Access Tuition

A-Level Physics

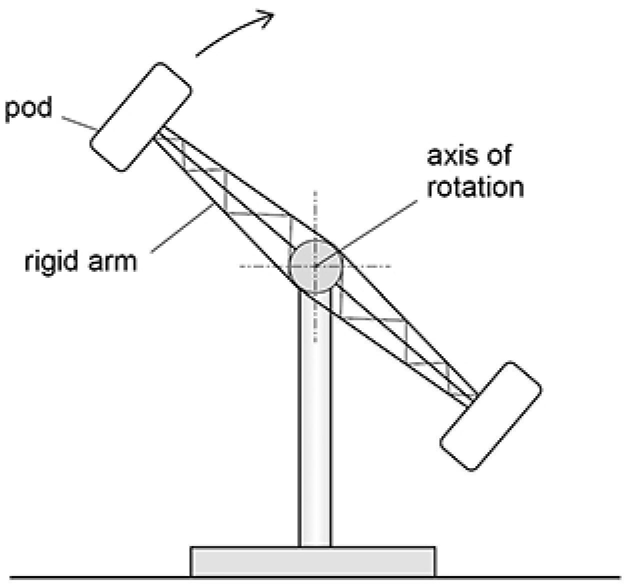
Torque and Angular Acceleration

Question Paper

Time available: 51 minutes
Marks available: 39 marks

1. **Figure 1** shows a fairground ride.

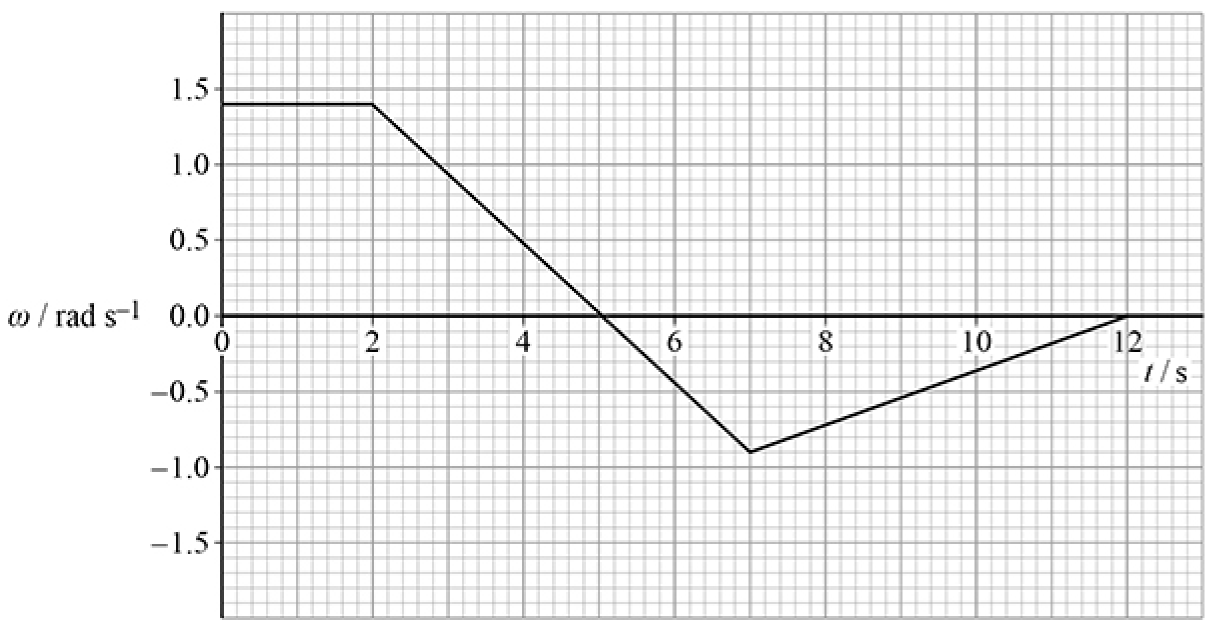
Figure 1



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 $2.1 \times 10^4 \text{ kg m}^2$.
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.

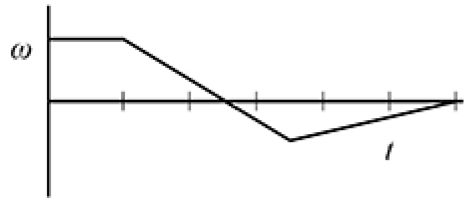
angular impulse = _______________ N m s

(1)

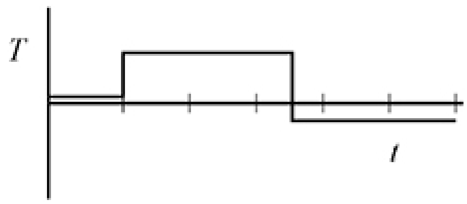
(e) Which graph best shows the variation of the torque T applied to the rotor for the 12 s period?

Tick (✓) **one** box.

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



copy of **Figure 2**



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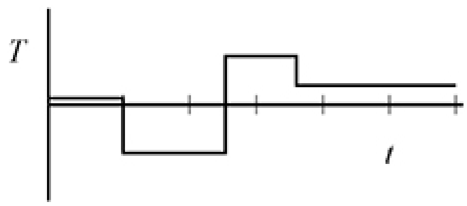

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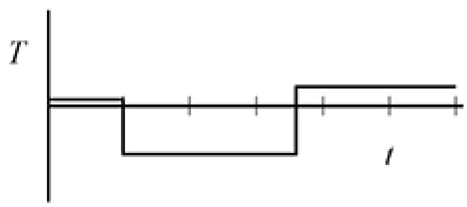

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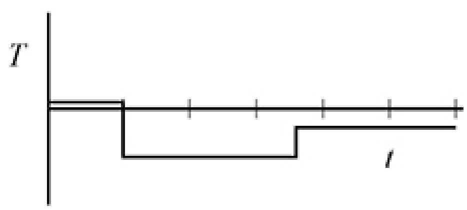

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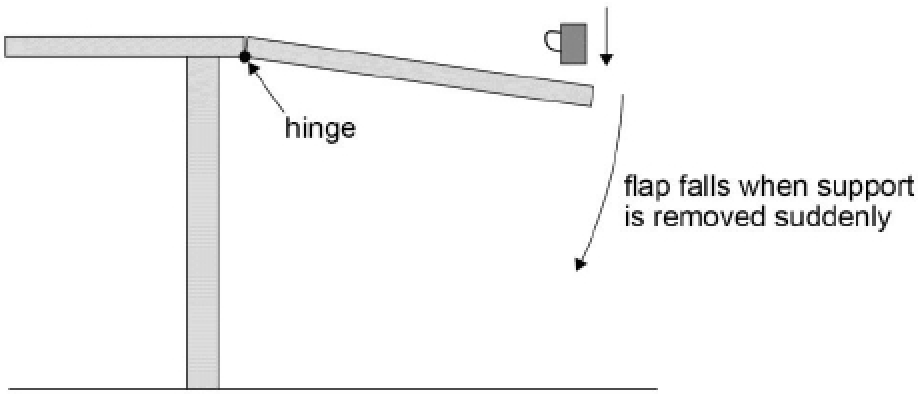
(1)
(Total 8 marks)

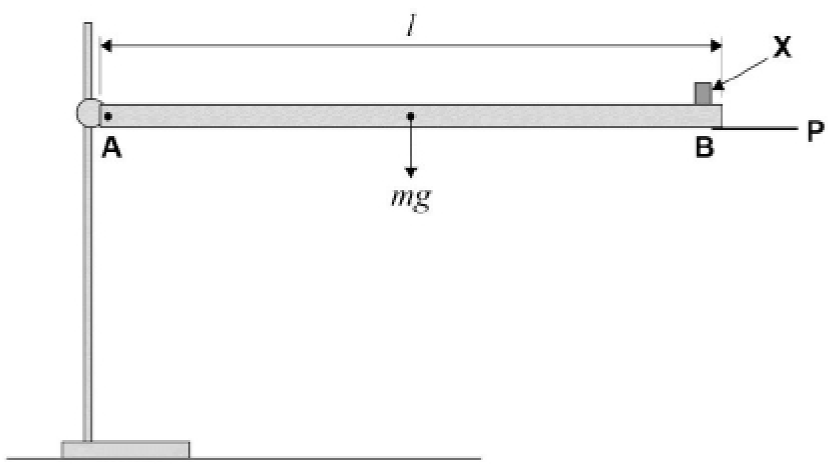
2. A student is told that if a small cup of coffee is placed near the edge of a table flap, the cup and the flap will lose contact if the flap support is suddenly removed. This is shown in **Figure 1**.

Figure 1



The student does not believe this to be true so decides to model the arrangement using a metre ruler free to pivot about one end **A**, with a small mass **X** resting on the ruler at the other end **B**. The arrangement is shown in **Figure 2**. The mass of **X** is negligible compared to the mass of the ruler. The metre ruler is held in the horizontal position by a support **P** which is quickly removed. A video is taken of the subsequent motion of the ruler and mass.

Figure 2



Assume the ruler is a thin uniform beam of mass m and length l.

(a) Derive an expression for the torque T acting on the ruler at the moment of release.

____

____

(1)

(b) The moment of inertia I of the metre ruler about the axis through **A** is given by

$$I = \frac{m}{3} l^2$$

Show that the angular acceleration α of the ruler at the moment of release is given by

$$\alpha = \frac{3g}{2l}$$

(2)

(c) The linear acceleration a of a point on a rotating rigid body at a distance r from the axis of rotation is related to the angular acceleration α by

$$a = r \times \alpha$$

Explain why this causes the small mass to lose contact with the metre ruler as soon as the ruler is released.

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(2)

(d) Estimate how far from **A** the small mass must be placed to ensure it just maintains contact with the ruler when the ruler is released.

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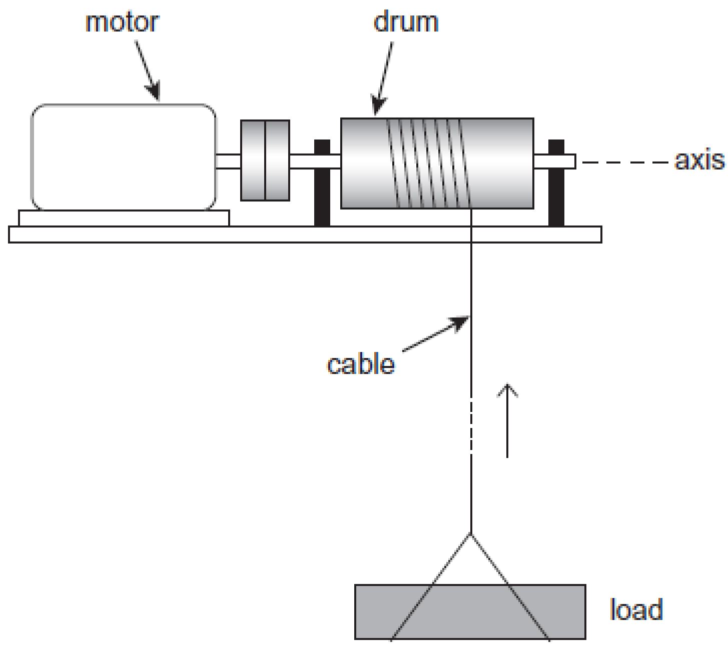
(1)

(Total 6 marks)

3. The following figure shows a motor-driven winch for raising loads on a building site. As the motor turns the cable is wound around the drum, raising the load.



The drum, axle and other rotating parts have a moment of inertia about the axis of rotation of 7.4 kg m^2, and the mass of the load is 85 kg. The drum has a radius of 0.088 m.

The load is accelerated uniformly from rest to a speed of 2.2 m s^{-1}. When it is accelerating it rises through a height of 3.5 m. It then continues at the constant speed of 2.2 m s^{-1}.

(a) Show that the drum turns through 40 rad as the load accelerates.

(1)

(b) Calculate the angular speed of the drum when the load is moving at 2.2 m s^{-1}.

angular speed ____________________ rad s^{-1}

(1)

(c) (i) Show that for the time that the load is accelerating the total increase in energy of the load and the rotating parts is about 5400 J.

(3)

(ii) A constant frictional torque of 5.2 N m acts at the bearings of the winch.

Calculate the total work done by the motor to accelerate the load.

Give your answer to an appropriate number of significant figures.

total work done ____________________ J

(3)

(d) Calculate the **maximum** power developed by the motor.

maximum power ____________________ W

(2)

(Total 10 marks)

4. **Figure 1** shows a 'firewheel' used at a firework display. Thrust produced by the captive rockets creates a torque which rotates the beam about a horizontal pivot at its centre. The shower of brilliant sparks in the exhaust gases of the rapidly orbiting rockets creates the illusion of a solid wheel.

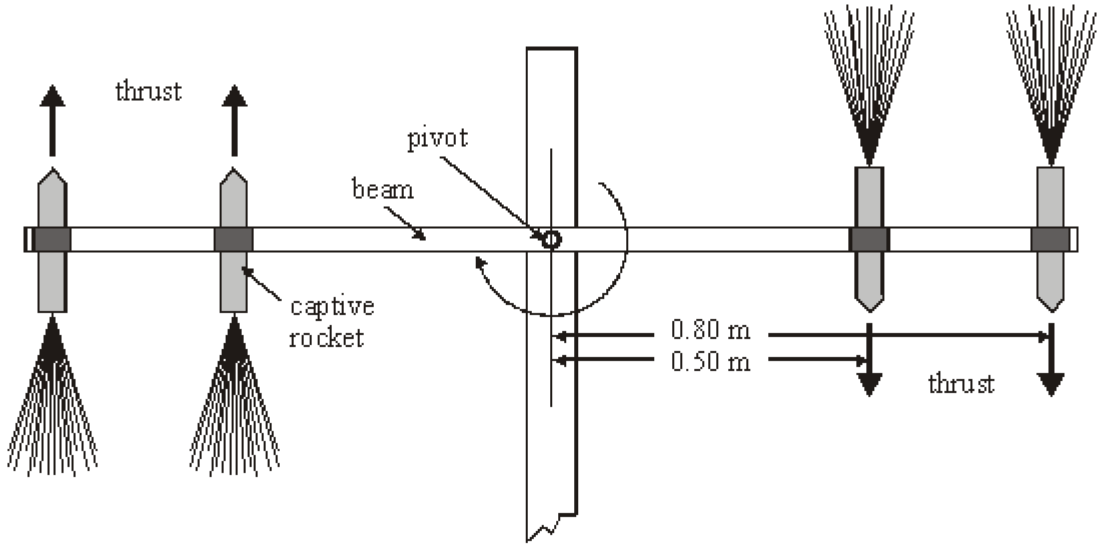


Figure 1

(a) The rockets are fixed symmetrically about the pivot at distances of 0.50 m and 0.80 m from the pivot. The initial mass of each rocket is 0.54 kg and the moment of inertia of the beam about the pivot is 0.14 kg m^2.

Show that the initial moment of inertia of the firewheel about the pivot is 1.10 kg m^2.

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(2)

(b) The rockets are ignited simultaneously and each produces a constant thrust of 3.5 N. The frictional torque at the pivot is negligible. Calculate

(i) the total torque about the pivot when all the rockets are producing thrust,

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(ii) the initial angular acceleration of the firewheel,

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(iii) the time taken for the firewheel to make its first complete turn, starting from rest.

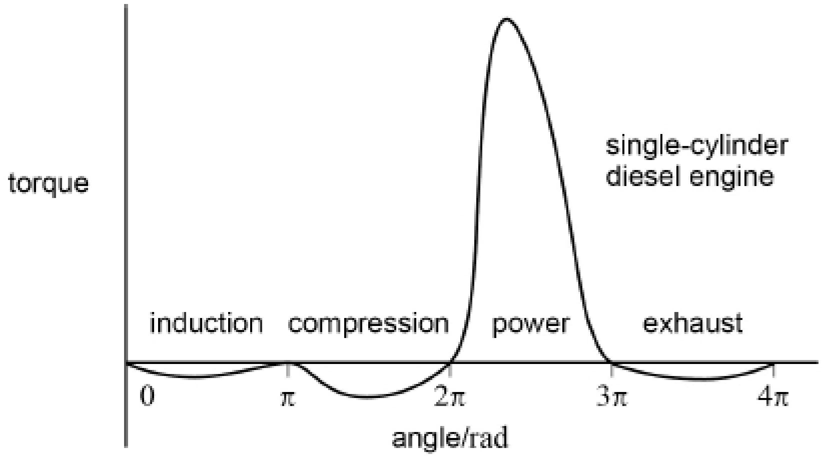
(4)

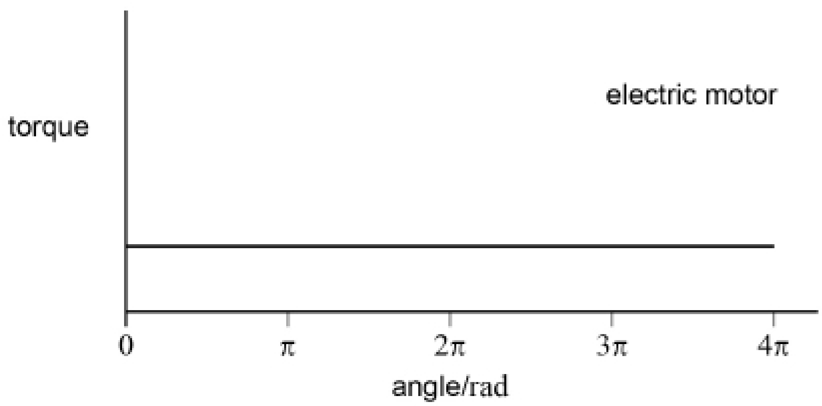
(c) The total thrust exerted by the rockets remains constant as the firewheel accelerates. Explain why, after a short time, the firewheel is rotating at a constant angular speed which is maintained until the rocket fuel is exhausted.

(2)
(Total 8 marks)

5. 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.

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





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

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(1)

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

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

In your answer you should explain

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

(6)

(Total 7 marks)