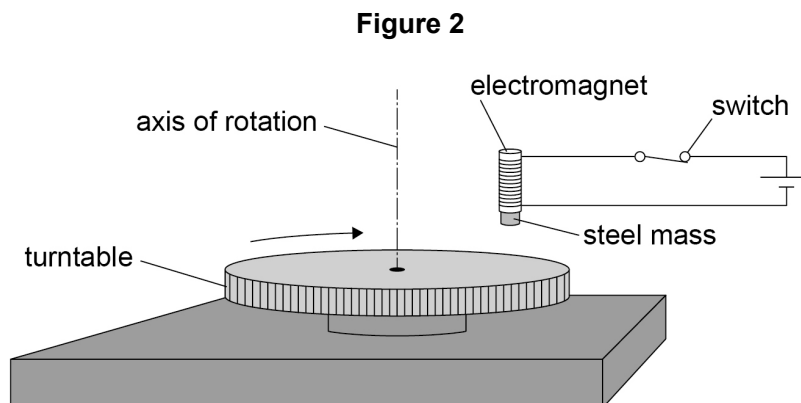
Compare, with reference to angular momentum, the motions of the turntable and the propeller.

[3 marks]

Question 1 continues on the next page

0 1 . 2

Figure 2 shows an arrangement used to determine the moment of inertia of the turntable.



A small steel mass is held by an electromagnet above the top surface of the turntable. The diameter of the turntable is about half a metre. The turntable rotates freely at an initial angular speed ω_1 .

The switch is opened so that the mass falls and sticks to the surface of the turntable. This changes the angular speed of the turntable to ω_2 . The steel mass can be considered to be a point mass.

Describe how to determine the moment of inertia of the turntable using observations of ω_1 and ω_2 .

In your answer you should:

- suggest how ω_1 and ω_2 are measured
- state any other measurements needed and name the equipment used to make them
- explain how the moment of inertia of the turntable is determined from the measurements.

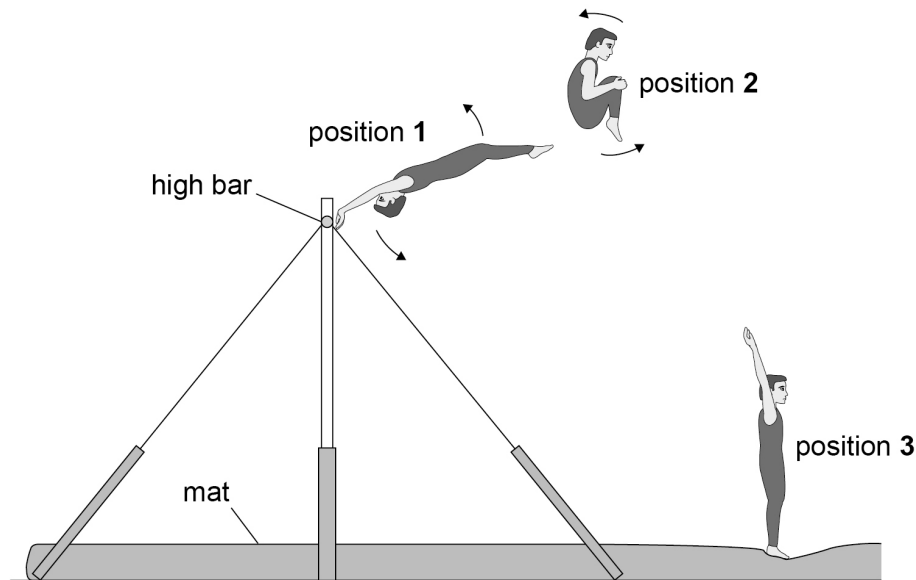
[6 marks]

0	1
---	---

A gymnast dismounts from an exercise in which he swings on a high bar. The gymnast rotates in the air before landing.

Figure 1 shows the gymnast in three positions during the dismount.

Figure 1



The arrows show the direction of rotation of the gymnast.

In **position 1** the gymnast has just let go of the bar. His body is fully extended.

Position 2 shows the rotating gymnast a short time later. His knees have been brought close to his chest into a 'tuck'.

Position 3 is at the end of the dismount as the gymnast lands on the mat. His body is once again fully extended.

0 1 . 1

Explain why the moment of inertia about the axis of rotation decreases when his knees are moved towards his chest.

Go on to explain the effect this has on his angular speed.

[3 marks]

Table 1 gives some data about the gymnast in position **1** and in position **2**.

Table 1

Position	Moment of inertia / kg m ²	Angular speed / rad s ⁻¹
1	13.5	ω
2	4.1	14.2

0 1 . 2

Calculate the angular speed ω of the gymnast in position **1**.

[1 mark]

$$\omega = \text{_____} \text{ rad s}^{-1}$$

Question 1 continues on the next page



0 1 . 3 The gymnast stays in the tuck for 1.2 s.

Determine the number of **complete** rotations performed by the gymnast when in the tuck during the dismount.

[2 marks]

number of complete rotations = _____

0 1 . 4 The gymnast repeats the exercise. The height of the bar remains unchanged.

State and explain **two** actions the gymnast can take to complete more rotations during the dismount.

[4 marks]

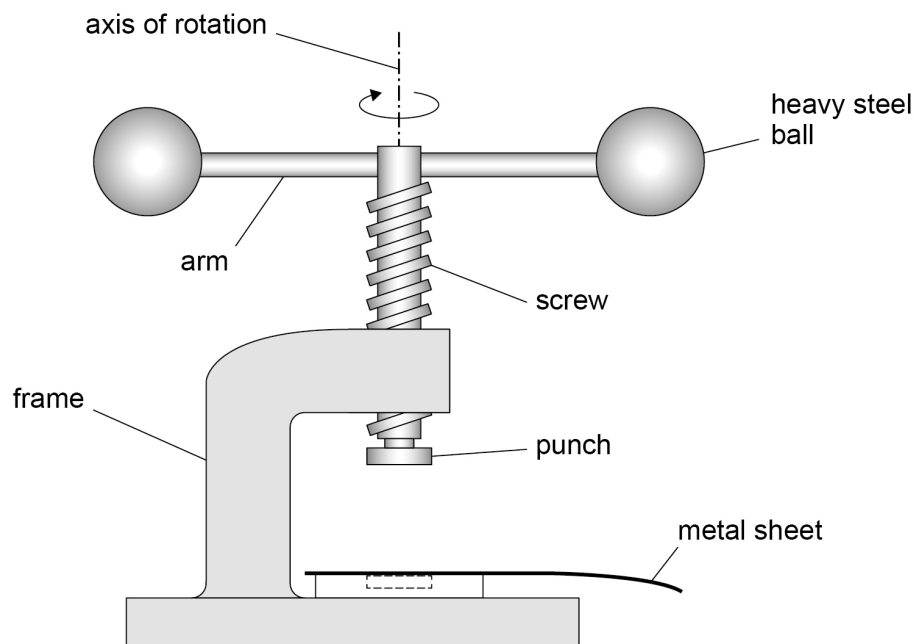
- 1 _____

- 2 _____

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]

moment of inertia = _____ 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]

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]

angular deceleration = _____ rad s^{-2}

angle = _____ rad

Question 1 continues on the next page



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]

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

☐

$\text{kg m}^2 \text{s}^{-2}$

☐

0 2

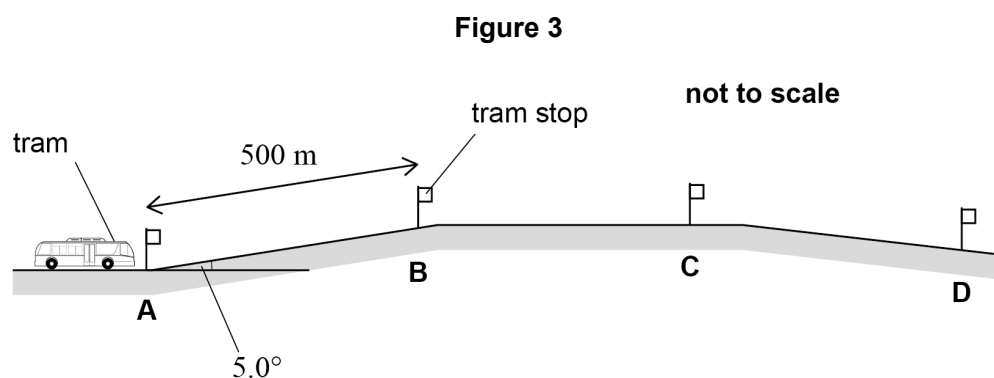
A moving tram is powered by energy stored in a rapidly spinning flywheel.

When the tram is at a tram stop, the flywheel is 'charged' by being accelerated to a high rotational speed.

The mass of the tram, flywheel and passengers is 1.46×10^4 kg.

The distance between tram stops is 500 m.

Figure 3 shows that between stops **A** and **B** the track is inclined at a constant 5.0° to the horizontal.



The tram must travel 500 m along this incline on one charge of energy.

The total resistive force on the tram due to its motion is constant at 1.18 kN.

The flywheel is a solid steel disc of diameter 1.00 m. It has a moment of inertia of 62.5 kg m^2 .

0 2 . 1

Calculate the minimum angular speed of the flywheel when the tram leaves stop **A** so that the tram reaches stop **B** using only energy stored in the flywheel.

[3 marks]

minimum angular speed = _____ rad s^{-1}

0 2 . 2

Between stops **C** and **D** the tram travels downhill.

Suggest **two** advantages of keeping the flywheel connected to the driving wheels when the tram travels downhill.

[2 marks]

1 _____

2 _____

Question 2 continues on the next page



0 2 . 3

The same tram is to be used on a track where the stops are further apart, so the flywheel system needs to be modified.

Discuss the design features of the flywheel that will enable it to store more energy without increasing the mass of the tram.

In your answer you should consider:

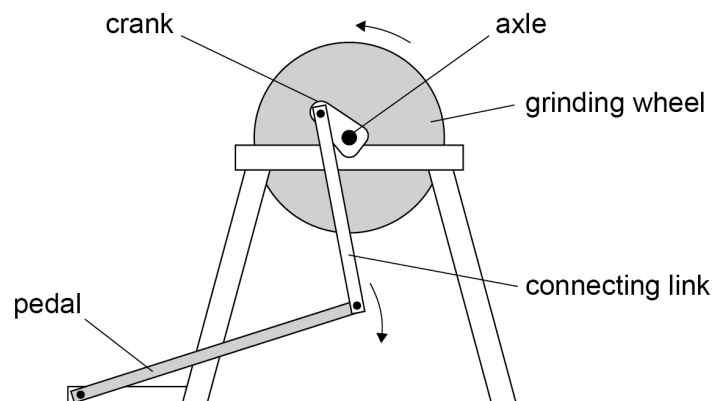
- the design of the flywheel
- how the choice of materials used to make the flywheel is influenced by its design and maximum angular speed
- other design aspects that allow for high angular speeds of the flywheel.

[6 marks]

0 2

Figure 3 shows a heavy stone grinding wheel used for sharpening tools.

Figure 3



The pedal is connected to the axle of the wheel by a connecting link and crank. The operator pushes the pedal downwards to accelerate the wheel from rest. The wheel begins to rotate in the direction shown.

0 2 . 1

Explain why the torque applied to the axle varies as the operator pushes downwards on the pedal.

[2 marks]

Question 2 continues on the next page

0 2 . 2

The wheel is rotating at a high angular speed. The operator is told not to use the pedal to stop the rotation of the wheel suddenly.

Explain, with reference to angular impulse, why a sudden stop is likely to damage the mechanism.

[2 marks]

0 2 . 3

The connecting link breaks. At this instant the angular speed of the wheel is 13.8 rad s^{-1} .

It takes 15.0 s for the wheel to come to rest.

The frictional torque acting at the axle bearings is 0.77 N m and is constant for all speeds.

Calculate the moment of inertia of the wheel.

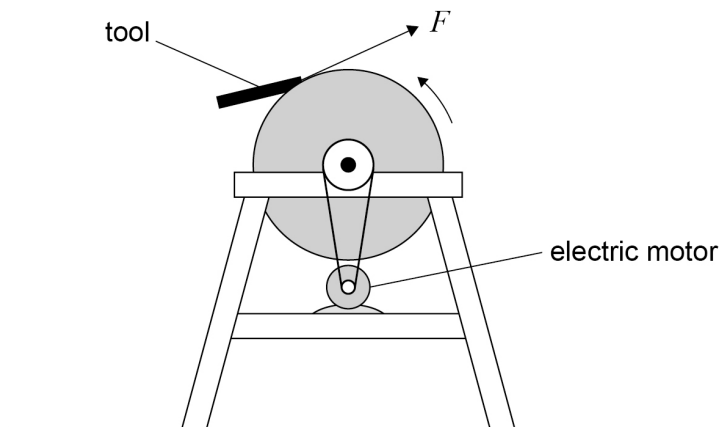
[2 marks]

moment of inertia = _____ kg m^2



The arrangement is modified as shown in **Figure 4**. The pedal, connecting link and crank are removed and the grinding wheel is driven by an electric motor.

Figure 4



0 2 . 4

Figure 4 also shows a tool being sharpened by pressing it on the edge of the rotating wheel.

The tool applies a tangential force F on the wheel.

A torque of 3.10 N m is needed at the axle to drive the wheel at constant angular speed while the tool is being sharpened.

frictional torque at the axle bearings = 0.77 N m

radius of wheel = 0.24 m

Calculate F .

[2 marks]

$F =$ _____ N

Question 2 continues on the next page

0 2 . 5

Three motors **E**, **F** and **G** were available to drive the wheel in **Figure 4**.

Figure 5 shows how the torque T varies with angular speed ω for each motor.

Figure 5

The no-load speed ω_0 is the angular speed of a motor when the torque applied is zero.

The maximum power of each motor is developed at about $0.5\omega_0$.

The required output power of the motor when a tool is being sharpened is 52 W.

The required output power of the chosen motor should be about $\frac{2}{3}$ of its maximum power.

Deduce which motor **E**, **F** or **G** was chosen for this application.

[3 marks]



SUB-TOPIC 3.11.2

THERMODYNAMICS AND ENGINES

Sub-topic 3.11.2 · 22 questions · 165 marks · lowest tariff first



0 5 . 1

Which is a correct statement about an ideal heat engine?

Tick (✓) **one** box.

[1 mark]

The efficiency is increased when the kelvin temperatures of the hot source and the cold sink are increased by equal amounts.

☐

The maximum efficiency depends on the p – V cycle.

☐

The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink.

☐

0 5 . 2

An ideal heat engine has an efficiency of 0.33

The same engine works in reverse as an ideal refrigerator between the same hot and cold spaces.

Determine the coefficient of performance COP_{ref} of the refrigerator.

[2 marks]

 $COP_{\text{ref}} =$ _____

END OF QUESTIONS



0 5 . 1

An ideal heat pump and an ideal refrigerator operate between the same hot and cold spaces.

Which statement relating to the coefficient of performance (COP) is correct?
Tick (✓) the correct answer.

[1 mark]

The COP of the refrigerator must be < 1 .

☐

The COP of the heat pump must be greater than the COP of the refrigerator.

☐

The COP of the heat pump will increase if the temperature of the hot space is increased.

☐

The COP of the refrigerator will decrease if the cold space temperature increases.

☐**0 5 . 2**

An ideal refrigerator operates between a cold space at a temperature of $-1\text{ }^{\circ}\text{C}$ and a hot space at a temperature of $70\text{ }^{\circ}\text{C}$.

Calculate the input power to the refrigerator if the rate of transfer of energy to the hot space is 100 W .

[3 marks]

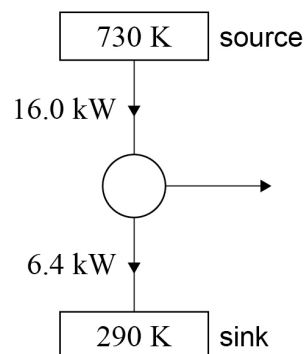
input power = _____ W

END OF QUESTIONS

0	5
---	---

Figure 9 shows an ideal heat engine.

Figure 9



The engine operates between a source at a temperature of 730 K and a sink at a temperature of 290 K.

The input power is 16.0 kW and the power rejected to the sink is 6.4 kW.

0	5	.	1
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Calculate the efficiency of this engine.

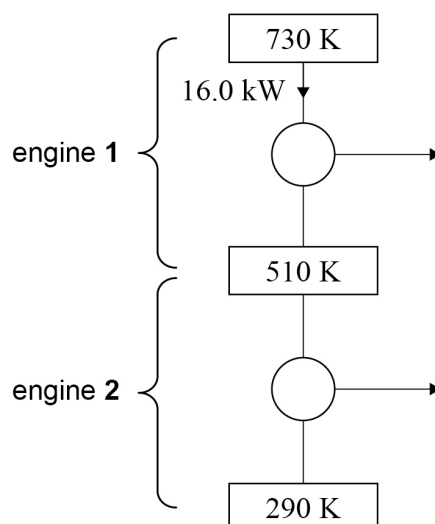
[1 mark]

efficiency = _____

0 5 . 2

Figure 10 shows another system operating between the same overall temperatures and with the same input power as the engine in **Figure 9**. This system consists of two ideal engines.

Figure 10



The sink for engine 1 forms the source for engine 2. The temperature of the intermediate reservoir is 510 K.

All the energy rejected by heat transfer in engine 1 provides the input energy to engine 2.

A student suggests that the system in **Figure 10** can provide more output power and be more efficient than the engine in **Figure 9**.

Deduce whether the student's suggestions are correct.

You may annotate **Figures 9** and **10**.

[3 marks]

END OF QUESTIONS



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]



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 $160\text{ }^{\circ}\text{C}$.

A heat pump tumble-dryer can be placed in a kitchen at a temperature of $20\text{ }^{\circ}\text{C}$, or in a garage at around $5\text{ }^{\circ}\text{C}$.

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

[3 marks]

END OF QUESTIONS

0 4 . 1

State what is meant by the coefficient of performance of a heat pump.

[1 mark]

A jeweller hopes to reduce workshop heating costs by replacing a gas-fired boiler with an electric heat pump. The heat pump will provide underfloor heating using water at a temperature of 40 °C.

The air outside the building provides the low-temperature reservoir for the heat pump. Over the winter period the outside temperature will vary between 12 °C and –8 °C.

The salesperson for a heat pump company claims that:

- the coefficient of performance will vary greatly, depending on the outside temperature
- the colder the outside temperature, the lower the energy costs will be for running the heat pump.

0 4 . 2

Comment on the salesperson's claims.

[3 marks]**0 4 . 3**

A heat pump is installed. The average COP_{hp} over the winter period is 7.5. In this period the heat pump delivers 2880 kW h of underfloor heating.

What is the electrical energy used by the heat pump in this period?

Tick (✓) **one** box.

[1 mark]

333 kW h

☐

384 kW h

☐

2500 kW h

☐

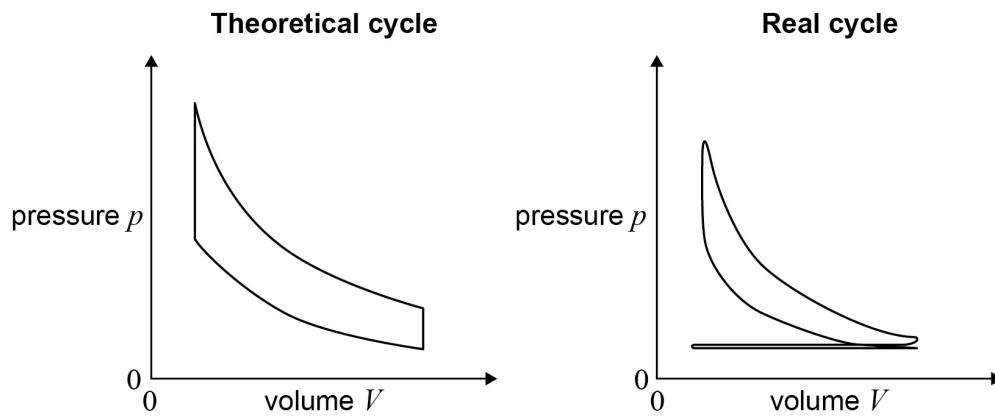
21 600 kW h

☐**END OF QUESTIONS**

0	4
---	---

Figure 5 shows the p – V diagram for a theoretical petrol engine cycle compared to the indicator diagram for a real four-stroke petrol engine with the same maximum and minimum volumes.

Figure 5



Compare the theoretical and real engine cycles. In your answer you should:

- state and explain the differences between the cycles
- explain why the work output per cycle of the real engine is less than that predicted by an analysis of the theoretical cycle.

[6 marks]

0 4

The National Grid is supplied mainly from power stations which have overall efficiencies of up to about 40%

Table 1 shows the average power requirements of a large paper-manufacturing business (a paper mill).

Table 1

Requirement	Average power / MW
for driving electric motors for wood grinders, pumps, fans, etc.	49
for heating, ie boiling and drying in the paper-making process and for heating the paper mill	141
for running electrical office equipment, lighting, etc.	8

The paper mill can either

- take all of its energy from the National Grid, or
- install an electrical generator of output 60 MW driven by a gas turbine of efficiency 36% as part of a combined heat and power (CHP) scheme. The hot exhaust gases from the turbine are used to produce steam at high temperature and pressure for heating.

The owners of the paper mill are considering the CHP option.

Explain, with reference to the data above and any other factors, the advice you would give them.

In your answer you should

- explain why the maximum theoretical efficiency of a heat engine is much less than 100%
- use the information above, including the numerical data, to compare the two options.

[6 marks]

Question 4 continues on the next page

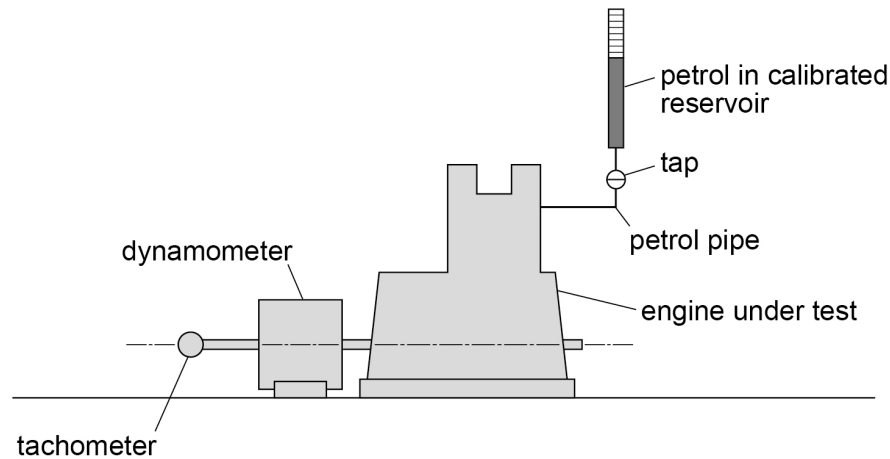
END OF QUESTIONS



0 3

Figure 4 shows some of the equipment used to investigate the thermal and mechanical efficiencies of a single-cylinder four-stroke petrol engine.

Figure 4



- Petrol is supplied to the engine from a calibrated reservoir.
- Sensors are used to measure the volume V and pressure p above the piston inside the cylinder.
- The dynamometer applies a load to the output shaft and measures the output torque of the engine.
- The tachometer measures the rotational speed of the engine in revolutions per second.

In one test the air intake valve (throttle) setting remains fixed and the load provided by the dynamometer is kept constant.

Describe how you would determine the input power, the indicated power, the brake power, the thermal efficiency and the mechanical efficiency.

In your answer you should

- describe the measurements that you would take
- show how you would use the measurements and any other necessary data.

[6 marks]

0 5 . 1

Explain how the second law of thermodynamics predicts that a heat engine can never be 100% efficient.

[2 marks]

0 5 . 2

A company plans to build a geothermal power station in a region where there is hot rock deep below the surface. The scheme is shown in **Figure 7**.

Figure 7

In the heat exchanger, energy from the hot rock is used to produce steam at $175\text{ }^{\circ}\text{C}$. The steam passes through a turbine that drives an electric generator. The exhaust steam is used to heat nearby greenhouses where it condenses before returning to the heat exchanger.

The lowest temperature in the turbine cycle is $30\text{ }^{\circ}\text{C}$.

The company claims that when the electrical power output is 2.9 MW , the power station will provide 6.4 MW for heating the greenhouses.

Deduce whether this claim is likely to be true.

Treat the power station as an ideal heat engine which obeys the second law of thermodynamics.

[4 marks]

END OF QUESTIONS





0	4
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Figure 6 shows a low-voltage solid-state thermoelectric cooling element. The element is a square of side 40 mm and is 4 mm thick.

Figure 6

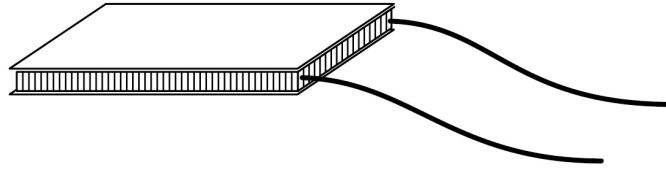
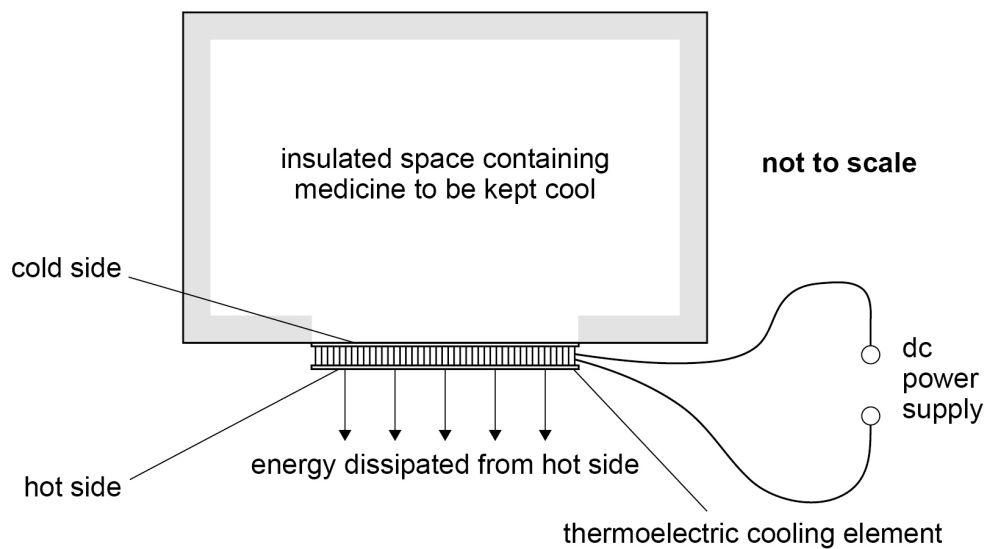


Figure 7 shows how the element is used as part of a thermoelectric refrigerator to keep small quantities of medicine at a low temperature.

Figure 7



The manufacturer's data for the element show that when the temperature of the hot side is $35\text{ }^{\circ}\text{C}$ and the temperature of the cold side is $5\text{ }^{\circ}\text{C}$:

- the rate at which energy is dissipated from the hot side is 65 W
- the electrical power supplied is 28 W .

0 4 . 1

It is claimed that the coefficient of performance (COP) of a thermoelectric refrigerator is much less than the COP of an ideal refrigerator.

Discuss whether the claim is valid for the thermoelectric refrigerator in this question.

[4 marks]

0 4 . 2

Suggest why a small value of the COP might be acceptable for this particular application of a thermoelectric cooling element.

[2 marks]

END OF QUESTIONS

0 4

Figure 7 shows the p – V diagram for a theoretical diesel engine cycle.
Figure 8 shows the indicator diagram for a real four-stroke diesel engine working between the same maximum and minimum volumes.

Figure 7

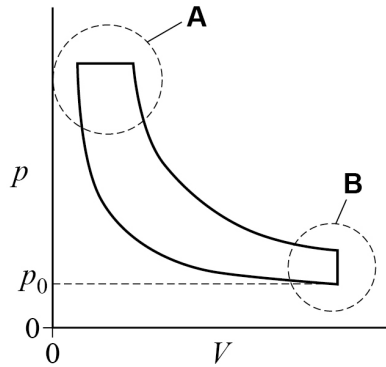
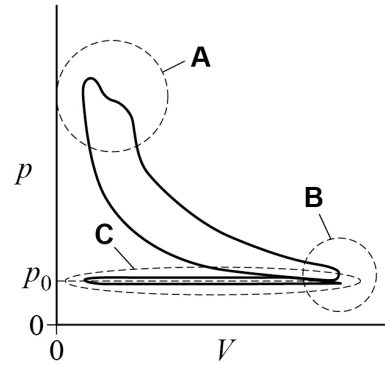


Figure 8



p_0 is atmospheric pressure.

Compare the indicator diagram with the theoretical diesel cycle.
 In your answer, explain:

- the differences between region **A** on **Figure 7** and region **A** on **Figure 8**
- the differences between region **B** on **Figure 7** and region **B** on **Figure 8**
- why the features shown in region **C** appear only on the indicator diagram
- why the efficiency of the real engine will always be less than the efficiency predicted by an analysis of the theoretical cycle.

[6 marks]

0 3 . 1 The first law of thermodynamics can be written as:

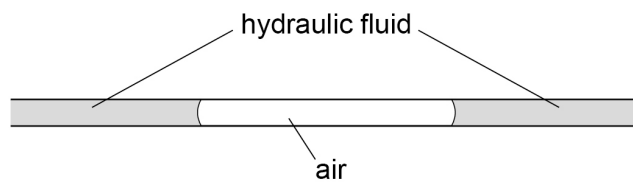
$$Q = \Delta U + W$$

State what Q represents in this equation.

[1 mark]

Air in the brake pipe of a bicycle hydraulic brake system can be dangerous. **Figure 6** shows a bubble of air in a brake pipe.

Figure 6



Assume that the hydraulic fluid is incompressible. During a sudden application of the brake, the air is compressed adiabatically to a high pressure.

0 3 . 2 The work done on the air when it is compressed is 10.8 mJ.

Which row is correct for this adiabatic compression?

Tick (✓) **one** box.

[1 mark]

W / mJ	Q / mJ	$\Delta U / \text{mJ}$	
-10.8	0	10.8	☐
10.8	10.8	0	☐
-10.8	-10.8	0	☐
10.8	0	-10.8	☐

0 3 . 3 The initial conditions for the air are:

volume of air = $2.91 \times 10^{-8} \text{ m}^3$

pressure of air = $1.05 \times 10^5 \text{ Pa}$

temperature of air = 293 K.

During sudden braking, the air in the bubble is compressed adiabatically to a volume of $3.19 \times 10^{-9} \text{ m}^3$.

Calculate the pressure and the temperature of the air immediately after the compression.

γ for air = 1.4

[3 marks]

pressure = _____ Pa

temperature = _____ K

Question 3 continues on the next page



0	3	.	4
---	---	---	---

To produce the adiabatic change, the brake lever is pulled very quickly. The cyclist thinks that by applying the brake slowly, the work done to compress the bubble to a volume of $3.19 \times 10^{-9} \text{ m}^3$ will be greater than 10.8 mJ.

Deduce without calculation whether the cyclist is correct.

[2 marks]



0 4 . 1 Which row in **Table 3** shows

- **Process 1** in which work done is zero, and
- **Process 2** in which the change in internal energy is zero?

Tick (✓) **one** box.

[1 mark]

Table 3

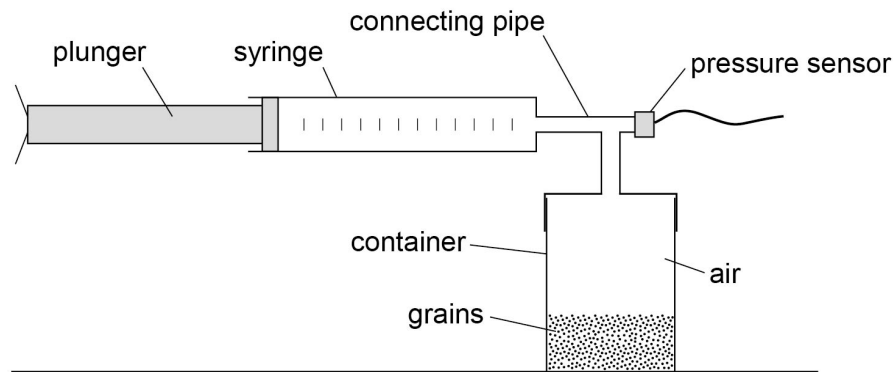
Process 1	Process 2	
constant pressure	isothermal	☐
constant volume	adiabatic	☐
constant pressure	adiabatic	☐
constant volume	isothermal	☐

0 4 . 2

When irregular particles are packed, air gaps are left between the particles. The true volume of a quantity of irregular particles must be determined using a method that does not include the volume of the air spaces between them.

The apparatus shown in **Figure 5** is used by an agricultural engineer to measure the true volume of some grains.

Figure 5



The volume of air in the syringe is $1.00 \times 10^{-4} \text{ m}^3$.

The volume of the **empty** container and connecting pipe is $2.80 \times 10^{-4} \text{ m}^3$.

Grains of total true volume V are now placed in the container and the lid is screwed on.

The pressure inside both the syringe and the container is $1.01 \times 10^5 \text{ Pa}$.

The plunger is slowly pushed fully into the cylinder of the syringe, compressing the air isothermally.

The pressure increases to $1.83 \times 10^5 \text{ Pa}$.

Determine V .

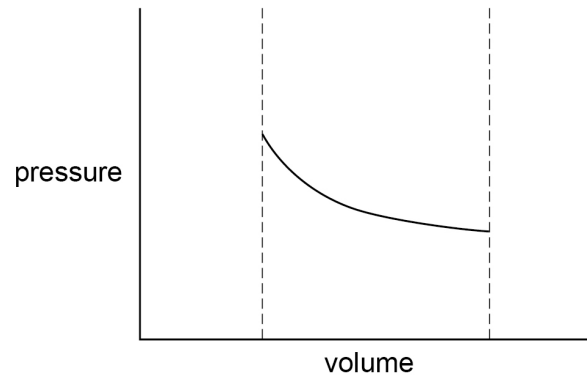
[3 marks]

$$V = \underline{\hspace{2cm}} \text{ m}^3$$

Question 4 continues on the next page

Figure 6 shows how the pressure in the container and syringe varies with volume as the plunger is pushed in fully very slowly.

Figure 6



0 4 . 3

Sketch on **Figure 6** the variation of pressure with volume when the plunger is pushed in fully very quickly and then left for several seconds. Assume no leakage past the plunger.

[2 marks]

0 4 . 4

Explain why the compression of a gas can be considered to be an isothermal change when the gas is compressed very slowly.

[2 marks]

0 3

Figure 4 shows the results of a test on an internal combustion engine which uses purified biogas.

Figure 4

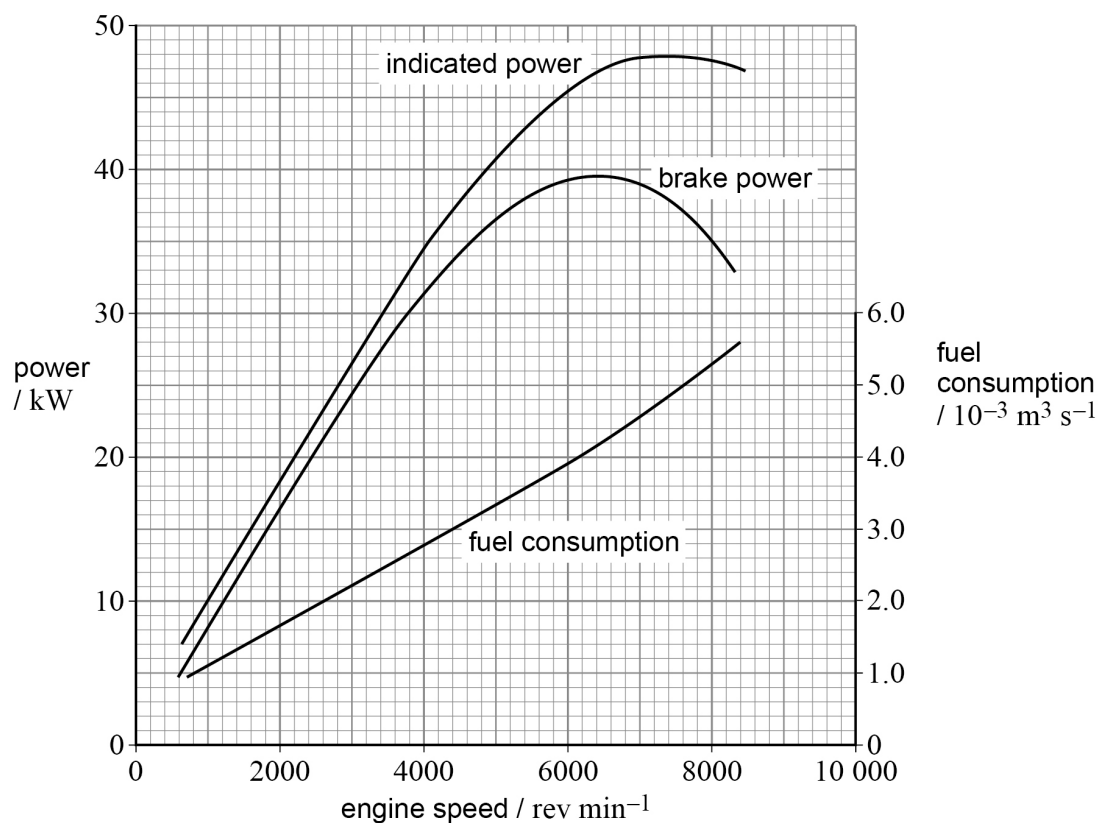


Figure 4 shows how the indicated power, brake (or output) power and fuel consumption of the engine vary with the engine speed. The scale on the left-hand axis is power and the scale on the right-hand axis is fuel consumption.

0 3 . 1

Figure 4 can be used to analyse the performance of the engine.

Determine, for the speed at which the engine develops its maximum brake power:

- the overall efficiency
- the thermal efficiency
- the mechanical efficiency.

Go on to explain how knowledge of these efficiencies can be useful to an engineer.

calorific value of biogas used in the test = $32.3 \times 10^6 \text{ J m}^{-3}$

[6 marks]

Answer space continues on the next page



0	3	.	2
---	---	---	---

Explain why it is **not** advisable to run this engine at speeds above $7000 \text{ rev min}^{-1}$.
Refer to **Figure 4** in your answer.

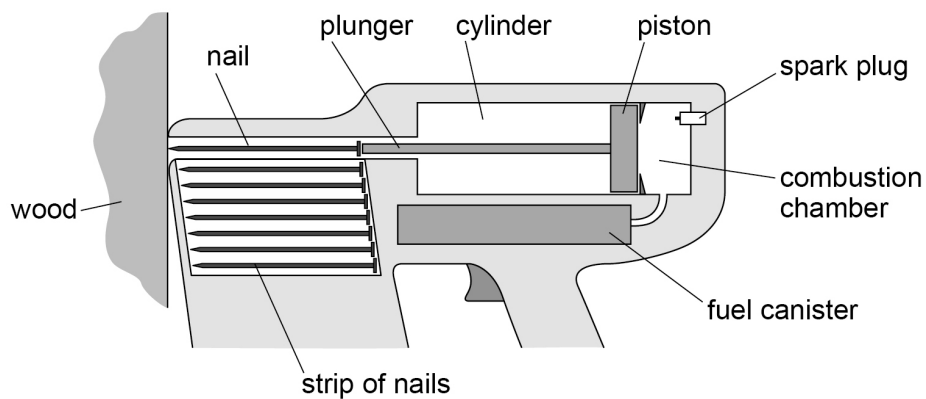
[2 marks]



0 4

Figure 5 shows a tool for driving nails into wood. Only part of the tool is shown.

Figure 5



Fuel is mixed with air in the combustion chamber and is ignited by a spark. The gas expands rapidly and drives the piston along the cylinder. The plunger attached to the piston drives the nail into the wood.

Table 2 shows the average force needed to drive nails of various lengths completely into a particular type of wood.

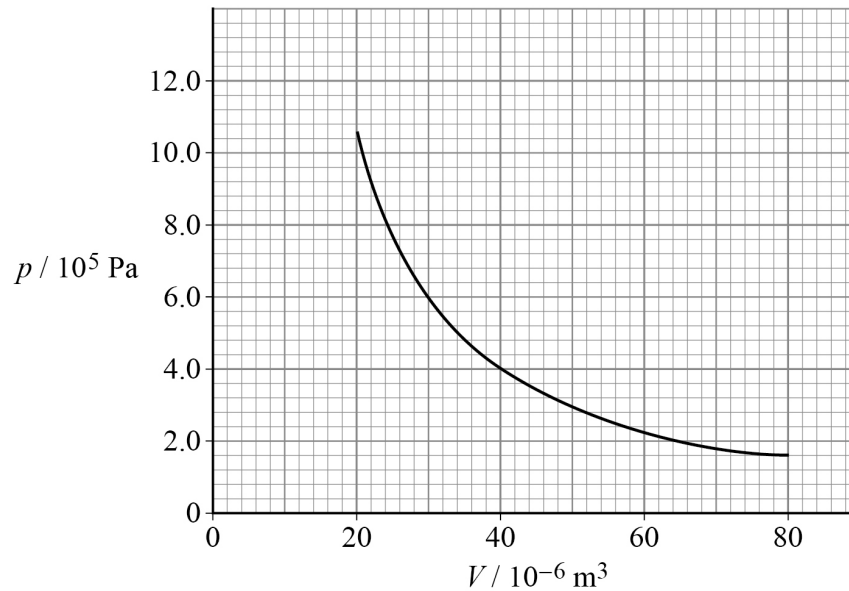
Table 2

Nail	Length / mm	Average force / N
A	32	250
B	38	320
C	45	370
D	50	420
E	63	560

0 4 . 1

Figure 6 shows the variation of pressure p with volume V as the gas expands on the right-hand side of the piston when the correct nail is used.

Figure 6



The combustion chamber has a volume of $20 \times 10^{-6} \text{ m}^3$ and the piston moves through a volume of $60 \times 10^{-6} \text{ m}^3$.

The work done by the expanding gas is just enough to drive the correct nail completely into the wood.

Deduce which nail in **Table 2** is the correct one to use in the tool.

[5 marks]

Question 4 continues on the next page

0	4	.	2
---	---	---	---

After a nail has been used, another nail takes its place automatically. The tool can drive up to 180 nails per minute.

Discuss why the expansion **cannot** be isothermal.

[3 marks]



0 4 . 1 The first law of thermodynamics can be expressed by the equation $Q = \Delta U + W$.

State the meaning of each term in this equation.

[2 marks]

Q _____

ΔU _____

W _____

0 4 . 2 A system consists of a perfectly insulated room containing only an empty refrigerator. The refrigerator is connected to the mains electricity and the refrigerator door is open.

Deduce, by applying the first law of thermodynamics, whether the internal energy of the room increases, decreases or stays the same.

[3 marks]

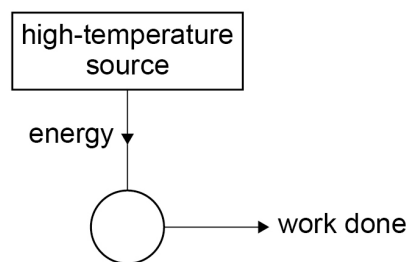


One definition of an ideal heat engine is:

‘a device which provides the maximum possible output of work from a given input of energy by heat transfer.’

Figure 8 shows a heat engine that appears to agree with this definition. The engine takes in energy from a high-temperature source and work is done by the engine.

Figure 8



0 4 . 3 Complete **Figure 8** so that the engine obeys the second law of thermodynamics.

[1 mark]

0 4 . 4 Explain why the maximum theoretical efficiency of an ideal heat engine must be less than 100%.

[2 marks]

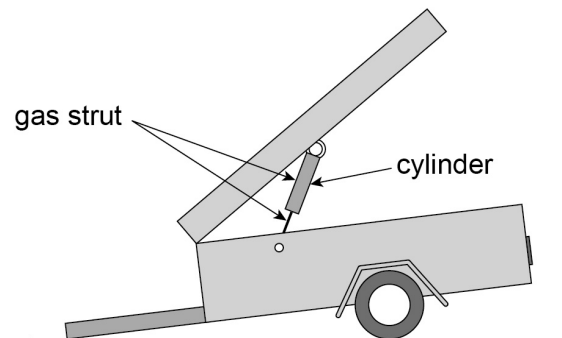
END OF QUESTIONS



0	3
---	---

Figure 4 shows a gas strut supporting the lid of a trailer.

Figure 4



A fixed mass of nitrogen gas is sealed into the cylinder of the strut.

0	3	.	1
---	---	---	---

The gas is initially at a pressure of 1.2×10^6 Pa, a volume of $9.0 \times 10^{-5} \text{ m}^3$ and a temperature of 290 K.

When the lid is closed quickly the gas is compressed rapidly to a final volume of $6.8 \times 10^{-5} \text{ m}^3$.

Calculate the pressure and temperature of the gas at the end of the compression assuming the compression to be an adiabatic process.

adiabatic index γ for nitrogen = 1.4

[4 marks]

pressure = _____ Pa

temperature = _____ K

0	3	.	2
---	---	---	---

Explain why the rapid compression of the gas can be assumed to be an adiabatic process.

[2 marks]

0	3	.	3
---	---	---	---

When the lid is closed slowly, the compression can be assumed to be isothermal.

The gas can be compressed either isothermally or adiabatically from the same initial conditions to the same final volume.

Compare without calculation the work done in each process.

[3 marks]

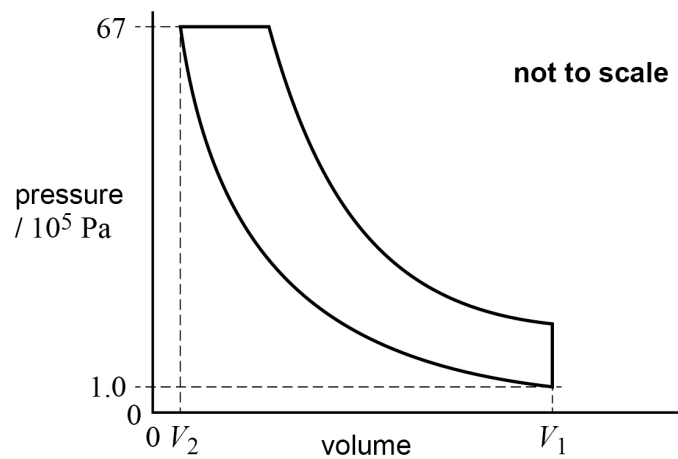


0 3 . 1 Explain what is meant by an adiabatic change.

[1 mark]

0 3 . 2 Figure 4 shows the p - V diagram for an ideal diesel engine cycle.

Figure 4



In this cycle, air is compressed adiabatically from a pressure of 1.0×10^5 Pa and volume V_1 to a pressure of 67×10^5 Pa and volume V_2 .

The adiabatic index γ for air = 1.4

Calculate the compression ratio $\frac{V_1}{V_2}$.

[2 marks]

compression ratio = _____

Question 3 continues on the next page



0 3 . 3

Explain why the compression ratio for a diesel engine must be greater than the compression ratio for a petrol engine.

[2 marks]

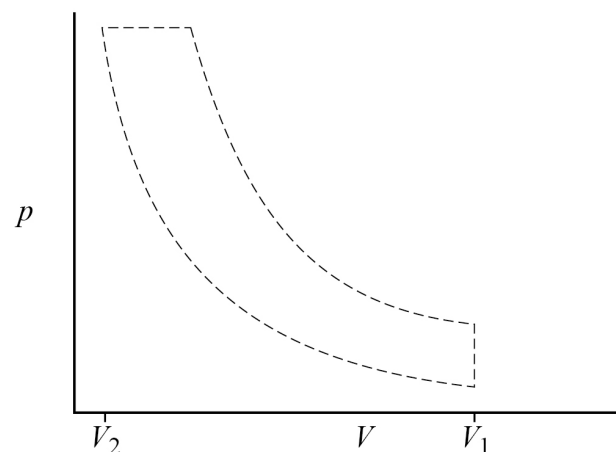
The dashed lines in **Figure 5** show the p - V diagram for the ideal diesel engine cycle.

0 3 . 4

Draw, on **Figure 5**, a typical indicator diagram for a real four-stroke diesel engine with the same values of V_1 and V_2 .

[2 marks]

Figure 5



0 3 . 5

Mark with an **X** on your diagram the point where the injection of fuel starts.

[1 mark]

03.6

Explain **two** differences between the ideal cycle and the indicator diagram for the real engine.

[2 marks]

1 _____

2 _____



0 3

The Lenoir engine was the first successful internal combustion engine.

Figure 6 shows the basic form of the Lenoir engine. The piston rod drives a crankshaft which is not shown. The fuel is a mixture of gas and air.

Figure 6

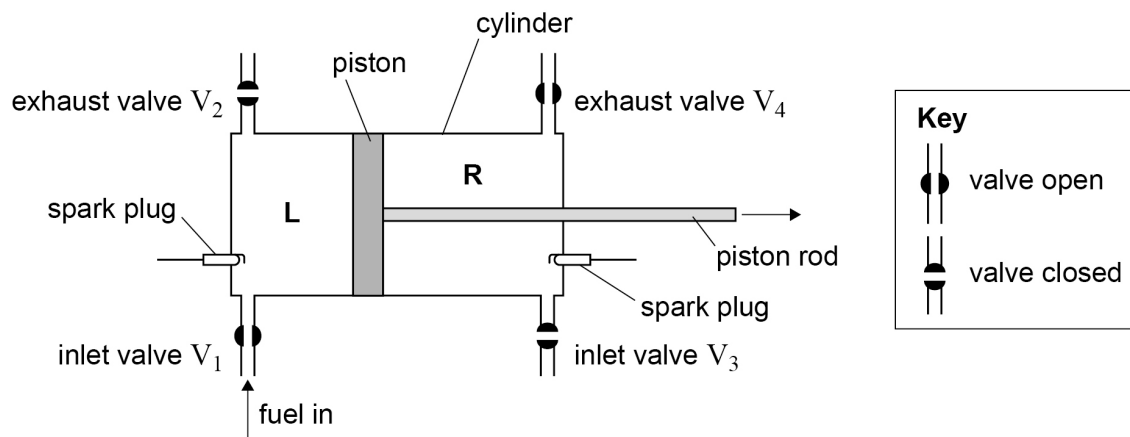


Figure 7 shows an indicator diagram for the space L, taken during a test on a Lenoir engine.

Figure 7

In one cycle the following changes occur in **L**.

- **Induction.** The piston starts at the left-hand end of the cylinder. It moves to the right and fuel passes through the open inlet valve V_1 into **L**. **Figure 6** shows the piston during this induction process, with V_1 open.
- **Ignition.** When the piston is nearly halfway along the cylinder, V_1 is closed. A spark ignites the fuel causing a sudden rise in pressure.
- **Expansion.** The hot gases expand and the piston moves to the end of the stroke.
- **Exhaust.** The exhaust valve V_2 opens. The piston moves to the left. The exhaust gases are expelled at atmospheric pressure.

The same processes are repeated in space **R** one half of a revolution of the crankshaft later than in **L**. So when the piston is moving to the left, induction, ignition and expansion occur in **R** at the same time as the exhaust process occurs in **L**.

03.1 The indicator diagram is for a rotational speed of the crankshaft of 120 rev min^{-1} .

Determine, using **Figure 7**, the indicated power of the engine.

Assume that the indicator diagram for **R** is identical to the indicator diagram for **L**.

[5 marks]

indicated power = _____ W

Question 3 continues on the next page



0 3 . 2 The following data are taken during the test on the engine:

fuel consumption = $6.44 \times 10^{-4} \text{ m}^3 \text{ s}^{-1}$
calorific value of fuel = $18.0 \times 10^6 \text{ J m}^{-3}$
torque at crankshaft = 39.0 N m
rotational speed = 120 rev min^{-1}

Calculate the input power and the output (brake) power of the engine.

[2 marks]

input power = _____ W

output power = _____ W

0 3 . 3 The output power of a four-stroke petrol engine of a similar working volume to that of the Lenoir engine is about 150 kW.

Suggest **two** reasons for the very low output power of the Lenoir engine compared with a four-stroke petrol engine.

[2 marks]

1 _____

2 _____



0 3 . 4 Which statement is correct?

Tick (✓) **one** box.

[1 mark]

Thermal efficiency is a measure of how much of the indicated power is converted into output power.

☐

Overall efficiency is the product of mechanical efficiency and thermal efficiency.

☐

Mechanical efficiency is equal to friction power divided by indicated power.

☐

Input power is equal to indicated power plus friction power.

☐

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.

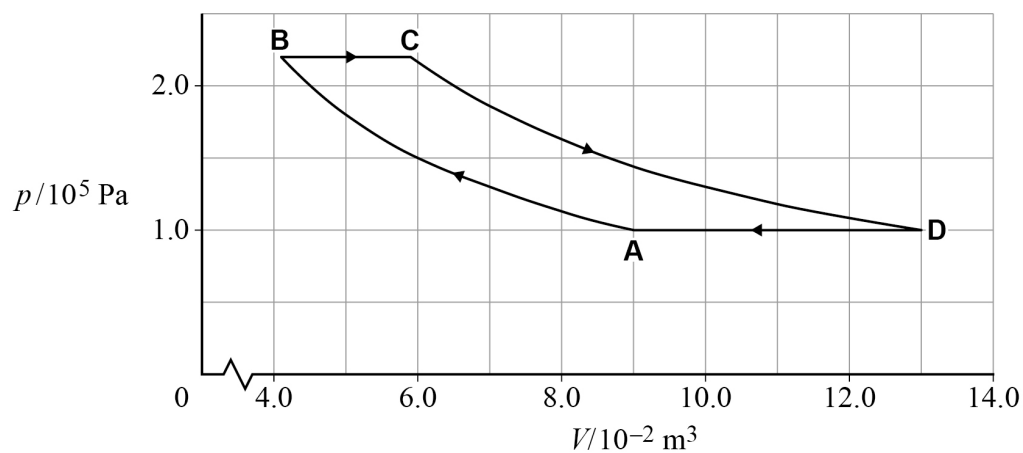
B → C increase in volume at constant pressure to a volume of $5.9 \times 10^{-2} \text{ m}^3$.

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]

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]

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** → **A** and gives up **all** this energy to the air in process **B** → **C**. This means that an external source supplies energy to the air by heating only in process **C** → **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 → B	−7100	−7100
B → C	4000	
C → D	10 300	10 300
D → A		−14 000

Question 3 continues on the next page



0 3 . 4 Explain why W is equal to Q in process **A** → **B** and in process **C** → **D**.

[2 marks]

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]

0 3 . 6 Discuss **one** problem that would be faced by an engineer designing a real engine based on this cycle.

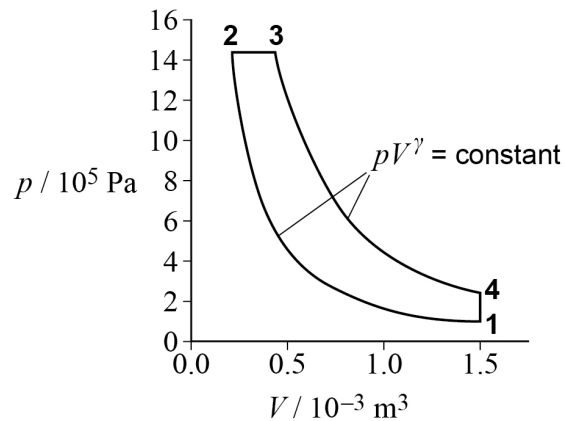
[2 marks]



0 3

Figure 3 shows the p – V diagram for an idealised diesel engine cycle. In this cycle a fixed mass of air is taken through four processes $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1$.

Figure 3



0 3 . 1

Which statement about this cycle is true?

Tick (✓) the correct answer.

[1 mark]

Work is done by the air in process $4 \rightarrow 1$.

☐

Energy is supplied to the air by heating only in process $2 \rightarrow 3$.

☐

The temperature of the air rises in process $3 \rightarrow 4$.

☐

The area enclosed by the loop $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1$ is the power output of the cycle.

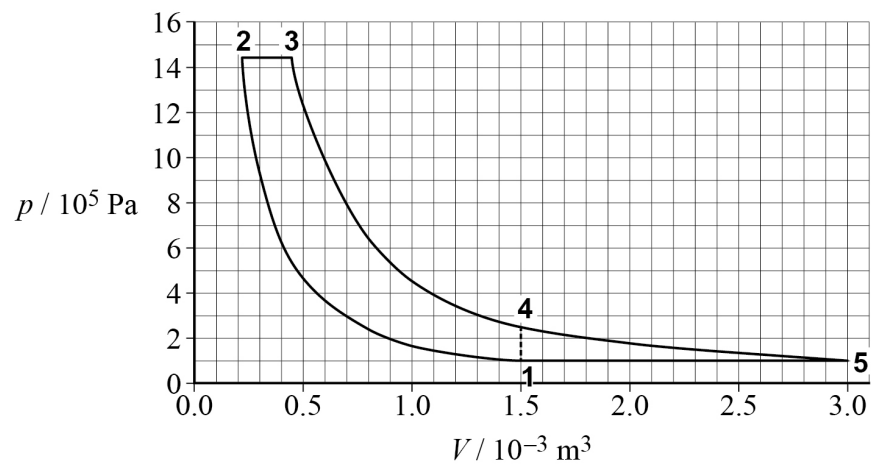
☐

0 3 . 2

The cycle in **Figure 3** may be modified by allowing the air to continue to expand adiabatically from state **4** until it is at atmospheric pressure at state **5**.

Figure 4 shows the modified cycle.

Figure 4



The expansion stroke $3 \rightarrow 5$ is now longer than the compression stroke $1 \rightarrow 2$. Process $5 \rightarrow 1$ takes place at constant pressure.

It has been claimed that, compared to the cycle in **Figure 3**, the modified cycle of **Figure 4** gives

- A** an increase in work done per cycle of 130 J
- B** an increase in efficiency of more than 15%

Deduce whether these claims are true.

[5 marks]

Claim **A**

Claim **B**

Question 3 continues on the next page



0 3 . 3 The first law of thermodynamics can be written as

$$Q = \Delta U + W$$

State the meaning of the terms Q and ΔU in this equation.

[2 marks]

Q _____

ΔU _____

0 3 . 4 For the air in process **5** → **1** in **Figure 4**, $\Delta U = -374$ J

Calculate the energy that must be removed by cooling for process **5** → **1**.

[2 marks]

energy removed by cooling = _____ J



0 3 . 5 0.060 mol of air is taken through the cycle.

Determine the maximum temperature in the cycle.

[3 marks]

maximum temperature = _____ K



0 3 . 1

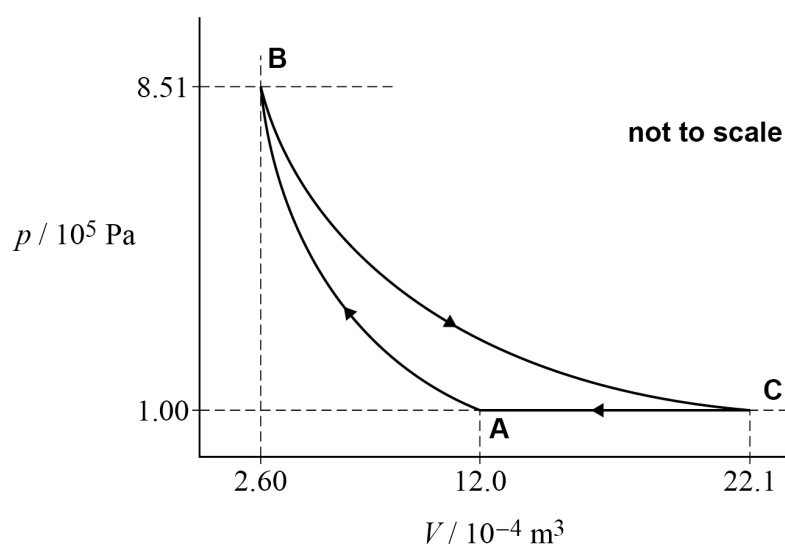
State what is meant by an isothermal change.

[1 mark]

Figure 6 shows a p – V diagram in which a fixed mass of an ideal gas is taken through a cycle of three processes.

- A** → **B**: adiabatic change
B → **C**: isothermal change
C → **A**: reduction in volume at constant pressure

Figure 6



The maximum temperature of the gas in the cycle is 536 K and the minimum temperature is 291 K.

0 3 . 2

Calculate, in mol, the amount of gas.

[2 marks]

amount of gas = _____ mol



03.3

Show that the work done in process **C** → **A** is about 100 J.

[1 mark]

03.4

Complete **Table 2** for each process and for the whole cycle.

[3 marks]

Table 2

	Q / J	W / J	$\Delta U / \text{J}$
Process A → B		−253	
Process B → C	473		
Process C → A			−253
Whole cycle		119	

03.5

Two criteria for a heat engine to achieve the maximum theoretical efficiency are:

1. the gas must always be at the same temperature as the hot source when energy is being transferred **to** the gas by heat transfer

2. the gas must always be at the same temperature as the cold sink when energy is being transferred **from** the gas by heat transfer.

The temperatures of the source and sink do not change.

Deduce whether the cycle in **Figure 6** satisfies either or both of these criteria.

[2 marks]

Question 3 continues on the next page

0 3 . 6

The overall efficiency of a heat engine is defined as

$$\text{overall efficiency} = \frac{\text{net work output in one cycle}}{\text{energy supplied by heat transfer in one cycle}}$$

An engineer suggests designing a real engine based on the cycle shown in **Figure 6**.

Discuss the engineer's suggestion.

In your answer you should:

- use **Table 2** to determine the overall efficiency of a theoretical engine that uses the cycle
- compare this overall efficiency with the efficiency of an ideal engine working between the same temperatures as the cycle
- discuss with reasons the problems that would need to be overcome in making a real engine work on this cycle
- explain whether the engineer's suggestion would lead to a useful engine.

[6 marks]

MARK SCHEMES

official mark schemes



02.1	Equates initial E_p to linear E_k and rotational E_k ✓ Substitutes values and uses $V = r\omega$ ✓ Calculates V to give 0.51 m s^{-1} ✓	$9.2 \times 10^{-2} \times 9.81 \times 0.5 = (\frac{1}{2} \times 9.2 \times 10^{-2} V^2) + (\frac{1}{2} \times 8.6 \times 10^{-5} \times \frac{V^2}{0.005^2})$ $V = 0.51 \text{ m s}^{-1}$ Some substitution of data must be seen for MP2 Do not allow MP3 for no consideration of linear E_k Give 1 mark if $mgh = \frac{1}{2}I\omega^2$ used with answer 0.51 m s^{-1}	3	AO2.1f or AO2.1h × 3
------	---	--	---	-------------------------------

Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Calculates α from $\alpha = T/I$ ✓ Attempts to use any appropriate equation(s) of motion (for angular motion) ✓ Substitutes into equation(s) of motion and calculates θ ✓	$\alpha = (8.3 \times 10^{-4}) / 8.6 \times 10^{-5} = 9.65 \text{ rad s}^{-2}$ or 9.7 rad s^{-2} $\theta = 145 \times 10 - \frac{1}{2} \times 9.7 \times 10^2 = 967 \text{ rad}$ or 970 rad MP2: $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ is not enough on its own as there are two unknowns. MP2: Quoting appropriate formula(e) is not enough. There must be some attempt at substituting the data.	3	AO2.1b × 3
Total			6	

8

Question	Answers	Additional comments/Guidelines	Mark	AO
	The mark scheme gives some guidance as to what statements are expected	Numerical answers:		



02.1	OR to store (rotational kinetic) energy ✓ OR to smooth (fluctuations in) torque/power ✓	Do not allow an <i>application</i> (eg regenerative braking) unless one of the answers shown alongside is included.	1
02.2	Use of $0.075 \sin 8^\circ$ or $0.075 \tan 8^\circ$ or $0.075 (\pi - 3)$ to calculate h $h = 1.04 \times 10^{-2}$ (m) OR 1.05×10^{-2} (m) OR 1.06×10^{-2} (m) ✓ $mgh = 0.020 \times 9.81 \times 1.04 \times 10^{-2} = 2.04 \times 10^{-3}$ (J) ✓ $T\theta = 2.04 \times 10^{-3}$ (J) $T = 2.04 \times 10^{-3} / 3.00 = 6.80 \times 10^{-4}$ Nm ✓	1st mark for calculating h 2nd mark for calculating mgh. 3rd mark for dividing mgh by 3.00 rad. Use of tan gives $h = 1.05 \times 10^{-2}$ (m) Use of arc length gives $h = 1.06 \times 10^{-2}$ (m) 3rd mark only awarded for arriving at correct answer to more than 1 sig fig.	3
02.3	Attempt to use $0 = \omega_1^2 - 2\alpha\theta$ ✓ or $\theta = 573 \times 2\pi = 3600$ rad ✓ leading to $\alpha = 0.087$ (rad s⁻²) ✓ $I = \frac{T}{\alpha} = 7.82 \times 10^{-3}$ kg m² ✓ OR Attempt to use $T\theta = \frac{1}{2} I (\omega_2^2 - \omega_1^2)$ ✓ or $\theta = 573 \times 2\pi = 3600$ rad ✓ $(I = 2T\theta/\omega_1^2)$ $= 2 \times 6.8 \times 10^{-4} \times 573 \times 2\pi/25^2$ ✓ $= 7.82 \times 10^{-3}$ kg m² ✓	1st mark for either use of equation or converting rotations to rad ECF for 3rd mark. The value of torque used must be a correctly calculated answer to 02.2 or 7×10^{-4} N m <u>For 2nd method</u> 1st mark for either use of equation or converting rotations to rad 2nd mark for correct substitution 3rd mark for calculating answer	3

8

Total			7
-------	--	--	---

Question	Answers	Additional Comments/Guidelines	Mark
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02.1	Work done ✓		1	1.1b
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02.2	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question.		Likely answer points: <u>1st bullet</u> 1. Electric motor's constant torque means smooth motion/doesn't need smoothing/doesn't need a flywheel 2. motor's output torque matches the described load <u>2nd bullet</u> 3. relates force/pressure on piston to torque 4. force on piston varies over one cycle (as pressure in cylinder varies) 5. Torque = Fr and effective r varies as crank rotates 6. -ve torque: when work is being done on (the gas in) the engine (during induction, comp, exhaust strokes) 7. Zero torque when con rod and crank are in line/at top and bottom dead centres 8. This happens at crank angles which are multiples of π <u>3rd bullet</u> 9. Diesel engine's (varying torque) will give uneven/jerky motion/cause stalling 10. Flywheel acts as energy store 11. Flywheel absorbs energy on power/expansion stroke 12. and gives up energy on other parts of cycle 13. Flywheel speeds up on expansion stroke 14. and slows down during other strokes. 15. The greater the M of I of flywheel, the smoother the motion 16. If no flywheel engine will stall/become very uneven/jerky 17. The greater the M of I of flywheel, the longer engine will take to speed up, slow down/stop 18. Because machine has low M of I it will not be able to store energy itself or smooth the motion.	6	1.1a x 3 2.1a x 3															
	<table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>There is a response to all 3 bullet points in the question. There is a good understanding of the function of a flywheel, and why the torque varies markedly in a diesel engine. Student can relate the answer to the two graphs. Includes 6 or more answer points from the list alongside</td></tr><tr><td>5</td><td>There is a response to all 3 bullet points in the question covering 6 answer points. Answers will not be as confident or detailed as for 6 marks, or answers may not be expressed using scientific terminology.</td></tr><tr><td>4</td><td>The student gives five or more answer points covering at least two of the bullet points.</td></tr><tr><td>3</td><td>At least four pertinent statements. They may show little understanding of the electric motor but should be able to give some reasons why a diesel engine needs a flywheel.</td></tr><tr><td>2</td><td>Two or three pertinent statements taken from the list of likely answer points.</td></tr><tr><td>1</td><td>One pertinent statement.</td></tr><tr><td>0</td><td>No sensible statements made.</td></tr></table>	Mark	Criteria			6	There is a response to all 3 bullet points in the question. There is a good understanding of the function of a flywheel, and why the torque varies markedly in a diesel engine. Student can relate the answer to the two graphs. Includes 6 or more answer points from the list alongside	5	There is a response to all 3 bullet points in the question covering 6 answer points. Answers will not be as confident or detailed as for 6 marks, or answers may not be expressed using scientific terminology.	4	The student gives five or more answer points covering at least two of the bullet points.	3	At least four pertinent statements. They may show little understanding of the electric motor but should be able to give some reasons why a diesel engine needs a flywheel.	2	Two or three pertinent statements taken from the list of likely answer points.	1	One pertinent statement.	0	No sensible statements made.	
	Mark	Criteria																		
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	2	Two or three pertinent statements taken from the list of likely answer points.																		
	1	One pertinent statement.																		
	0	No sensible statements made.																		
Other sensible and applicable points can be accepted in lieu of any of those alongside.																				

Question	Answers	Additional Comments/Guidance	Mark	ID details
	$p_A V_A = p_B V_B$	The mark is for attempt to use Boyle's Law		1.1b × 1 ?



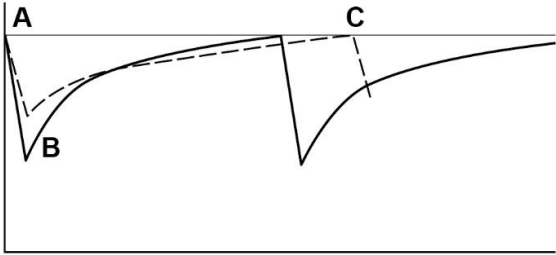
02.1	No (net) external torque acts (on the system) ✓	Do not accept force for torque	1	AO1.1a ×1
02.2	$I_A \omega_A + I_B \omega_B = (I_A + I_B) \omega$ ✓ (taking clockwise as positive) $(7.2 \times 95) + (11.5 \times -45) = 18.7\omega$ $\omega = (+)8.9 \text{ rad s}^{-1}$ ✓ clockwise ✓	Accept answers with anticlockwise taken as positive. 1st mark for equation or substitution, but condone any incorrect sign for angular velocity. 2nd mark: answer to at least 2 sf 3rd mark for direction, ECF provided direction agrees with sign in calculated answer and sign convention used. 3rd mark is not an independent mark and is contingent on some attempt at calculation using angular momentum	3	AO2.1f ×3 L2M ×2
02.3	Attempts to use Angular impulse = $Tt = \Delta(I\omega)$ ✓ Clutch C: $600 t = 7.2 \times (95 - 8.9) = 620 \text{ (N m s)}$ $t = 1.03 \text{ s}$ OR $\alpha = (95 - 8.9)/t$ $600 = I\alpha = 7.2 (95 - 8.9)/t$ $t = 1.03 \text{ s}$ Clutch D: $320 t = 7.2 \times (95 - 8.9)$ $t = 1.93 \text{ s}$ ✓ (for either or both times calculated) Compares correct times with $1\text{s} < t < 2\text{s}$ and concludes both clutches satisfy criterion. ✓	1st mark: attempts to use idea of angular impulse Mark not given for just quoting formula. 2nd mark: correct time(s) calculated for either or both clutches OR torques calculated for 1 s and/or 2 s [620 Nm and 310 Nm] 3rd mark: correct conclusion based on correct times for both clutches OR based on comparing calculated torques for 1 and 2 s with data in Table 2 Answers may be worked out using shaft B: $T \times t = 11.5 \times (-45 - 8.9) = (-)620 \text{ N m s}$	3	AO3.1a ×3 L2M ×2

		Give full marks if 9 rad s^{-1} is used, giving angular impulse = 619 N m s t for clutch C = 1.03 s t for clutch D = 1.93 s		
Total			7	



01.1	torque $\tau = \text{moment of inertia} \times \text{angular acceleration}$ ✓	$\tau = I \alpha$ 2 marks any two of τ I α 1 mark Do not accept 'inertia' for 'moment of inertia' or 'acceleration' or 'rotational acceleration' for 'angular acceleration' If = or equals, or $\times$ or multiplied by, is missing or in wrong place: 0 marks Condone 'proportional to' for '='.	2	2 × AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Refers to $I = \sum mr^2$ in symbols or in words ✓ (Plate) A because more of the mass is distributed at a greater distance from the axis of rotation (than for plate B) ✓	Look for I depending on radius/distance of (constituent) masses squared. Do not accept ' $I = mr^2$ ' alone A alone is not enough. There must be a statement about the mass distribution or spread.	2	2 × AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	decrease in speed from ω_A not as much / ω_B greater ✓ curved line (from new B) with smaller initial gradient up to ω_A ✓	 Slope of new AB can be ignored unless it is shown with a much smaller gradient. Position of new C can vary, but shape of cycle must be similar to original. Do not mark beyond candidate's first C	2	2 × AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Either: For same energy, in $E = \frac{1}{2} I (\omega_A^2 - \omega_B^2)$, (new) ω_B will be greater for greater I and same E ✓ OR For same motor torque, greater I means smaller angular acceleration, so smaller initial slope for BC ✓	Accept same idea expressed in other ways, eg initial (rotational kinetic) energy greater, so less fall in speed for same energy loss (during punching). If B to C curve starts at same ω_B as Figure 2 with smaller initial gradient, and their B to C takes longer time to ω_A allow: For same motor torque, greater I means lower angular acceleration, so longer time for B to C	1	1 × AO3
Total			7	

Question	Answers	Additional comments/Guidance	Mark	AO
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02.1	Equates E_P to $E_{K\text{linear}}$ plus $E_{K\text{rot}}$ ✓ Substitutes Amr^2 for I and $v = r\omega$ in some form to eliminate r and ω ✓ Cancels m and rearranges ✓	The award of each mark is contingent on the award of the previous mark. MP1: Accept words or symbols: $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$ MP2: $mgh = \frac{1}{2}mv^2 + \frac{1}{2}(Amr^2)\frac{v^2}{r^2}$ m cancels, r^2 cancels Condone missing $\frac{1}{2}mv^2$ in MP1 and MP2 but withhold MP2 if required answer is (incorrectly) derived. (expect to see $v = \sqrt{\frac{2gh}{A}}$)	3	1× AO1 2× AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Idea that more of the mass is at greater distance from the axis (in the hollow sphere) (so moment of inertia greater) ✓	Accept idea that (for hollow sphere) mass is distributed further from axis Do not allow idea that Q has more mass or greater radius than P. Treat references to density as neutral.	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	Derives expression for v for any one object ✓_{1a} Repeats for all other objects ✓_{2a} (Order of descending v =) P, R, Q, S ✓_{3a} OR $A = \frac{2}{5}, \frac{2}{3}, \frac{1}{2}, 1$ ✓_{1b} Idea that the greater the value of A, the smaller the value of v ✓_{2b} (Order of descending v =) P, R, Q, S ✓_{3b}	Expect to see: P solid sphere $v = \sqrt{\frac{10gh}{7}}$ (leading to: $v = 3.7 \times \sqrt{h} \text{ m s}^{-1}$) Q hollow sphere $v = \sqrt{\frac{6gh}{5}}$ (leading to: $v = 3.4 \times \sqrt{h} \text{ m s}^{-1}$) R solid cylinder $v = \sqrt{\frac{4gh}{3}}$ (leading to: $v = 3.6 \times \sqrt{h} \text{ m s}^{-1}$) S hollow cylinder $v = \sqrt{gh}$ (leading to: $v = 3.1 \times \sqrt{h} \text{ m s}^{-1}$) condone missing g and/or h in their calculations. In alternative ✓_{2b}: allow reverse argument; condone idea that the greater value of I, the smaller the value of v. Do not accept argument based on angular acceleration or angular velocity without support in terms of v or t.	3	2× AO2 1× AO3
Total			15	

Question	Answers	Additional comments/Guidance	Mark	AO
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01.1	force	torque ✓	Do not allow 'inertia'	2
	mass	moment of inertia ✓		
01.2	$I_T = 2.6 \times 10^7 + (2.2 \times 10^3 \times 35^2)$ $= 2.9 \times 10^7 \text{ (kg m}^2\text{)} \checkmark$		Mark only awarded for arriving at correct answer to more than 1 sf.	1
01.3	Use of (total) area under graph = (angular) displacement/distance ✓ $\omega_{\max}((\frac{1}{2} \times 30) + 20 + (\frac{1}{2} \times 45)) = 4.7$ $\omega_{\max} = 0.082 \text{ (rad s}^{-1}\text{)} \checkmark$		Alternative route is area of trapezium $\frac{1}{2} \omega_{\max} (20 + 95) = 4.7$	2
01.4	moment of inertia of rotating jib + load increases as trolley moves outwards ✓ reference to $T = I\alpha$ with T constant, so α decreases ✓ decreased α means longer time to stop(than 95 s) ✓			3
Total				8

Question	Answer	Additional Comments/Guidance	Mark
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02.1	$T = 6.0 \times 0.036 = 0.22 \text{ (N m)} \checkmark$		1
02.2	power cannot increase $\checkmark$ $P = T\omega$ so if ω is 4 x greater, T cannot be more than $1/4\checkmark$ OR Work done by (torque) on C cannot be greater than work done (by torque) on B $\checkmark$ $W = T\theta$, if θ is 4 x greater, T cannot be more than $1/4\checkmark$ Or $T_C \times 4\theta_B = T_B\theta_B$ so $T_C = T_B/4$ OR Force same on both/force cannot increase/ r_C is $1/4 r_B \checkmark$ $F \times r_C = F \times r_B/4$ so $T_C = T_B/4$ Or Because radius is $1/4$, torque on C must be $1/4 \checkmark$	Accept other valid argument e.g using knowledge that radius of C is $1/4$ radius of B, or velocity v at point of mesh of gears is the same for both. Do not allow 'it is not possible' (WTTE) unless backed up by valid argument.	2
02.3	$\alpha = 76/2.1 = 36 \text{ (rad s}^{-1}\text{)} \text{ (36.2 rad s}^{-1}\text{)} \checkmark$ $I = T/\alpha = \frac{0.054}{36} = 1.5 \times 10^{-3} \text{ (kg m}^2\text{)} \checkmark$	ECF for 2nd mark for AE or transposing error.	2
02.4	angular impulse = ang. momentum change = $T\Delta t \checkmark$ Reference to (large) $\Delta(I\omega)$ in small Δt gives large $T\checkmark$ ($T = F \times r$) so large F on gear teeth. $\checkmark$	1st mark for statement defining angular impulse 2nd for relating momentum change in small t to high T 3rd for relating high T to high force	3

Total			8
Question	Answer	Additional Comments/Guidance	Mark
	$p_1 V_1^{1.4} = p_2 V_2^{1.4}$ $p_2 = p_1 (V_1/V_2)^{1.4}$ $= 1.2 \times 10^6 (9.0/6.8)^{1.4} \quad \checkmark \quad = 1.8 \times 10^6 \text{ (Pa)} \quad \checkmark$ $T_2 = \frac{p_2 V_2}{p_1 V_1} T_1 = \frac{1.8 \times 10^6 \times (6.8 \times 10^{-5})}{1.2 \times 10^6 \times 9.0 \times 10^{-5}} \times 290 \quad \checkmark$	1st mark for substituting correct values into either equation 2nd mark for answer p_2 3rd mark for substituting correct values into $p_1 V_1/T_1 = p_2 V_2/T_2$ or $T_2 = \frac{p_2 V_2 T_1}{p_1 V_1}$	



01.1	Sum of all constituent masses $\times$ their radius/distance from the axis squared	Allow Σmr^2 with m defined as small mass or constituent mass or particle at a radius r and Σ explained. Condone: 'from the axis' missing Condone: a quantity expressing a body's tendency to resist angular acceleration/change in angular speed	1	AO1.1a $\times 1$
01.2	E_P lost (by falling mass) = E_K pulley + E_K mass ✓ $0.5Mgh = \frac{1}{2}(0.5M)v^2 + \frac{1}{2}(0.5MR^2)\omega^2$ Cancel 0.5 and M and substitute $\omega = \frac{v}{R}$ for ω gives $gh = \frac{1}{2}v^2 + \frac{1}{2}v^2 = v^2$ ✓ use of $v^2 = u^2 + 2as$ giving $v^2 = 2ah$ ✓ substitutes $v^2 = 2ah$ in $gh = v^2$ (so $a = 0.5g$) ✓ OR $0.5Mg - F = 0.5Ma$ ✓ Torque = $I\alpha$ $F \times R = (0.5MR^2)\alpha$ ✓ (giving $F = 0.5MR\alpha$) and substitute $\alpha = a/R$ leading to $F = 0.5Ma$ ✓ Substitute for F in $0.5Mg - F = 0.5Ma$ (gives $a = 0.5g$) ✓	1st mark for equating E_P lost by mass to E_K gained by both mass and pulley. Accept this step in words or symbols 2nd mark for $gh = v^2$ 3rd mark for v^2 in terms of h 4th mark for combining correctly (to get $a = 0.5g$) OR with F or other letter as tension in string: 1st mark for Newton's 2nd law applied to mass in words or symbols 2nd mark for accelerating torque equation 3rd mark F in terms of a 4th mark for substituting to get $a = 0.5g$ <i>Note: $\alpha = a/R$ is not in the spec, but students may know it and use this route.</i> Give ECF if M is used for the falling mass in place of $0.5M$	4	AO2.1d $\times 4$ L2M $\times 3$

Question	Answers		Additional comments/Guidance	Mark	AO
01.3	Route 1	Route 2	WTTE For $\checkmark_3$ and $\checkmark_4$ marks in route 2 $0.5M(g - a) = F$ $0.5M(g - a)R = I\alpha$ $0.5Mg = a(0.5M + I/R^2)a$ If I increases, a decreases.	Max 3	AO3.1b ×3
	M of I spoked pulley is greater $\checkmark_1$ Reason given for greater M of I but must have reference to distribution or spread of mass about axis $\checkmark_2$ Greater proportion of E_P loss given to pulley OR lower prop to E_K of falling mass $\checkmark_3$ v of mass in same time will be lower so acceleration lower $\checkmark_4$	M of I spoked pulley is greater $\checkmark_1$ Reason given for greater M of I but must have reference to distribution or spread of mass about axis $\checkmark_2$ Presents valid argument relating I to α $\checkmark_3$ $\alpha = a/R$ (with α less) so acceleration of mass is less OR wheel turns through fewer rotations in same time so point on rim moves less distance so acceleration less $\checkmark_4$			
Total				8	

Question	Answers	Additional comments/Guidance	Mark	AO
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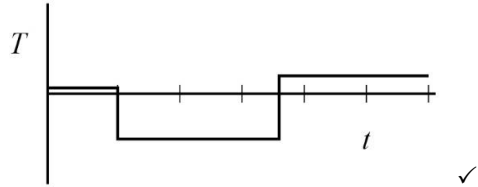


01.1	Attempt at calculating area above or below t axis or both ✓ (Ang displacement $\Rightarrow$ $2.80 + 2.10 - 3.15 = 1.75$ rad) $(\frac{1.75}{12.0} \Rightarrow) 0.15$ (rad s⁻¹) ✓	Method must be valid MP2: correct answer only (calculator value = 0.145833) MAX1 if counting square method used and answer rounds to 0.15 (rad s⁻¹)	2	2 x AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	$P = T\omega$ giving 546 (W) ✓	Allow ecf for 590 (W) from using $\omega_1 = 1.5$ rad s⁻¹	1	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	Selects steepest part of graph and determines gradient $\alpha = \frac{1.40 - -0.90}{5.0} = 0.46 \text{ (rad s}^{-2}\text{)} \checkmark_1$ $T = I \alpha = 9660 \text{ N m } \checkmark_2$ Adds friction torque to give 10 100 (N m) $\checkmark_3$	Accept any correct calculation of steepest graph slope: eg from 2 s to 5 s $\alpha = \frac{1.4}{3.0} = 0.467$ giving $T = 9800 \text{ N m}$ or 5 s to 7 s $\alpha = \frac{0.9}{2.0} = 0.45$ giving $T = 9450 \text{ N m}$ Allow ECF from MP2 to MP3 Treat 10 000 (Nm) as a 2 sf answer if consistent with their working.	3	3 x AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	(net) $T \times t = 9660 \times 5.0 = 4.8 \times 10^4 \text{ (N m s)} \checkmark$ OR $\Delta(I\omega) = 2.1 \times 10^4 (1.40 - (-0.90)) = 4.8 \times 10^4 \text{ (N m s)} \checkmark$	For first method allow ECF for torque $\checkmark_2$ from 01.3, but not for $\checkmark_3$ value (calculator value = 48300)	1	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.5		Tick (✓) against 3rd box	1	AO3
Total			8	

Question	Answers	Additional comments/Guidance	Mark	AO
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02.1	Use of total area under graph = 2.52 rad ✓ Valid attempt at calculating the area in Figure 4 ✓ $\omega_{\max} = 0.87(1) \text{ rad s}^{-1}$ ✓	MP2 eg: $2.52 = \left[\frac{1}{2} (1.5 \times 0.35) \right] + \left[\frac{1}{2} (\omega_{\max} + 0.35) \times 1.2 \right] + \left[\frac{1}{2} \times 3.5 \times \omega_{\max} \right]$ Must show calculation answer to 2 sf or more.	3	AO2 ×3
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Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Idea that $T = I\alpha$ must be used at times where there is a peak of the Figure 5 graph. ✓ Calculates one value of $I\alpha$ at the time during any of the 3 accelerations where I is at a peak ✓ Calculates the maximum values of torque for all three acceleration and shows overall maximum value is at $t = 2.1$ s ✓	MP1: must show that they have considered using peak at 2.1 s and at least one other peak 1st acctn: $T_{\max} = 12200 \times 0.35/1.5 = 2850$ N m (at 0.65 s) 2nd acctn: $T_{\max} = 10400 \times (0.87 - 0.35)/1.2 = 4510$ N m at 2.1 s 3rd acctn: $T_{\max} = 12800 \times -0.87/3.5 = -3180$ N m (at 5.1 s) Allow ± 200 kg m² on I Allow use of $\omega_{\max} = 0.9$ rad s⁻¹ giving 2nd acctn $T_{\max} = 4760$ N m 3rd acctn $T_{\max} = 3320$ N m Where comparisons are made condone answers that miss $\times 10^3$ factor in I For MP3, condone a calculation of max values of torque for both accelerations up to $t = 2.7$ s with a mention of the negative acceleration from $t = 2.7$s.	3	AO2 $\times 2$ AO3 $\times 1$

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	ALTERNATIVE 1 at times near 2.7 s: $T = I\alpha$; I is slightly smaller and α is constant so that torque is slightly smaller OR $P = T\omega$; T is slightly smaller but ω is increasing (as α positive). ✓ Both statements together with conclusion that $P_{\max}$ must occur at a time other than 2.1 s ✓ ALTERNATIVE 2 Calculates power at $t = 2.1$ s ✓ Calculates power at a different time and concludes that P is greater at this time ✓	Answer does not have to be fully quantitative eg between 2.1 s and 2.7 s the torque decreases slightly because I decreases slightly and α remains constant. But ω increases greatly to a max at 2.7 s, $P = T\omega$ so P greater at 2.7 s. Ignore friction torque Condone POT errors when a comparison is made.	2	AO3 ×2
Total			8	

Question	Answers	Additional comments/Guidelines	Mark	AO
1.1.1	MAV 4 from		-	



01.1	Two correct substitutions with consistent signs✓ $\omega_1 = 0 = \omega_0 + \alpha t_1$ giving $t_1 = 0.32(3)$ (s) ✓	Mark MP1 and MP2 independently Allow their symbols. $\omega_1=0, \omega_0=98, \alpha=-303$ Allow use of $\frac{\Delta\omega}{\Delta t} = \alpha$ provided signs consistent and “0” is seen. Calculator value: 0.32343234	2	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Two correct substitutions with consistent signs From t_1 to t_2 : $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ OR $\omega_2 = \omega_1 + \alpha t$ AND $\theta = \omega_1 t + \frac{1}{2} \alpha t^2$ OR $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$ OR Divides their θ by 2π ✓ Divides correct θ by 2π to get number (of rev) = 3.78 ✓	Expect to see $(-120)^2 = 2(-303)\theta$ $\theta = (-)23.8$ rad (or similar) with $\omega_2 = -120, \omega_1 = 0, \alpha = -303$ Condone one substitution error. All substitutions must have internally consistent signs. Condone “number of revolutions = 3” (1 sf only) on answer line if correct answer seen in working Accept 2 or more sf answers Condone final answer which has minus sign	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	(Angular impulse = $\Delta(I \omega) = 9.6 \times 10^{-2} \times (-120 - 98)$) = (-) 21 (N m s) ✓	Calculator value: 20.928 Penalise rounding errors	1	AO2
Question	Answers	Additional comments/Guidance	Mark	AO
01.4	MAX 2 from ✓✓ • Calculates $r = (0.080 - 0.011 =) 0.069$ m • Determines $T (= Fr)$ with their r and $F = 182$ or 364 N • Uses $\alpha = \frac{T}{I}$ with their T $\alpha = 249 \text{ rad s}^{-2}$ AND reversing connections provides greater deceleration than disc brake ✓	r = distance from axis to line of action of force NO POT penalty in bullet points. Do not accept a force for their T Allow 250 or answers that round to 248 or 249 Award 3 marks when correct α and correct conclusion seen Ignore minus sign	3	AO3
Total			8	

Question	Answers	Additional comments/Guidance	Mark	AO
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01.1		momentum after OR initial angular momentum = final angular momentum Allow $I\omega$ is constant if symbols explained Do not allow 'force' in place of 'torque'	1
01.2	Use of $I = I_{\text{BODY}} + 2 \times mr^2$ ✓ $I_1 = (71 + 2 \times 5.0 \times 4.1^2) = 239 \text{ kg m}^2$ ✓ ($\approx 240 \text{ kg m}^2$)	For 2 marks 239 must be seen	2
01.3	M of I decreases ✓ Because more mass closer to axis OR (for pods) $I = (\sum)mr^2$ with r less ✓ $I\omega$ / angular momentum remains constant/is conserved (So as I decreases) ω must increase ✓	Condone 'inertia' for 'moment of inertia' 2nd mark is for the reason why I is decreasing. Answer must relate to pods or masses getting closer to the axis. 'radius decreasing' on its own is not enough. Accept: pods get closer to axis/body as this implies mass is getting closer. Both points needed for 3rd mark	3

Question	Answers	Additional Comments/Guidelines	Mark
01.4	(Applies conservation of angular momentum/ $I_1\omega_1 = I_2\omega_2$) $I_1\omega_1 = 240 \times 1.3 = (312 \text{ (N m s)}) \checkmark$ $312 = (71 + 2 \times 5.0 \times 0.74^2) \omega_2$ $\omega_2 = 4.08 \text{ rad s}^{-1} \checkmark$ therefore max speed not reached OR arms can be retracted safely✓ OR $I_1\omega_1 = 240 \times 1.3 = (312 \text{ (N m s)}) \checkmark$ $312 = (71 + 2 \times 5.0 \times r_2^2) 4.2$ $r_2 = 0.57 \text{ m} \checkmark$ so with r at circumference max speed not reached OR arms can be retracted safely✓ OR $I_1\omega_1 = 240 \times 1.3 = (312 \text{ (N m s)}) \checkmark$ $312 = 4.2 I_2$ at safety limit $I_2 = 74(.3) \text{ kg m}^2 \checkmark$ Actual $I_2 = 76.5 \text{ kg m}^2$ therefore max speed not reached OR arms can be retracted safely✓	Using 239 kg m^2 instead of 240 kg m^2 leads to $\omega^2 = 4.06 \text{ rad s}^{-1}$ Useful: $I_2 = 76.5 \text{ kg m}^2$ Only credit last mark if conservation of angular momentum is used. Allow a judgement based on incorrect working (eg AE) provided conservation of angular momentum is used. Using 239 kg m^2 instead of 240 kg m^2 leads to $r_2 = 0.55 \text{ m}$	3
Total			9



Question	Answers	Additional Comments/Guidelines	Mark
	To smooth out (fluctuations in) rotational speed ✓ OR to store (rotational kinetic) energy ✓	Any named form of energy must be (rotational) kinetic	



01.1	(No external torque acts so) conservation of angular momentum applies ₁✓ Ang. momentum of turntable equal and opposite to ang. momentum of propeller so turntable rotates anticlockwise/in opposite direction to propeller ₂✓ $I_T > I_P$ so turntable rotates more slowly than propeller ₃✓	Can be expressed in symbols eg $I_T \omega_T = -(I_P \omega_P)$ For ₂✓ and ₃✓ there must be correct statement and reason. Do not allow $\text{mass}_T > \text{mass}_P$ instead of $I_T > I_P$	3	AO1 ×1 AO2 ×2
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Question	Answers	Additional comments/Guidance	Mark	AO																
01.2	The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist marking this question. <table><thead><tr><th>Mark</th><th>Criteria</th></tr></thead><tbody><tr><td>6</td><td>All three areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr><tr><td>5</td><td>A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.</td></tr><tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td></tr><tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr><tr><td>2</td><td>Only one area discussed, or makes a partial attempt at two areas.</td></tr><tr><td>1</td><td>One of the three areas covered without significant error.</td></tr><tr><td>0</td><td>No relevant analysis.</td></tr></tbody></table>	Mark	Criteria	6	All three areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.	5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.	2	Only one area discussed, or makes a partial attempt at two areas.	1	One of the three areas covered without significant error.	0	No relevant analysis.	Measuring angular speeds (ω_1 and ω_2) (Both required for full) 1A. Use of optical or magnetic sensor 2A. with datalogger/data-recorder/ more detail 1B. use of video /mobile phone/stroboscope 2B. with more detail 1C. stopwatch and fiducial mark 2C. and finding time for several revs Other measurements (Both required for full) 3. Mass of dropped mass AND Distance of (centre of) mass to centre of turntable/axis of rotation 4A. using top pan balance/scales 4B. using vernier callipers or ruler Calculation (Three points for full; one/two for partial) 5. idea that rev s^{-1} must be converted to rad s^{-1} 6A. M of I of mass = mr^2 ($= I_{\text{mass}}$) 7A. $(I_{\text{mass}} + I) \omega_2 = I \omega_1$ 6A & 7A. $I = \frac{mr^2 \omega_2}{(\omega_1 - \omega_2)}$ OR substitute ω_1 ω_2 m and r into above equations to find I A graphical method might be described, eg 6B. Plot $\frac{\omega_1}{\omega_2}$ against r^2 for various r 7B. $I = \frac{m}{\text{gradient}}$	6	AO1 ×1 AO2 ×3 AO3 ×2
		Mark	Criteria																	
		6	All three areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.																	
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		2	Only one area discussed, or makes a partial attempt at two areas.																	
		1	One of the three areas covered without significant error.																	
		0	No relevant analysis.																	
Total			9																	

Question	Answers	Additional comments/Guidance	Mark	AO
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01.1	(The M of I decreases) because more mass closer to axis of rotation ✓ ₁ $I\omega$ /angular momentum constant since no external torque ✓ ₂ since I decreases, ω must increase ✓ ₃	For ✓ ₁ must have the idea of mass distribution around axis of rotation. Do not accept answers which give only decrease in radius as reason for lower M of I. For ✓ ₂ condone answers which do not mention the condition of no external torque. ✓ ₃ cannot be awarded if conservation of rotational kinetic energy used.	3	AO1.1a × 3
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01.2	$I_1\omega_1 = I_2\omega_2$ $\omega_1 = 4.3 \text{ rad s}^{-1}$ ✓	Accept the answer 4.3 rad s^{-1} if no working shown.	1	AO2.1f × 1
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01.3	Finds time for one rotation ✓ Divides 1.2 by time AND gives answer for complete rotations, not rounded up. ✓ OR Finds angle turned through in 1.2 s ✓ Divides by 2π AND gives answer for complete rotations, not rounded up. ✓	time for 1 rotation = $2\pi/14.2 = 0.442 \text{ s}$ $1.2/0.442 = 2.7$ rotations/turns/somersaults. OR Angle turned through = $14.2 \times 1.2 = 17.04 \text{ rad}$ $17.04/2\pi = 2.7$ rotations Expect to see 2 complete rotations/turns/somersaults. For MP2 give CE for time or angle from MP1	2	AO2.1f × 2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Any 2 from: • build up a greater initial angular speed around the bar ✓ so reaches a greater height/will rotate faster in tuck ✓ • release at a greater angle from the horizontal ✓ so will rise to greater height giving more time for somersaults ✓ • get into tuck position earlier/get out of tuck position later ✓ so turning for more time ✓ • get into tighter tuck position ✓ reducing I_2, and increasing ω_2 ✓	Any 2 statement ✓ and correct reason ✓ scores 2 marks for each.	4	AO3.1b × 4
Total			10	

Question	Answers	Additional comments/Guidance	Mark	AO
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01.1	OR $I = \frac{2 E_k}{\omega^2}$ OR correct substitution in $E_k = \frac{1}{2} I \omega^2$ ✓ leading to $I = 6.2 \times 10^{-2} \text{ kg m}^2$ ✓	correct substitution in $E_k = \frac{1}{2} I \omega^2$ 2nd mark for correct answer. Do not allow final answer to 1 sig fig e.g. 0.06	2	1.10×10^{-2} $\text{L2M} \times 2$
01.2	I depends on how mass is distributed about axis (of rotation) For arms, screw and punch same mass is/point masses are closer to axis than the steel balls (making M of I lower) ✓ I depends on r^2 so I changes greatly for small change in r ✓	Allow 'other parts' or 'other components' if it is clear this means screw, punch and arms	2	$2.1a \times 1$
01.3	$\alpha = \frac{2 \times \pi \times (0 - 2.9)}{0.089} = -205 \text{ rad s}^{-2}$ ✓ Attempt to use $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ or $\theta = \omega_1 t + \frac{1}{2} \alpha t^2$ or $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$ ✓ giving $\theta = 0.81 \text{ rad}$ ✓	Condone missing sign or α given as positive Accept 200 rad s^{-2} If α positive, 2nd mark for attempt to use $\omega_2^2 = \omega_1^2 - 2\alpha\theta$ or $\theta = \omega_1 t - \frac{1}{2} \alpha t^2$ or $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$ ✓ ECF for value of ω used in 01.1	3	$2.1e \times 3$ $\text{L2M} \times 3$
01.4	($I = 2 m r^2$ and $E_k = \frac{1}{2} I \omega^2$) Increasing y by 15% gives new $I = 1.15^2 \times \text{original } I$ (or 1.32) ✓ Increasing R by 15% increases I by 1.15^3 (or 1.52) ✓ Second option gives greater increase in I, and E_k also increased (by same ratio). ✓	Accept answers without calculation: I prop to y^2 ✓ I prop to R^3 ✓ For <u>same</u> % increase in y or R, I and hence E_k increases more by increasing R ✓ Note: $E_k = m r^2 \omega^2 = \frac{4}{3} \pi R^3 \rho r^2 \omega^2$ for each ball	3	$3.1a \times 3$ $\text{L2M} \times 2?$

Total			11
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Question	Answers	Additional Comments/Guidance	Mark	ID details
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02.1	Attempt to use work done = force $\times$ distance with either incline work or resistance work or both $\checkmark_1$ Work done by flywheel $= [(1.46 \times 10^4 \times 9.81 \times \sin 5^\circ) + 1.18 \times 10^3] \times 500 \checkmark_2$ $(= 6.83 \times 10^6 \text{ J})$ $\frac{1}{2}I\omega^2 = 6.83 \times 10^6$ giving $\omega = 468 \text{ (rad s}^{-1}\text{)} \checkmark_3$	MP1: award mark for valid attempt to calculate mgh or $F \times s$ or both $mgh = 6.24 \times 10^6 \text{ J}$ $F \times s = 5.9 \times 10^5 \text{ J}$ MP2 for correct calculation of work done. MP3 for using their work done and $\frac{1}{2}I\omega^2$ to calculate ω ECF for $\checkmark_3$	3	3 x AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
02.2	✓₁ for idea of use of flywheel as brake ✓₂ for idea of storing and reusing this energy	E_p change of tram can be converted to E_k of flywheel so less energy transferred to brakes/brakes last longer/tram will not reach a high speed ✓₁ OR Energy otherwise dissipated/lost in brakes can be fed back to flywheel ✓₁ Fly wheel is charged/stores energy and energy can be used for later acceleration/driving ✓₂ OR Fly wheel is charged/stores energy and at next stop less recharging energy will be needed. ✓₂ Give two marks if both points covered in their answer to part 1 Treat as neutral answers in terms of providing a smoother ride or less wear on parts due to connecting and reconnecting flywheel. If no other marks are given, allow 1 MAX for a correct reference to regenerative braking.	2	2 x AO3

Question	Answers	Additional comments/Guidance	Mark	AO																
02.3	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist in marking this question. <table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>The factors which affect E_k and all three areas of shape, material and design for high ω will be covered in some detail. 6 marks can be awarded even if there is an error and/or if parts of one aspect are missing.</td></tr><tr><td>5</td><td>The factors which affect E_k and all three areas will be covered, at least two in detail.</td></tr><tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td></tr><tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr><tr><td>2</td><td>Only one area discussed or makes a partial attempt at two areas.</td></tr><tr><td>1</td><td>None of the three areas covered without significant error.</td></tr><tr><td>0</td><td>No relevant analysis.</td></tr></table>	Mark	Criteria	6	The factors which affect E_k and all three areas of shape, material and design for high ω will be covered in some detail. 6 marks can be awarded even if there is an error and/or if parts of one aspect are missing.	5	The factors which affect E_k and all three areas will be covered, at least two in detail.	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.	2	Only one area discussed or makes a partial attempt at two areas.	1	None of the three areas covered without significant error.	0	No relevant analysis.	examples of the points made in the response E_k proportional to ω^2 E_k proportional to I - for same mass of tram I or ω increased but not mass of flywheel <u>Shape</u> I depends on mass and distribution of mass around axis ($I = \Sigma mr^2$ so) arrange more m at outer edge of flywheel - by using heavy rim and spokes/thin centre web - increase radius <u>Material</u> - use higher density material at rim - use material of higher strength/ tensile strength/breaking stress - for higher speeds without bursting/to withstand rotational/centripetal stresses - eg titanium, CFRP <u>Design for high ω - increase ω by:</u> - reduce friction at bearings - use lubrication or roller bearings/air bearings/magnetic bearings - smooth outer surfaces/encase in vacuum - small increase in ω gives large increase in E_k (because ω^2) Also allow - sketches which convey correct info clearly - use of ‘depends on’ for ‘proportional to’ - need for perfect balance - gyroscopic effects	6	4 x AO1 1 x AO2 1 x AO3
Mark	Criteria																			
6	The factors which affect E_k and all three areas of shape, material and design for high ω will be covered in some detail. 6 marks can be awarded even if there is an error and/or if parts of one aspect are missing.																			
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3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.																			
2	Only one area discussed or makes a partial attempt at two areas.																			
1	None of the three areas covered without significant error.																			
0	No relevant analysis.																			
Total			11																	

Question	Answers	Additional comments/Guidance	Mark	AO
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02.1	$T = F \times r$ applies with some explanation of r in this context. ✓ force on pedal will vary/down force greater than up force/operator cannot keep force constant OR Component of force varies with position/rotation of crank OR Distance/radius of line of action of F from axle varies (as crank moves) ✓	Simply quoting $T = F \times r$ is not enough for MP1 2nd mark: accept: use of the term 'dead centre' 'Radius varies' is not enough Accept idea that moment of force/torque varies with position of crank	2	2 × AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Relates angular impulse to change in angular momentum and to torque $\times$ time ✓ If angular momentum/angular velocity reduced to zero in short time, high torque results (which will strain mechanism) ✓	Accept answer using formulae: Application of $T\Delta t = \Delta(I\omega)$ with understanding of symbols shown Accept $Tt = \Delta I\omega$ Angular impulse does not have to be seen if $Tt = \Delta I\omega$ is correctly applied $\Delta I\omega$ is fixed, t small, so T high (enough to strain mechanism)	2	2 $\times$ AO2

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	$\alpha = 13.8 \div 15.0 = 0.92 \text{ (rad s}^{-2}\text{)} \checkmark$ Calculates I using $T = I \alpha$ giving $0.84 \text{ (kg m}^2\text{)} \checkmark$ OR $\theta = \frac{1}{2}(\omega_1 + \omega_2)t = \frac{1}{2} \times 13.8 \times 15 = 103.5 \text{ (rad)}$ Calculates I using $\frac{1}{2}I\omega^2 = T\theta$ giving $0.84 \text{ (kg m}^2\text{)}$	$I = \frac{0.77}{0.92} = 0.84 \text{ kg m}^2$ ECF for incorrect α $I = \frac{0.77 \times 103.5}{95.2} = 0.84 \text{ kg m}^2$ ECF from incorrect θ (e.g. use of max speed instead of average speed)	2	2 × AO2



Question	Answers	Additional comments/Guidance	Mark	AO
02.4	Equates 3.1 N m to 'sharpening' torque + frictional torque ✓ calculates sharpening torque and equates to $F \times r$ to give $F = 9.7 \text{ N}$ ✓	'sharpening' torque = 2.33 N m Condone ECF for MP2 (but do not give MP1) if total torque is added to frictional torque, but neither MP1 nor MP2 given for ignoring friction torque or using <i>only</i> frictional torque. Expect to see $F \times 0.24 = 3.87$ giving $F = 16.1 \text{ N}$ No marks for $F \times 0.24 = 0.77$ giving $F = 3.2 \text{ N}$ No marks for $F \times 0.24 = 3.1$ giving $F = 12.9 \text{ N}$	2	2 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
02.5	calculates any power by multiplying any corresponding $T \times \omega$ from any graph ✓ does this at $\frac{1}{2}\omega_0$ for 2 or 3 of the motors ✓ shows F is only motor to satisfy $\frac{2}{3}P_{\max}$ criteria ✓ OR calculates any power by multiplying any corresponding $T \times \omega$ from any graph ✓ calculates max power output of required motor as $1.5 \times 52 = 78 \text{ W}$ ✓ Shows only motor F satisfies this at $\frac{1}{2}\omega_0$ ✓	For E: $P_{\max} = 120 \times 0.43 = 52 \text{ W}$ $\frac{2}{3} \times 52 = 35 \text{ W}$ For F: $P_{\max} = 150 \times 0.52 = 78 \text{ W}$ $\frac{2}{3} \times 78 = 52 \text{ W}$ For G: $P_{\max} = 90 \times 0.64 = 58 \text{ W}$ $\frac{2}{3} \times 58 = 39 \text{ W}$	3	3 × AO3

13

Question	Answers	Additional comments/Guidelines	Mark	AO
	energy supplied/transformed/input to system/loss (for	Do not allow 'heat' in place of 'energy'		1 × AO1



05.1	The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink. ✓		1	AO1.1a × 1
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Question	Answers	Additional comments/Guidance	Mark	AO
05.2	Identifies $Q_H = 3 \times W$ and $Q_C = Q_H - W$ ✓ In reverse $COP_{ref} = Q_C / W$ Leading to $COP_{ref} = 2$ ✓	MP1 can be awarded for $Q_H - Q_C = 0.33Q_H$ or $Q_C = 0.67Q_H$ Give credit for substituting numbers in equations eg $W = 1$ $Q_H = 3$, $Q_C = 2$ OR $W = 33$ $Q_H = 100$, $Q_C = 67$ Accept working shown on a diagram Accept working using temperatures T_H T_C with numbers substituted eg $T_H = 300$ (K), $T_C = 200$ (K) No credit for simply quoting formulae from Formulae Booklet.	2	AO1.1b × 2
Total			3	

05.1	Tick against answer B ✓	Auto marked	1
05.2	$\text{COP}_{\text{Pref}} = \frac{272}{343-272} \quad (= 3.8 \quad (3.83)) \quad \checkmark$ $3.8 = Q_{\text{C}}/(100 - Q_{\text{C}}) \text{ giving } Q_{\text{C}} = 79 \text{ (W)} \quad (79.3\text{W}) \quad \checkmark$ $P_{\text{IN}} = 79/3.8 = 21 \text{ (W)} \quad (20.7 \text{ W}) \quad \checkmark$ OR for 2nd and 3rd marks $\text{COP}_{\text{Pref}} = Q_{\text{C}}/W \text{ and } Q_{\text{C}} + W = Q_{\text{H}} = 100 \quad \checkmark$ $3.8 W + W = 100$ $\text{So } W = 21 \text{ (W)} \quad \checkmark$ OR for 2nd and 3rd marks $\text{COP}_{\text{HP}} = \text{COP}_{\text{Pref}} + 1 \quad \checkmark$ $W = Q_{\text{H}}/4.8 = 100/4.8 = 21 \text{ (W)} \quad \checkmark$		3
Total			4

05.1	0.60 OR 60%✓	Condone 0.6 (1 st) $\eta = \frac{(730-290)}{730} = 0.60$ $\eta = \frac{16.0-6.4}{16.0} = 0.60$	1	1 × AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Calculates P_{OUT} from engine 1 and calculates Q_{C} ✓ Uses Q_{C} from engine 1 as Q_{H} for engine 2 and calculates P_{OUT} from engine 2 ✓ Compares total output power and overall efficiency of Figure 9 and Figure 10 engines and concludes that they are the same so student is not correct ✓	$\eta_1 = 220 \div 730 = 0.30$ $P_{\text{OUT}1} = 0.30 \times 16.0 = 4.8 \text{ kW}$ $Q_{\text{C}} = 11.2 \text{ kW}$ $\eta_2 = 220 \div 510 = 0.43$ $P_{\text{OUT}2} = 0.43 \times 11.2 = 4.8 \text{ kW}$ Allow ECF for MP2 from MP1 Total $P_{\text{OUT}} = 9.6 \text{ kW}$ Overall η for 2 stages = $9.6 \div 16 = 0.60$ Do not allow an ecf for MP3 Evidence can be seen on Figure 9 and Figure 10 but answer must make clear comparisons. If calculations are correct, but more than 2 sf is used, then answers will be slightly greater than 9.6 kW and greater than 0.60. Do not accept a comment that the student claim is correct as this answer arises from conclusions drawn from poor sf considerations.	3	3 × AO3
Total			4	

04.1	(electrical) energy needed by conventional dryer by energy/heat taken from cold space ✓ OR this means more energy given to hot space/dryer per unit of electrical energy input than for a conv. dryer	Conv. dryer $Q_H = W_1$ In heat pump $Q_H = W_2 + Q_C$ or WTTE ✓ So for same Q_H , $W_2 = W_1 - Q_C$ ✓	2	1.1a × 1 2.1a × 1
04.2	Converts temperatures to K (278 K, 293 K and 433 K) ✓ Calculates COP_{garage} for 278 K and 433 K = 2.8 and calculates COP_{kitchen} for 293 K and 433 K = 3.1 ✓ COP_{kitchen} is greater so lower energy input/running cost needed for the kitchen/20°C ✓	1st mark for temperatures in K 2nd mark for calculating COPs or for argument using $T_H/(T_H - T_C)$ showing COP less for lower cold space temperature 3rd mark for relating higher COP to lower energy input/running cost for given Q_H or more Q_H per kWh. For 2 nd mark condone temperatures not converted to K giving $COP_{\text{kitchen}} = 1.14$ $COP_{\text{garage}} = 1.03$. Award 3 rd mark as above. Condone 20°C space to identify kitchen	3	3.1a × 3
Total			5	

04.1	Idea of the ratio $\frac{\text{energy delivered to hot space}}{\text{work input}}$ ✓	Direction of energy transfer is needed. Do not accept $\frac{Q_H}{W}$ on without the terms defined, or answers in terms of temperatures only. Treat mention of efficiency as neutral.	1	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
04.2	Refers to / uses $COP_{hp} = \frac{T_H}{(T_H - T_C)}$ OR states that COP_{hp} depends on/inversely proportional to temperature difference ✓₁ 1st bullet: EITHER shows COP_{hp} varies from 11.2 to 6.5 AND idea that statement is correct OR states that COP_{hp} will vary greatly because temperature varies greatly AND idea that statement is correct ✓₂ 2nd bullet: (T_H is constant and) idea that the lower T_C is, the lower the COP_{hp} So more (electrical) energy needed AND idea that statement is incorrect ✓₃	If no other mark given: award MAX 1 for idea that first statement correct AND second statement incorrect. Allow a.e. in one calculation of COP_{hp} but no ecf for conclusion. An a.e. does not include failure to convert the T_H on the top of the fraction to kelvin. For ✓₃ : allow reverse argument accept idea that for lower T_C more work needed (per second) to raise water temp to 40 °C, so greater energy cost.	3	1× AO1 2× AO3

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	Tick in second box only ✓ 384 kW h		1	AO2
Total			5	

04	5	A fair attempt to answer both bullets. Answer includes 7 or 8 points taken from both lists, including at least two matching reasons for differences. Answers will not be as full as for 6 marks.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.	- In real cycle expansion & compression are <u>not adiabatic</u> - Reason: heat transfer takes place to cooling medium during these strokes - In ideal cycle <u>air only</u> is taken through cycle (repeatedly)/gas is ideal - In real engine some exhaust gas/fuel vapour is present/gas is not ideal - Max pressure is lower in real engine - Fuel may not be completely burnt - Ideal cycle makes no reference to any <u>mechanism</u> - In real engine a mechanism is necessary e.g. for	6
	4	Comparisons are less complete but good understanding is shown of the differences between the diagrams. Answer includes 5 or 6 of the points opposite with at least one taken from each part.			
	3	The student will address 4 or 5 of the points listed but reasons may not be given with confidence or reasons may not match the differences			



	2	Fewer than 4 points are covered. The student is more likely to state the differences rather than explain them. The answer addresses one or both bullets in the question but with limited scope. They are likely to refer to 'heat losses' or 'friction' without detail.	The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.	valve operation, generation of spark Second bullet: why work output less ▪ Area of loop is smaller for real engine, so less work done per cycle ▪ Area of pumping loop has to be subtracted from main loop, reducing work done ▪ Friction between moving surfaces/between piston & cylinder/in bearings has to be overcome ▪ energy is expended in driving oil and water pumps, opening and closing valves overcoming fluid viscosity etc Accept other reasonable answers in lieu. (eg variation in γ during expansion and compression)	
	1	Some attempt is made to compare the cycles.			
	0	No relevant analysis.	The student's presentation, SP&G seriously obstruct understanding.		



Question	Answer	Additional Comments/Guidance	Mark
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04	taken from both lists opposite and table below including use of data. Answers will not be as full as for 6 marks. Comes to a conclusion or advice given.		small difference between T_H and T_C gives low efficiency 5. Allow: inefficiencies from nature of working cycle, friction, incomplete combustion etc. Second bullet 6. 60 MW will cover electrical need (but not much margin for expansion) 7. input power = $57/0.36 = 158$ MW (or 167 MW at 60 MW output) 8. max heat available for heat requirement = 101 MW (or 107 MW at 60 MW output) 9. and likely to/will be less than this	6
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	4	Makes some attempt to use the numerical data correctly. Answer includes any 5 or 6 of the points opposite or in table below.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.	10. this is not enough for heating requirement		
	3	Any 4 of the answer points opposite or in table below are given May not make use of numerical data.		11. (at least) 34 MW will need to come from National Grid. 12. power station input to give 198 MW to mill = 495 MW 13. Energy <u>that would otherwise be wasted</u> is utilised. Other answer points (other factors) for 2nd bullet are in the table below; credit sensible alternatives		
	2	2 or 3 answer points opposite or in table below are covered. May not make use of the numerical data.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.			
	1	Any one pertinent statement.				
	0	No sensible statements made.	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.			

National Grid		CHP	
advantages	disadvantages	advantages	disadvantages
No need to build power plant in mill - capital saving.	Cost /kWh includes cost of waste heat at power station and transmission cost.	Can provide all (average) electric power and most of heating need.	Space/land needed for installation.
High probability of uninterrupted supply.	Subject to power cuts.	Independent of any National Grid supply problems.	Maintenance and depreciation costs.
		Can sell any excess electrical power to grid.	Not all heating need can be supplied by CHP.
		Gives lower overall carbon footprint	Spikes in production may require more than 60 MW



03	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist marking this question.		Likely answer points: <u>1st bullet</u> Measurements/info needed and how obtained <i>A input power from c.v. $\times$ fuel flow rate</i> 1. measure volume of fuel used in given time 2. by using reservoir/measuring cylinder and stopclock 3. find/look up calorific value of fuel; accept c.v. is known <i>B indicated power from area of indicator diagram $\times$ cycles s^{-1}</i> 4. need cylinder pressures and corresponding volumes 5. take an indicator diagram / p – V diagram 6. using sensors (data logger + computer + software) 7. determine area of indicator diagram with method 8. measure speed from tachometer <u>and</u> $\times \frac{1}{2}$ <i>C brake (output) power from $P = T\omega$</i> 9. torque on output shaft using dynamometer and engine speed using tachometer 10. multiply tachometer reading by 2π Note: no credit for formulae simply stated as they are in formulae booklet. <u>2nd bullet</u> 11. thermal efficiency = indicated power/input power 12. mechanical efficiency = brake power/indicated power (Note: these formulae are not in the formulae booklet)	6	AO1.1a $\times 3$ AO2.1g $\times 1$ AO3.2b $\times 2$
	Mark	Criteria			
	6	There is a response to both bullet points in the question. Student quotes or uses points A B C 11 and 12 in words or symbols and have 7 or more of detail points 1-10 covering all three powers.			
	5	There is a response to both bullet points in the question. Mark as for 6 above. Answers will not be as confident or detailed as for 6 marks, or answers may not be expressed using scientific terminology.			
	4	The student describes how to determine at least 2 of powers A, B, C with detail points for each. They may be able to give one of the efficiencies. They should have at least 7 of points 1 to 12. Answers show more confidence than for 3 marks.			
	3	Student describes how to determine at least 2 powers. They will have 5 points or more from 1 to 12 .They may miss out efficiency formulae altogether,or get them wrong.			
	2	Student includes 3 or 4 of points 1 to12, relating detail points 1 to 10 to the appropriate power formula.			
	1	Makes any 2 of points 1 to 12.			
	0	No sensible statements made.			
	Marks not awarded for simply quoting formulae from Data booklet.				
Total			6		

Question	Answers	Additional comments/Guidance	Mark	AO
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05.1	(For 2nd law of thermodynamics to apply...) Engine must operate between hot and cold reservoirs ✓ And must reject some energy to cold reservoir ✓ (Meaning W cannot equal Q_H)	accept hot and cold spaces / hot source and cold sink / high and low temperatures Accept for 2nd mark: For 100% efficiency T_C would have to be 0 K (which is impossible)	2	AO1.1a ×2
05.2	175 °C = 448 K and 30 °C = 303 K and ✓₁ $\eta = \frac{T_H - T_C}{T_H}$ ✓₁ $= \frac{448 - 303}{448} = 0.32$ ✓₂ $(\eta = \frac{W}{Q_C + W} \text{ so } Q_C = \frac{W}{\eta} - W)$ $Q_C = \frac{2.9}{0.32} - 2.9 = 6.2 \text{ MW}$ ✓₃ 6.2 MW < 6.4 MW so claim is not true ✓₄ Alternatives for 3rd and 4th marks: For $Q_C = 6.4 \text{ MW}$, $\eta = \frac{2.9}{2.9 + 6.4} = 0.31$ ✓₃ Actual $\eta > 0.31$ so Q_C has to be < 6.4 MW so claim not true ✓₄ OR	1st mark for converting to K and giving thermal efficiency equation 2nd mark for calculating efficiency 3rd mark for another relevant calculation 4th mark for a comparison leading to a conclusion regarding claim. This is not an independent mark. e.g. 4th mark: claim is not true (based on ideal engine) because 6.2 MW < 6.4 MW ✓₄ OR accept: claim is true; for real engine η will be (considerably) less, so energy available for greenhouse heating will be/is likely to be higher than 6.4 MW If temperatures <u>not</u> changed to K condone giving ECF for marks ✓₃ and ✓₄ : $\eta = \frac{175 - 30}{175} = 0.83$ $Q_C = \frac{2.9}{0.83} - 2.9 = 0.6 \text{ MW}$ ✓₃ 0.6 < 6.4 so claim not true ✓₄	4	AO1.1b ×1 AO3.1b ×3 L2M ×3

	input power = $\frac{2.9}{0.32} = 9.1 \text{ MW}$ input power needed for company claim = $2.9 + 6.4 = 9.3 \text{ MW}$ ✓ ₃ $9.1 < 9.3$ so claim not true ✓ ₄		
Total			6



04.1	$Q_C = Q_H - W = 65 - 28 = 37 \text{ W} \checkmark_1$ $\text{COP}_{\text{ref}} = 37/28 = 1.32 \checkmark_2$ $\text{COP}_{\text{ref}} \text{ for ideal refrigerator} = 278/(308 - 278) = 9.3 \checkmark_3$ Actual COP is very low compared to ideal so claim is valid $\checkmark_4$	If temperature not changed to K do not award marks $\checkmark_3$ and $\checkmark_4$ Condone consistent use of Celsius in the denominator. No ECF for $\checkmark_4$ from incorrect values of COP, unless from arithmetic error.	4	4 x AO3
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Question	Answers	Additional comments/Guidance	Mark	AO
04.2	One factor from $\checkmark_1$ • Thermoelectric cooler is small/convenient/of simple construction/(highly) portable • can run off batteries/solar panel • has no moving parts • requires low maintenance • no risk of leaking fluids • temperature is about 5 °C, not cooler • low energy/power consumption (28W) For $\checkmark_2$ • convenience outweighs poor COP • any COP >1 means cooling power > power supplied • waste of electrical energy from having low COP is acceptable	$\checkmark_1$ for advantage from bullet point list For $\checkmark_1$ accept application, eg use in hot countries, by campers, climbers, walkers etc. $\checkmark_2$ mark for relating answer to COP	2	2 x AO3
Total			6	

04

The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question.

Mark	Criteria
6	All three areas (as outlined alongside) covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	One of the three areas covered without significant error.
0	No relevant analysis.

The following points are likely to be present.

First two bullets: differences at A and B

- Corners rounded** at B on real cycle. Reason: valves take finite time to open and close.
- Cooling cannot occur at **constant volume** in real cycle. Reason: piston would have to stop/cooling takes finite time.
- Heating cannot occur at **constant pressure** in real cycle. Reason: heating cannot be (precisely) controlled.
- Max **pressure is lower** in real engine.
Reason: e.g. incomplete combustion

Third bullet: region C

- Real engine needs **induction and exhaust** strokes/ pumping loop.
- In theoretical cycle **same air used repeatedly** (so needs no pumping loop).
- In ideal cycle **air only** is taken through cycle (repeatedly)/gas is ideal.
- Upper line is exhaust, lower line is induction.

Fourth bullet: why efficiency less

- Area of loop is smaller for real engine, so less work done per cycle/indicated power.
- Area of pumping loop has to be subtracted from main loop, reducing work done.
- Friction between moving surfaces/between piston & cylinder/in bearings has to be overcome.

6

5 ×
AO11 ×
AO2

		12. Energy is expended in driving oil and water pumps, opening and closing valves, overcoming fluid viscosity etc. 13. In real cycle expansion & compression are not adiabatic. Reason: heat transfer takes place to cooling medium during these strokes 14. Calorific value of fuel cannot be completely released/ Fuel may not be completely burnt. Accept other reasonable answers in lieu (eg variation in γ during expansion and compression).		
Total			6	

18

Question	Answers	Additional comments/Guidelines	Mark	AO
	0.60 OR 60%✓	Condense 0.6 (1 sf)		1 ×

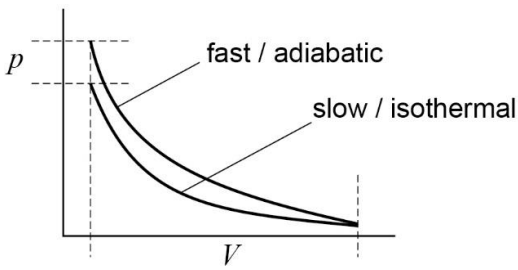


03.1	energy supplied/transferred/input to system/gas (by heating/heat transfer) ✓ OR energy transferred/lost/output from system/gas (by cooling heat transfer) if Q negative	Do not allow 'neat' in place of 'energy' Do not accept 'heat transferred' on its own Accept 'heat energy supplied' but not 'heat supplied'.	1	1 × AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Tick against top line only -10.8 0 10.8		1	1 × AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Use of $p_1 V_1^{1.4} = p_2 V_2^{1.4}$ ✓ Giving $p_2 = 2.32 \times 10^6$ (Pa) ✓ $T_2 (= \frac{p_2 V_2 T_1}{p_1 V_1}) = 710$ (K) ✓	'use of' means by substitution or manipulation to make p_2 the subject of the equation eg $p_2 = p_1 \left(\frac{V_1}{V_2} \right)^{1.4}$ seen Accept γ for 1.4. $T_2 = \frac{2.32 \times 10^6 \times (3.19 \times 10^{-9}) \times 293}{1.05 \times 10^5 \times 2.91 \times 10^{-8}}$ ECF for T_2 using their p_2	3	3 × AO2



Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	Slow change means internal energy remains (nearly) constant due to energy loss by heat transfer OR Slow change means (nearer to) isothermal change ✓ (Therefore) the work done would be lower because the area under the graph would be lower OR the work done would be lower because the pressures are lower ✓ (Therefore cyclist is not correct)	Allow reverse argument from fast change perspective. Accept answers where shown in a diagram:  Alternative MP2: smaller (average) p for same ΔV will give less W	Max 2	2 × AO3
Total			7	

Question	Answers	Additional comments/Guidelines	Mark	AO
	The mark scheme gives some evidence as to what statements are	The following points are likely to be present		5 ×

04.1	Process 1	Process 2		Tick only in cell indicated.	1	AO1.1a ×1
	constant pressure	isothermal				
	constant volume	adiabatic				
	constant pressure	adiabatic				
	constant volume	isothermal	✓			
04.2	Attempt to apply $p_1V_1 = p_2V_2$ or $pV = \text{constant}$ ✓ $(1.00 \times 10^{-4} + 2.80 \times 10^{-4} - V) 1.01 \times 10^5 =$ $1.83 \times 10^5 \times (2.80 \times 10^{-4} - V)$ ✓ Leading to $V = 1.57 \times 10^{-4} \text{ m}^3$ ✓			1st mark for equating pV before to pV after plunger pushed in - in words or symbols or numbers 2nd mark for correct substitution in either p_1V_1 or p_2V_2 or both 3rd mark for answer	3	AO2.1h ×3 L2M ×2
04.3	steeper curve ✓ vertical line ✓ (as shown alongside)			Allow vertical line that does not come right down to end of isothermal compression line	2	AO1.1b ×1 AO2.1d ×1
04.4	(In isothermal process) (for internal energy to remain constant) energy transfer must take place ✓ If change is slow there is enough/sufficient time (for energy transfer) ✓			Statements showing the First Law applied to an isothermal compression in symbols are not enough unless symbols are explained.	2	AO1.1a ×2

11

Total			8
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Question	Answers	Additional comments/Guidance	Mark	AO
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03.1	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question Level 3 (5–6 marks) 6 marks: both areas of the question are covered (i.e. calculations and explanations) with all efficiencies calculated correctly and at least two of points 7,8,9. 5 marks: both areas covered but with one or two minor errors in calculations or explanations. Level 2 (3–4 marks) 4 marks: all efficiencies calculated correctly with no explanation of usefulness of efficiencies OR a good attempt at calculating efficiencies and some explanation given of usefulness of efficiencies. 3 marks: Both areas covered partially or one area covered reasonably well but not fully. E.g may only be able to calculate correctly 2 of the three required efficiencies and give no explanation of their usefulness. Level 1 (1–2 marks) Student is likely to make one or two calculations (e.g input power and one efficiency) at any speed, but not likely to be able to explain the usefulness of efficiency. 0 marks The student shows inadequate understanding of the graphs. Formulae may be quoted from the Formulae Booklet or from memory, but the student is unable to apply their meaning to the question.	Numerical answers: 1. Peak brake power occurs at (6200 to 6600) rev min⁻¹ 2. Input power = 136 kW 3. Overall efficiency = 0.29 4. Thermal efficiency = 0.35 5. Mechanical efficiency = 0.84 6. Friction power = 7.5 kW General points: 7. Relates thermal efficiency to how well the calorific value of fuel is converted into work/power inside the engine. 8. Relates mechanical efficiency to work/power used in overcoming friction/viscosity inside engine and work/power to operate valves, water/oil pumps etc. 9. Overall efficiency gives an idea of how well energy in fuel is converted into useful work output. If student uses peak <u>indicated</u> power points 1 to 5 become 1. Peak power occurs at (7200 to 7600) rev min⁻¹ 2. Input power = 150 kW 3. Overall efficiency = 0.26 4. Thermal efficiency = 0.32 5. Mechanical efficiency = 0.80 Do not allow marks at Level 3.	6	AO3.1a ×1 AO1.1a ×3 AO2.1h ×2
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Question	Answers	Additional comments/Guidance	Mark	AO
03.2	Links two quantities from Figure 4 at speeds above 7000 rev min⁻¹ ✓ Gives reason for not running engine at speeds above 7000 rev min⁻¹ ✓	Examples of points expected for MP1: • brake power drops whilst input power continues to increase (as shown by fuel consumption curve) • brake power drops whilst indicated power flattens off • indicated power flattens off while fuel consumption increases Do not accept: the brake power gets less with no reference to other power(s). MP2: any of overall, thermal or mechanical efficiency decreases, or efficiency decreases. friction or friction power increases at high engine speeds breakdown of lubrication and/or greater work done against viscosity at high engine speeds. Do not accept: damage to engine may occur - unless backed up by reason relating to friction/friction power.	Max 2	AO3.1b ×1 AO2.1g ×1
Total			8	

Question	Answers	Additional comments/Guidance	Mark	AO
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04.1	Attempt to determine area under graph ✓₁ Use of correct scaling factors to find area in J ✓₂ Calculates area to be between 22 J and 25 J ✓₃ Finds work needed to drive at least one nail into wood using $W = F \times s$ ✓₄ Concludes that expansion roughly matches energy to drive nail D ✓₅	Eg counting squares 9 large sq $\times 2 \times 10^5 \times 10 \times 10^{-6} = 18 \text{ J}$ 67 small sq $\times 2/25 = 5.4 \text{ J}$ Total 23(.4) J Accept 11 to 12½ large sq giving 22 to 25 J W for D = $420 \times 0.050 = 21.0 \text{ J}$ Nail E needs much more W, others need less W. OR $F = (\text{wd by gas}) \div \text{length}$ and compares with forces in Table 2. For ✓₅ do not accept 'closest' answer unless answer for w.d by gas $\geq$ work needed to drive nail. ECF for ✓₅ for their calculated area	5	AO1.1b $\times 1$ AO3.1b $\times 4$
04.2	Isothermal process/expansion requires (relatively) long time for expansion to take place OR Process/expansion must occur slowly ✓₁ Reason: isothermal needs energy transfer (Q) for temperature/internal energy to remain constant ✓₂ nail fired in less than 1/3 second so expansion very fast/not enough time for energy transfer ✓₃ (so process cannot be isothermal)	For ✓₂ do not credit energy must be supplied without reference to temperature or internal energy. For ✓₃ must relate time to the data in the question.	3	AO3.1a $\times 1$ AO1.1a $\times 2$
Total			8	

Question	Answers	Additional comments/Guidance	Mark	AO
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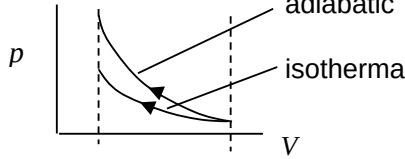


04.1	All three terms stated correctly: Q: energy transferred/supplied to system (by heating) ✓ ΔU: increase in internal energy (of system) ✓ W: work done by system ✓	2 terms correct for 1 mark 3 terms correct for 2 marks Allow 'gas' in place of 'system' For Q: Accept 'heat energy supplied' but not 'heat supplied'. Do not allow 'heat' in place of 'energy' Do not accept 'heat transferred' on its own Do not accept 'thermal energy' or 'heat energy' on its own. For ΔU: 'of system' does not have to be seen	Max 2	AO1 ×2
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Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	$(Q = W + \Delta U)$ where W (is provided by electrical input and) is –ve since W is done on the system ✓ $Q = 0$ because system is insulated ✓ $0 = -W + \Delta U$ and so internal energy of the room increases. ✓	MP2 and MP3: reasons must be given	3	AO3 ×2 AO2 ×1

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Cold sink / cold reservoir / cold space drawn and labelled with line connecting to engine with downwards arrow ✓	Accept 'low temperature' for 'cold' Do not allow 'cold/low temperature source' 'Sink' or 'heat sink' on its own is not enough, but give the mark if T_C is written in or near implying cold temperature.	1	AO1 ×1

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Use of maximum theoretical efficiency = $\frac{T_H - T_C}{T_H}$ ✓ efficiency < 100 % as $T_C > 0$ (in practice) OR efficiency can only be 100 % when T_C is 0 K which is impossible ✓	Condone following argument for max 1 mark: $\eta = (Q_H - Q_C)/Q_H$ OR $= \frac{W}{Q_H}$ so $\eta < 1$ (or < 100%) ✓ as there must be some Q_C to cold sink (in a practical case) ✓	2	AO1 ×2
Total			8	

03.1	$p_1 V_1 = 1.2 \times 10^6 \times (9.0 \times 10^{-5})$ $T_2 = 328 \text{ (K)} \checkmark$ OR use of $p_1 V_1 = nRT_1$ to find n or $nR \checkmark$ and substitute in $p_2 V_2 = nRT_2$ to find $T_2 \checkmark$	$p_1 V_1 / T_1 = p_2 V_2 / T_2$ OR $T_2 = \frac{p_2 V_2}{p_1 V_1} T_1$ 4th mark for answer T_2 ECF for p_2 With rounding answers range from 320 to 330 K	4
03.2	in adiabatic compression there is no heat transfer/ $Q = 0 \checkmark$ If compression is quick there is no time for heat transfer $\checkmark$ (so can be considered adiabatic)		2
03.3	For isothermal compression (for same volume change) (final) pressure not as high OR adiabatic compression curve is steeper (on $p - V$ diagram) than isothermal $\checkmark$ Area under a $p - V$ curve between same volumes would be less OR addition of all $p\Delta V$ during compression will be less $\checkmark$ So less work done $\checkmark$	Give credit for these ideas shown with help of a diagram or diagrams.  Award last mark only if either or both of first two marks have been given.	3

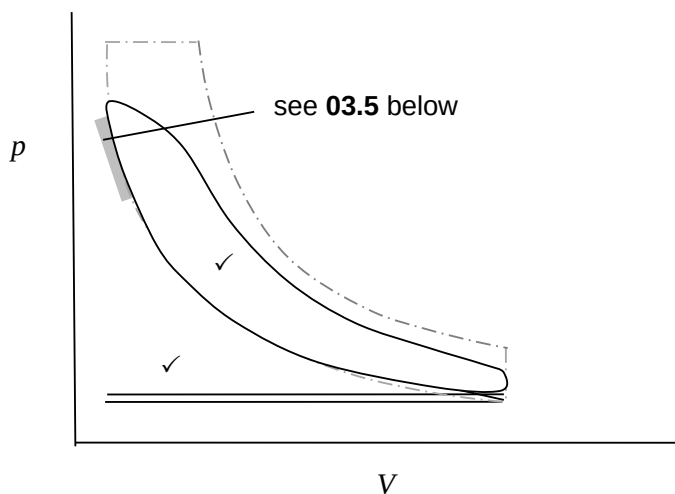
Total			9
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The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.			The following statements are likely to be present. First bullet: differences between cycles - Real engine needs induction and exhaust strokes/ pumping loop - Ideal cycle needs no pumping loop/same air used repeatedly <u>Corners rounded</u> on real cycle - Reason: valves take finite time to open and close/combustion not instantaneous - Heating/cooling cannot occur at <u>constant volume</u> in real cycle - Reason: piston would have to stop
Mark	Criteria	QoWC	
6	Both bullets in question are answered. Answer includes 9 or more points taken from both lists opposite with reasons mainly matching differences. Allow for answers which state the events in both cycles, provided points alongside are covered and some reasons given for differences.	The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.	

03.1	(A change in which there is) no energy/heat transfer to or from the gas/system ✓	WTTE Condone: no heat enters or leaves the system.	1	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
03.2	$(p_1 V_1^\gamma = p_2 V_2^\gamma)$ $1.0 \times 10^5 \times V_1^{1.4} = 67 \times 10^5 \times V_2^{1.4}$ ✓ $\frac{V_1}{V_2} = 20(.2)$ ✓	First mark for correct substitution of data into $p_1 V_1^\gamma = p_2 V_2^\gamma$ or $\frac{V_1}{V_2} = \left(\frac{p_2}{p_1}\right)^{1/1.4}$ Condone POT error in MP1 Accept answer as ratio (20:1) (calculator value = 20.15297)	2	2 x AO2

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	Diesel requires a high compression ratio to give a temperature high enough to ignite fuel / for fuel to self-ignite ✓ Petrol vapour–air mixture is ignited by spark at lower pressures/temperatures. ✓		2	2 x AO1

Question	Answers	Additional comments/Guidance	Mark	AO
03.4		Look for: - complete loop contained within/smaller than ideal loop with no sharp corners. Compression stroke may be below ideal cycle line. ✓ <u>Two close parallel lines</u> or <u>one single line</u> or <u>one narrow loop</u> parallel to V axis at or near atmospheric pressure ✓ 2 marks for both above points provided left-hand and right-hand edges of loop and induction/exhaust loop/lines are fairly close to correct V_1 and V_2.	2	1 x AO1 1 x AO3

Question	Answers	Additional comments/Guidance	Mark	AO
03.5	X placed on/near curve anywhere in shaded area shown above	Near (but not at) top end of compression stroke on indicator diagram Do not allow X on ideal cycle	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
03.6	Any 2 from: ✓✓ • <i>curved corners</i>: because valves take finite time to open and close • <i>no constant volume process</i>: because engine would have to stop/piston is constantly moving • <i>compression and expansion not adiabatic curves</i>: because energy is lost by heat transfer • <i>pumping loop/ the cycle is open</i> because engine needs to draw in air and expel exhaust • <i>heating not at constant pressure</i>: because fuel injection and combustion cannot be exactly controlled • <i>area of diagram is less</i> because energy is lost by heat transfer/incomplete combustion/CV of fuel not fully released • <i>pressure not as high</i> because incomplete combustion/CV of fuel not fully released	The explanation of the difference must match the stated difference. Do not accept answers which refer to smaller area as a result of friction in engine.	2	2 x AO1
Total			10	

Question	Answers	Additional comments/Guidance	Mark	AO
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03.1	MAX 4 from: - Attempts to find area of large loop - Subtracts area of small loop - Shows suitable scaling factor - Uses 4 cycles s^{-1} - correctly calculates indicated power using their values. 592 W ✓ (cao)	eg counting small squares $157 - 9 \text{ squares} = 148 \text{ squares}$ scaling factor of $0.10 \times 10^{-3} \times 0.1 \times 10^5 = 1.0 \text{ J per square}$ $148 \text{ J} \times 1.0 = 148 \text{ J}$ If counting 'large' squares: $(6.5 - 0.5) \text{ squares} \times 0.50 \times 10^{-3} \times 0.50 \times 10^5$ gives 150 J Accept approximating to triangles cycles $s^{-1} = 4$ (as it is double acting at 2 rev s^{-1}) indicated power = $148 \times 4 = 592 \text{ W} \pm 30 \text{ W}$	5	AO1 ×1 AO3 ×2 AO2 ×2
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Input power = $6.44 \times 10^{-4} \times 18.0 \times 10^6 = 11.6 \times 10^3 \text{ W}$ ✓ Output power = $T\omega = 39.0 \times 2 \times 2\pi = 490 \text{ W}$ ✓	Correct answers only Accept $1.2 \times 10^4 \text{ W}$ or 12000W Condone working not shown provided answers are correct.	2	AO1 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	MAX 2 from: - Power is developed for only about half of the stroke ₁✓ - Maximum pressure is very much lower than in a petrol engine ₂✓ - The fuel is not compressed before ignition ₃✓ - Pumping loop/negative work is large compared to work output loop ₄✓ - The speed of the engine is very low ₅✓ - Difficulty in lubricating cylinder so friction likely to be high ₆✓ - Calorific value of fuel is low ₇✓	Allow for other sensible reasons eg efficiency from 03.2 is only about 4% Do not accept simple references to 'low efficiency' or 'less efficient' For ₆✓ Do not accept 'more friction' without a reason	2	AO3 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	Tick in 2nd box ✓ Overall efficiency is the product of mechanical efficiency and thermal efficiency.		1	AO1 ×1
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
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03.1	$V_B = \frac{1.0 \times 10^5 \times 9.0 \times 10^{-2}}{2.2 \times 10^5} \quad \checkmark \quad (= 4.1 \times 10^{-2} \text{ m}^3)$	The mark is for attempt to use Boyle's Law with correct numbers substituted.	1	or 2.1f $\times$ 1 L2M $\times$ 1															
03.2	Use of $\frac{V_B}{T_B} = \frac{V_C}{T_C} \quad \checkmark$ OR Use of $\frac{p_A V_A}{T_A} = \frac{p_C V_C}{T_C} \quad \checkmark$ Leading to $T_C = 425 \text{ K} \quad \checkmark$	Allow ECF from 03.1 Accept any correct application of $pV/T = \text{constant}$ 426 K if $4.09 \times 10^{-2} \text{ m}^3$ used for V_B At least 3 sig fig answer must be seen	2	1.1b $\times$ 2 ? or 2.1f $\times$ 1 L2M $\times$ 2															
03.3	<table><tr><th>Process</th><th>Work W/J</th><th>Heat transfer Q/J</th></tr><tr><td>A $\rightarrow$ B</td><td>-7100</td><td>-7100</td></tr><tr><td>B $\rightarrow$ C</td><td>4000</td><td>14000 $\checkmark$</td></tr><tr><td>C $\rightarrow$ D</td><td>10 300</td><td>10 300</td></tr><tr><td>D $\rightarrow$ A</td><td>-4000 $\checkmark$</td><td>-14 000</td></tr></table>	Process	Work W/J	Heat transfer Q/J	A $\rightarrow$ B	-7100	-7100	B $\rightarrow$ C	4000	14000 $\checkmark$	C $\rightarrow$ D	10 300	10 300	D $\rightarrow$ A	-4000 $\checkmark$	-14 000	1st mark for either italicised answer correct including sign 2nd mark for both italicised answers correct including sign Calculations might show W for D $\rightarrow$ A $= p\Delta V = 1.0 \times 10^5 \times (13.0 - 9.0) \times 10^{-2} \text{ J} = 4000 \text{ J}$	2	2.1b $\times$ 2
Process	Work W/J	Heat transfer Q/J																	
A $\rightarrow$ B	-7100	-7100																	
B $\rightarrow$ C	4000	14000 $\checkmark$																	
C $\rightarrow$ D	10 300	10 300																	
D $\rightarrow$ A	-4000 $\checkmark$	-14 000																	
03.4	1st Law applies/must be obeyed OR $Q = \Delta U + W \quad \checkmark$ (for isothermal process) $\Delta U = 0$ so $Q = W \quad \checkmark$	1st mark for any reference to First Law in words or equation. 2nd mark for stating $\Delta U = 0$ (in isothermal process) and showing $Q = W$	2	2.1f $\times$ 2															

03.5	Claim is correct as Net work = 3200 J ✓₁ $\eta = 3200 / 10300 = 0.31$ or 31% ✓₂ $\eta_{\max} = \frac{425 - 295}{425} = 0.31$ or 31% ✓₃ OR $\eta_{\max} = \frac{420 - 295}{420} = 0.30$ or 30%	Alternative for 1st mark: Net work = area of loop in Fig 3 = 6.5 squares × 500 J = 3250 J allow ± 250 J If student tots up their W column in Table 1 correctly for their values, award the 1st mark point ✓₁ (or if they use the area of the cycle correctly calculated) Also award ✓₁ for 3200 J even if it does not agree with their Table 1. If they have been awarded ✓₁ for net work, and divide this value by 10300, give the 2nd mark point ✓₂ If they calculate the max theoretical efficiency correctly give ✓₃ Then if they have ✓₁, ✓₂ and ✓₃: If there is no concluding statement award 2 marks If the concluding statement is incorrect for their efficiencies award 2 marks If their concluding statement is correct for their efficiencies award 3 marks If they only get the max theoretical efficiency, award 1 mark. If 420 K has been used allow argument that efficiencies are not (quite) the same	3	3.1b × 1 3.1a × 2
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03.6	OR perfect conducting material used ✓ OR Economiser will not store/transfer energy effectively ✓ because it will lose heat to surroundings ✓ OR unless it has large/have large surface area OR because it will not be perfectly insulated Accept other sensible suggestions and corresponding reasons	on the cycle. Do not allow problems common to all heat engines e.g. ignore 'friction' and simple statements relating to 'heat loss to surroundings'. Give 1 mark if student spots that Work/power output is very small for size of engine 1 mark if they back this up.	2	$3.1a \times 2$
Total			12	

question	answers	additional comments/clarifications	marks	details
1.1a	Heat pump takes energy/heat from cold space/sink/reservoir/surroundings (and gives to hot space) ✓ (Electrical) energy needed by heat pump is less than (electrical) energy needed by conventional driver by	Accept answers as equations: Conv. driver $Q_{\text{L}} = W$	1	1.1a x1?



03.1	Energy is supplied to the air by heating only in process 2 → 3 ✓	Automarked	1
03.2	<u>Claim A:</u> Each square represents 10 J ✓ Area of loop 4→5→1→4 = 9 squares Giving increase in work done = 90 J ✓ <u>Claim B:</u> area enclosed by loop 1→2→3→4→1 = 55 sq /550 J ✓ (Each square represents 10 J) increase in efficiency = 9 sq/55 sq or 90 J/550 J = 16% ✓ So claim A not met, claim B efficiency better than claimed ✓ OR Claim B: area enclosed by loop 1 →2→3→ 4→1 = 55 sq /550 J ✓ divides 550 J and 640 J by any same value for (heat) input energy and calculates increase in efficiency ✓ draws correct conclusion for A and B for answers ✓	W done per square = $0.1 \times 10^{-3} \times 1.00 \times 10^5 = 10 \text{ J}$ Allow 8 to 11 squares giving 80J to 110 J Accept answers where area 4→5→1→4 is approximated to a triangle giving 112(.5) J Allow 50 to 60 squares giving 500 to 600 J ECF from above areas if out of tolerance Allow last mark only if statements re claims agree with answers Example $550/1000 = 0.55$ or 55%; $640/1000 = .64$ or 64% Increase in efficiency = 9% Values for input energy must > 640 J	5

03.3	Q: energy supplied/transferred/input (to system/gas by heating/heat transfer) ✓ OR energy transferred/lost/output (from system/gas by cooling heat transfer) if Q negative ΔU: increase/change in internal energy ✓ OR decrease if negative.	Do not allow 'heat' in place of 'energy' 'heat transferred' on its own is not enough Accept heat energy supplied but not heat supplied.	2
03.4	$W = p\Delta V = 1.0 \times 10^5 \times (3.00 - 1.50) \times 10^{-3} \text{ J } (= 150 \text{ J}) \checkmark$ (Use of $Q = \Delta U + W$) gives $Q = -150 + (-374) = (-) 524 \text{ J } \checkmark$	Check that sign convention is consistent for 2nd mark. Allow if – sign not seen on answer line	2
03.5	Attempt to use $pV = nRT \checkmark$ Recognises max temperature is at point 3 in the cycle ✓ Substitution of p, V and n in $T = \frac{pV}{nR}$ for point 3 giving $T = 1310 \text{ K } \checkmark$	2nd mark can be implied from values of p and V used in the equation. p from 14.2×10^5 to $14.8 \times 10^5 \text{ Pa}$ V from 0.42×10^{-3} to $0.48 \times 10^{-3} \text{ m}^3$	3
Total			13

Question	Answers		Additional Comments/Guidelines	Mark
	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist marking this question.		Likely answer points:	
			First bullet	
			1. All heat engines must obey 2nd Law of thermodynamics	
			2. They must reject energy to a sink/surroundings (at low temperature)	
	Mark	Criteria	QoWC	
	6	Both bullets in question are answered. Answer includes 8 or more points taken from both lists opposite and table below including use of data. Comes to a conclusion or advice given..	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.	3. Maximum efficiency determined by source and sink temperatures / formula quoted $\eta = T_H - T_C/T_H$
	5	A fair attempt to answer both bullets. Answer includes 7 points		4. 100% efficiency would require $T_C = 0$ K and/or a small difference between T_H and T_C gives low

03.1	A change (of state that occurs) at constant temperature ✓	Acceptable alternatives: process in which the temperature remains constant compression or expansion of a gas at constant temperature Treat reference to pressure and volume as neutral. Do not allow 'no change in internal energy' OR $\Delta U = 0$	1	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
03.2	Use of $n = \frac{pV}{RT}$ ✓ at A using 291 K OR B or C using 536 K giving $n = 4.97 \times 10^{-2}$ (mol) ✓	'Use of' is by substitution; condone value of R not substituted. Correct answer gains both marks. Allow either T in MP1 for any correct pair of pV values. Accept 4.96, 0.050 but not 0.05	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
03.3	$W = p\Delta V$ $= (-)101 \text{ J} \checkmark$	For mark to be awarded, correct equation or correct substitution must be seen. E.g. accept $[1.00 \times] 10^5 \times (2.21 - 1.20) \times 10^{-3} = 100 \text{ J}$ Or $W = p\Delta V = (-)101 \text{ J}$ Ignore sign	1	AO1



Question	Answers	Additional comments/Guidance	Mark	AO																				
03.4	Any row correct ✓ up to Max 3	<table><tr><td></td><td>Q / J</td><td>W / J</td><td>$\Delta U / J$</td></tr><tr><td>Process A B</td><td>0</td><td>-253</td><td>253</td></tr><tr><td>Process B C</td><td>473</td><td>473</td><td>0</td></tr><tr><td>Process C A</td><td>-354</td><td>-101</td><td>-253</td></tr><tr><td>Whole cycle</td><td>119</td><td>119</td><td>0</td></tr></table> Give ECF in C A if their answer to 03.3 OR 100 (J) used for W. If no sign take as +ve. If no marks for rows look for any column in which whole cycle figure is consistent with process figures and award 1 Max.		Q / J	W / J	$\Delta U / J$	Process A B	0	-253	253	Process B C	473	473	0	Process C A	-354	-101	-253	Whole cycle	119	119	0	3	1× AO1 1× AO2 1× AO3
	Q / J	W / J	$\Delta U / J$																					
Process A B	0	-253	253																					
Process B C	473	473	0																					
Process C A	-354	-101	-253																					
Whole cycle	119	119	0																					

Question	Answers	Additional comments/Guidance	Mark	AO
03.5	Links criterion 1 to process B C AND Links criterion 2 to process C A ✓ Criterion 1 met AND Criterion 2 not met ✓	Penalise incorrect physics. E.g. getting adiabatic and isothermal processes the wrong way round.	2	1× AO1 1× AO3



Question	Answers	Additional comments/Guidance	Mark	AO
03.6	The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.		6	1× AO1 2× AO2 3× AO3
	Mark	Criteria		
	6	All three areas (as grouped alongside) covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing, provided points 1 and 3 are included.		
	5	All three areas covered, at least two in detail. Whilst there will be gaps, there should only be an occasional error.		
	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.		
	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.		
	2	Only one area discussed, or makes a partial attempt at two areas.		
	1	None of the three areas covered without significant error.		
In each area, a partial answer is given for 1 statement and a full answer for more than half the statements. Area 1 (1st two bullets in question) 1. max theoretical efficiency = $(536 - 291)/536 = 0.46$ or 46% 2. overall efficiency = $119/473 = 0.25$ or 25% 3. identifies that <i>their</i> theoretical efficiency is greater than <i>their</i> overall efficiency. Do not accept idea that max theoretical efficiency is 100% Area 2 (3rd bullet) 4. AB / adiabatic stroke would have to be very fast to ensure no time for heat transfer 5. BC / isothermal stroke would have to be very slow to ensure constant temperature 6. very difficult to arrange a slow 'stroke' and a fast 'stroke' in one engine OR output speed would vary over a cycle 7. difficulty in arranging for end of expansion and start of compression to occur at one point OR idea of need for induction/exhaust/pumping strokes 8. engine valves take time/energy to open and close OR incomplete fuel combustion Area 3 (4th bullet) NO because: 9. idea that very low net work per cycle OR area of the loop is small 10. real efficiency will be much lower than their overall efficiency (and much lower than engines currently available) (due to friction etc.) 11. low speed or cycle s^{-1} hence low power 12. because power = cycle $s^{-1} \times$ work done per cycle				

	0	No relevant comments	Accept ideas shown by sketches.		
Total				15	

15				
Question	Answers	Additional comments/Guidance	Mark	AO
		Direction of energy transfer is needed		