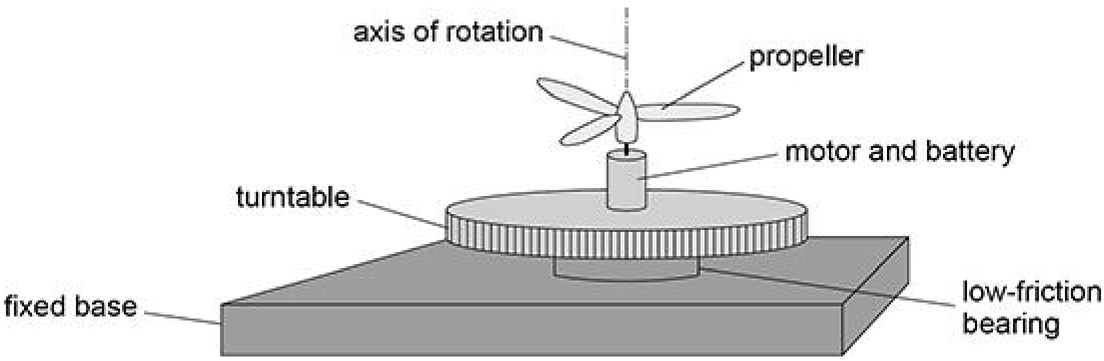
Q1.

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

(a) **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.

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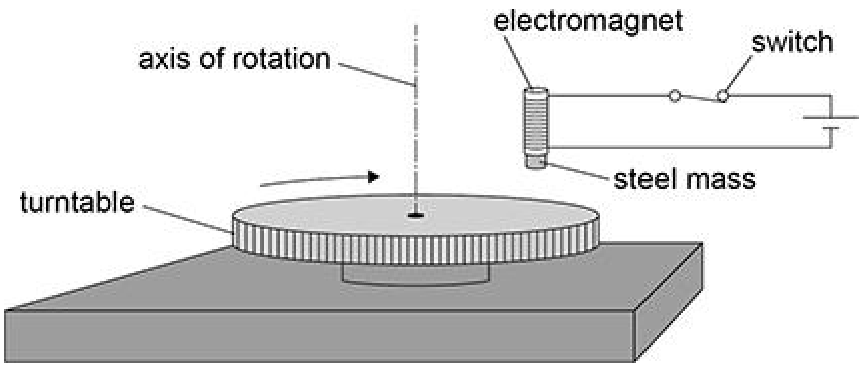
(3)

(b) **Figure 2** shows an arrangement used to determine the moment of inertia of the turntable.

Figure 2



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.

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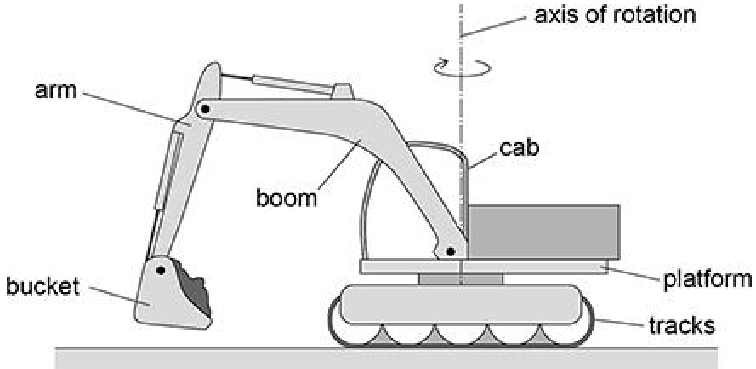
(6)

(Total 9 marks)

Q2.

Figure 1 shows an excavator.

Figure 1

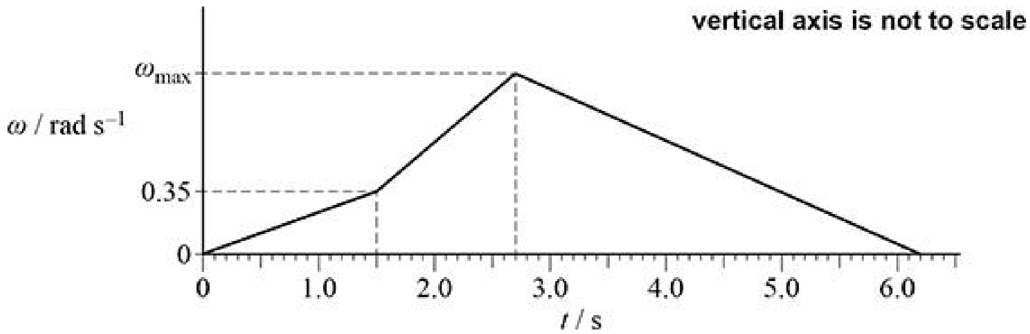


The bucket position can be changed by moving the boom and arm and by rotating the platform about the vertical axis of rotation.
For the purposes of this question, assume that the excavator tracks do not move.

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

Figure 2 shows the variation in angular velocity ω with time t for the rotation of the platform about the vertical axis.

Figure 2



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

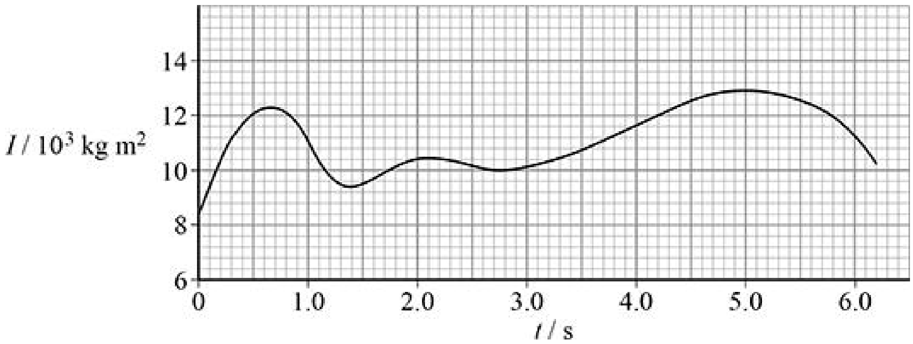
Show that ω_{max} is about 0.9 rad s^{-1}.

(3)

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 3 shows how I varies with t for the same time period as **Figure 2**.

Figure 3



(b) 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)

(c) Deduce whether the maximum power applied to the platform occurs at the same time of 2.1 s.

(2)
(Total 8 marks)

Q3.

(a) One equation used in translational dynamics is:

force = mass × acceleration

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

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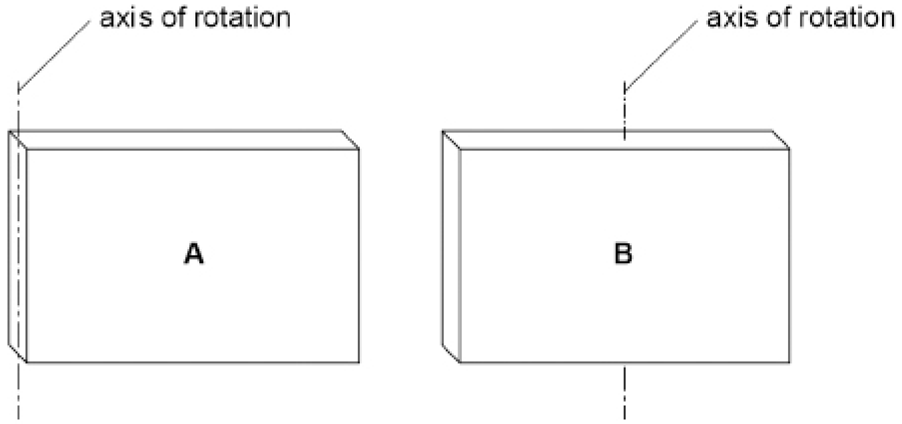
(2)

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

Figure 1



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

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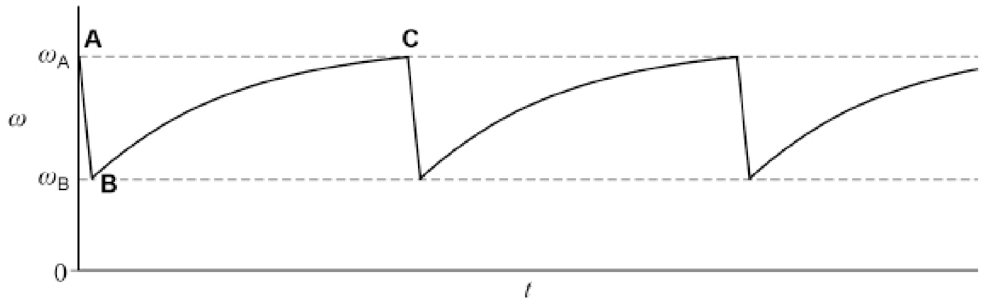
(2)

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



The table below describes the sequence for the machine after it has been brought up to speed ω_A.

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.

(c) 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)

(d) Explain **one** difference between your graph and the original graph.

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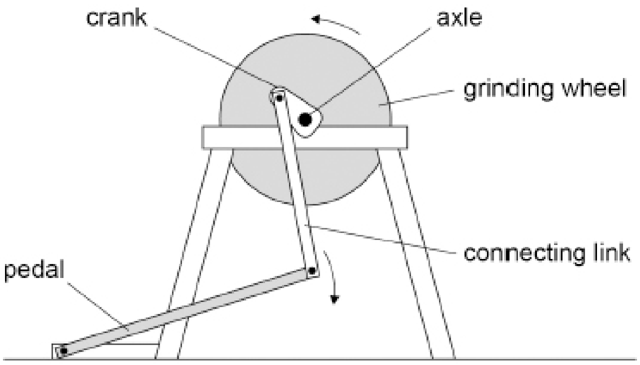
(1)

(Total 7 marks)

Q4.

Figure 1 shows a heavy stone grinding wheel used for sharpening tools.

Figure 1



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.

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

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(2)

(b) 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.

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(2)

(c) 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.

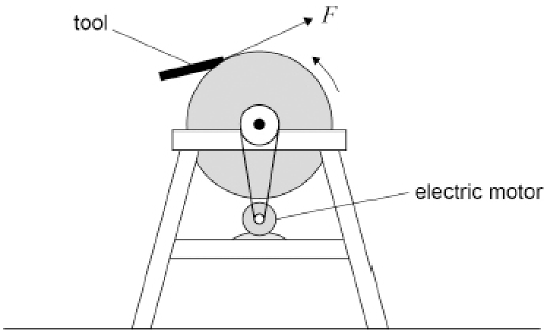
Calculate the moment of inertia of the wheel.

moment of inertia = ____________________ $kg\ m^2$

(2)

The arrangement is modified as shown in **Figure 2**. The pedal, connecting link and crank are removed and the grinding wheel is driven by an electric motor.

Figure 2



(d) **Figure 2** 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

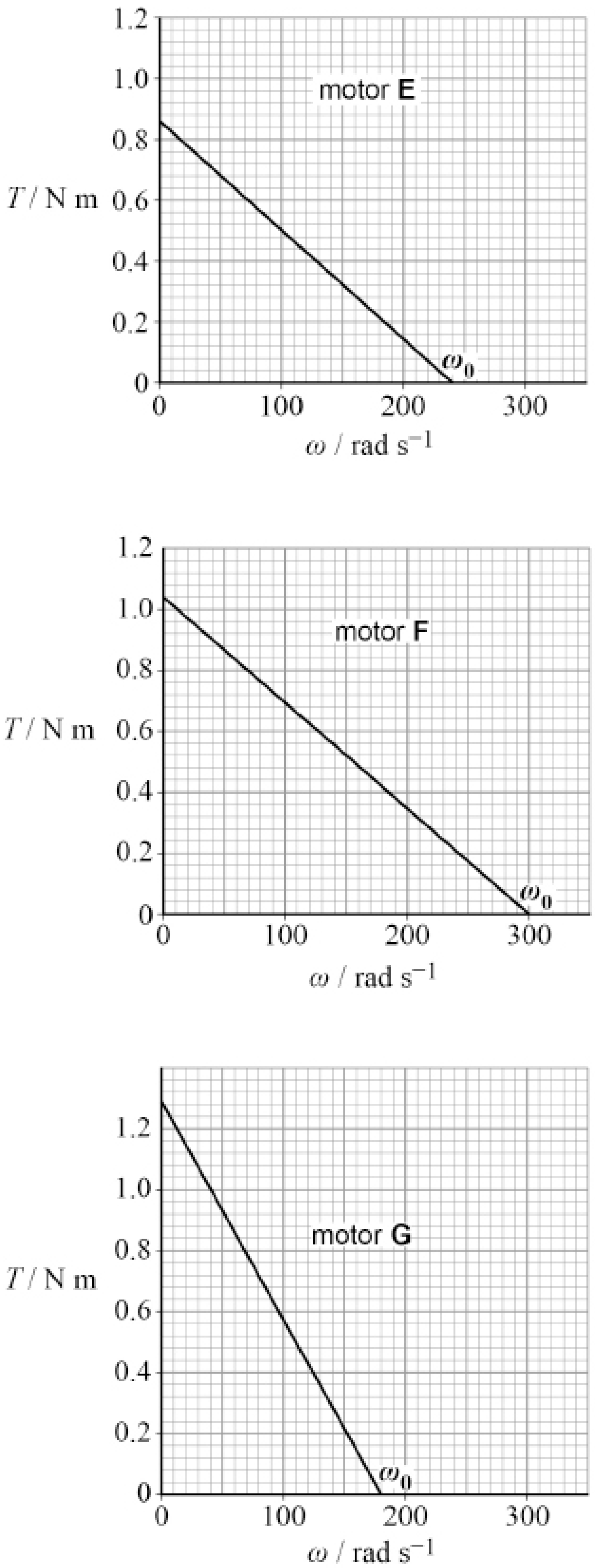
Calculate F.

F = ____________________ N

(2)

(e) Three motors **E**, **F** and **G** were available to drive the wheel in **Figure 2**. **Figure 3** shows how the torque T varies with angular speed ω for each motor.

Figure 3



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.

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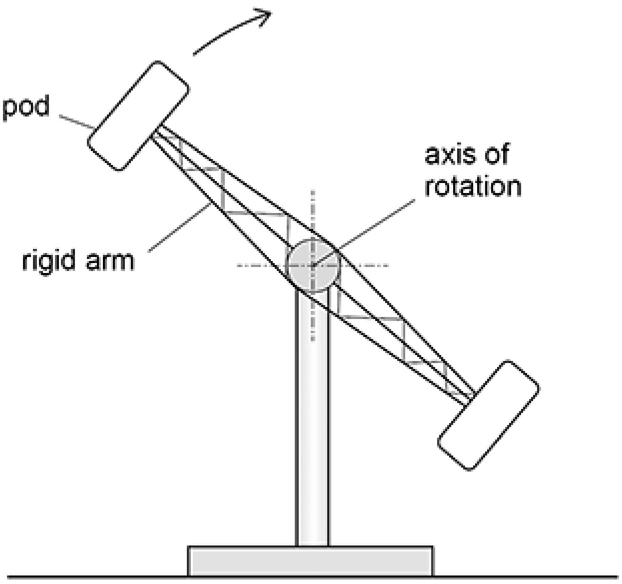
(3)
(Total 11 marks)

Q5.

Figure 1 shows a fairground ride.

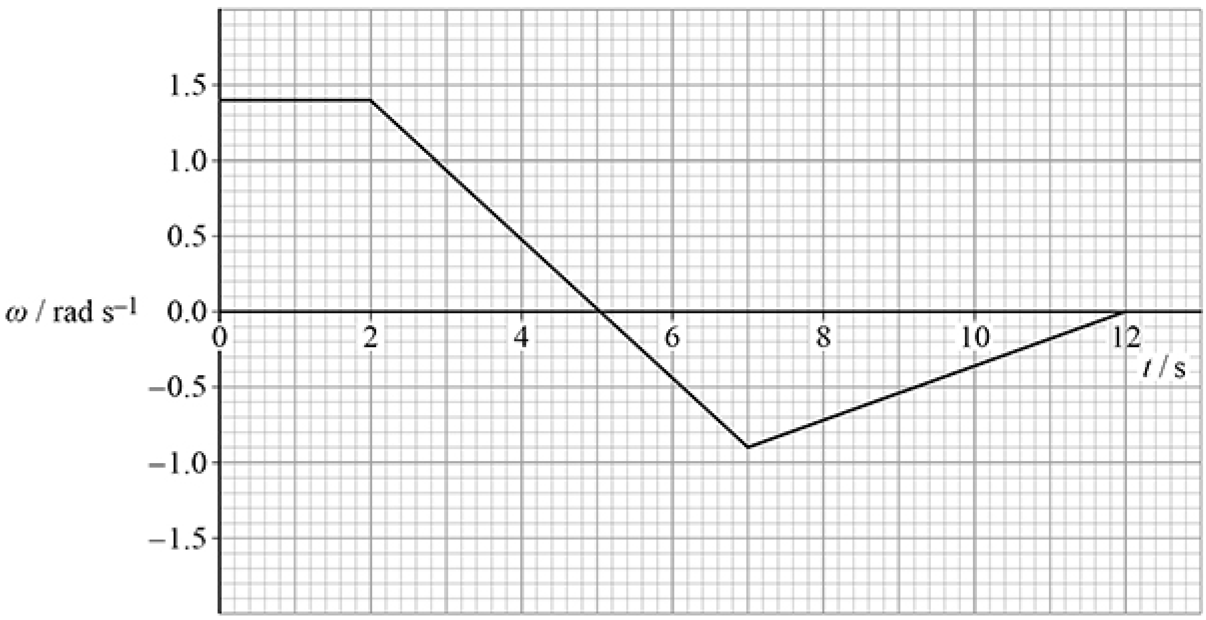
Figure 1



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.

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

Figure 2



(a) Determine the mean angular velocity of the rotor during the 12 s period.

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

(2)

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

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

power output = _______________ W

(1)

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

maximum torque = _______________ N m

(3)

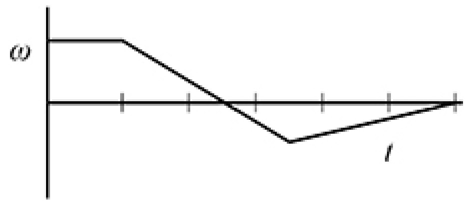
(d) Calculate the magnitude of the angular impulse on the rotor between t = 2.0 s and t = 7.0 s.

angular impulse = _______________ N m s

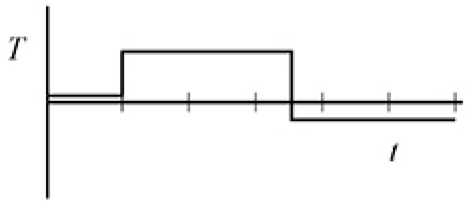
(1)

(e) 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.



copy of **Figure 2**



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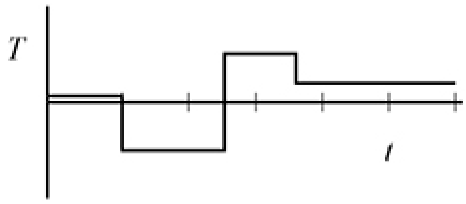

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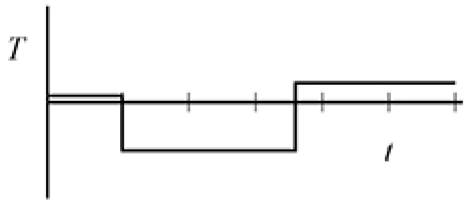

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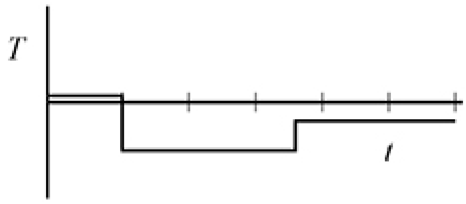

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(1)
(Total 8 marks)

Q6.

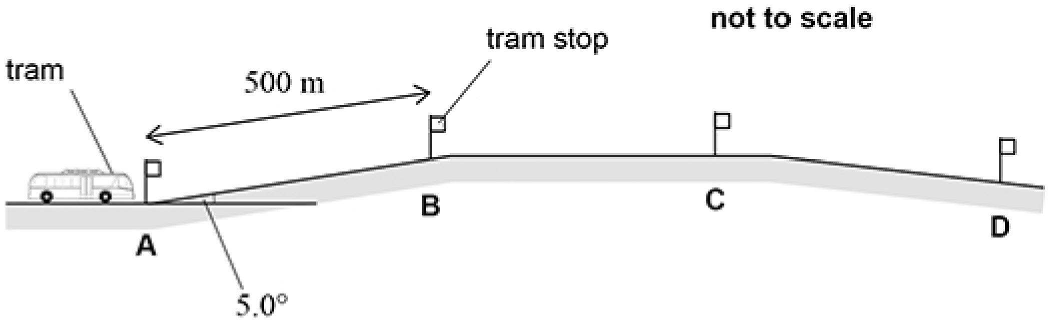
A moving tram is powered by energy stored in a rapidly spinning flywheel.

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.

The figure below 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.

(a) 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.

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

(3)

(b) 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.

1. ____

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2. ____

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(2)

(c) 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.

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(6)

(Total 11 marks)