A-Level Physics

Concept of Moment of Inertia

Question Paper

Time available: 54 minutes
Marks available: 43 marks

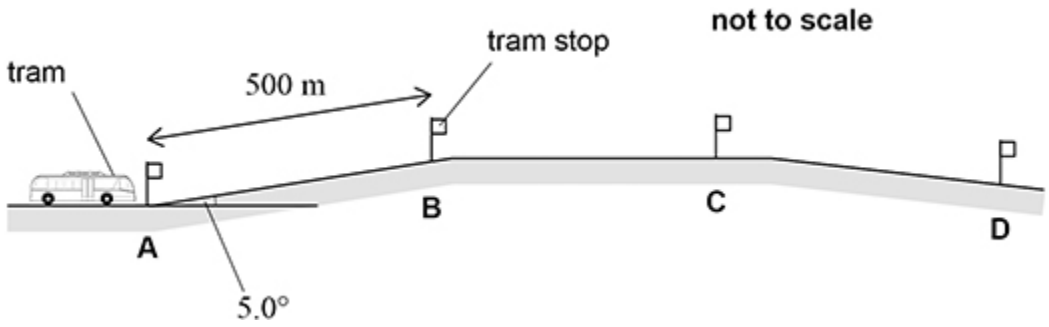
1. A moving tram is powered by energy stored in a rapidly spinning flywheel.

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. _____

_____

_____

_____

2. _____

_____

_____

_____

(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.

(6)

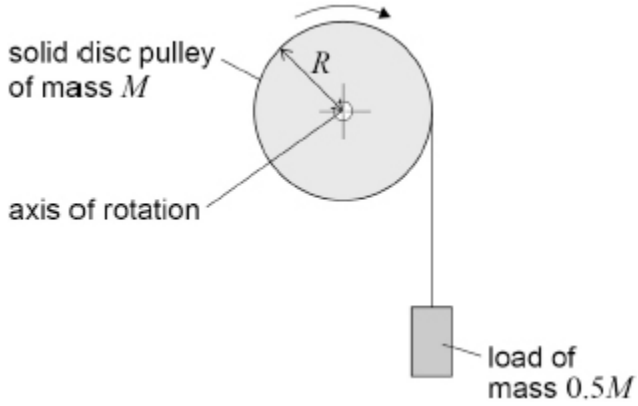
(Total 11 marks)

2. (a) State what is meant by the moment of inertia of an object about an axis.

(1)

(b) 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.

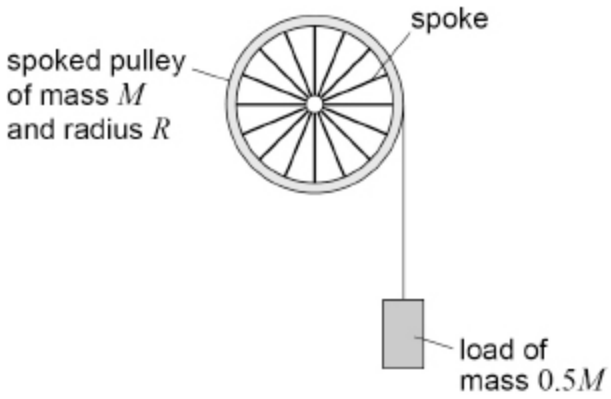
When the student releases the pulley, the load accelerates downwards uniformly and is at a velocity v after moving a distance h.

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

(4)

(c) 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)

(Total 8 marks)

3. (a) There is an analogy between quantities in rotational and translational dynamics.

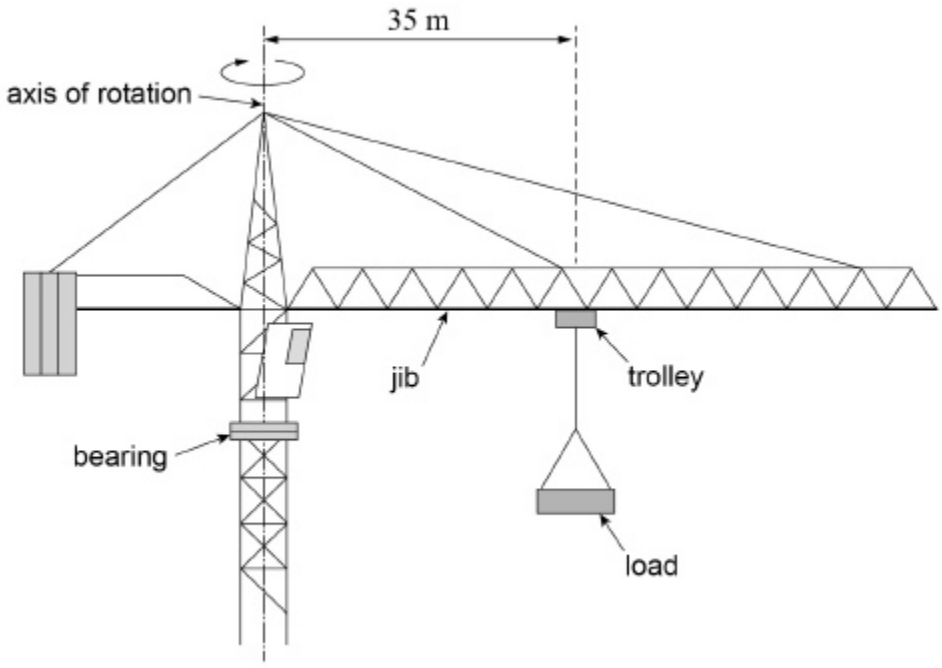
Complete the table, stating in words the quantities in rotational dynamics that are analogous to force and mass in translational dynamics.

Translational dynamics	Rotational dynamics
force	
mass	

(2)

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 = 2.6×10^7 kg m^2

Mass of trolley and load = 2.2×10^3 kg

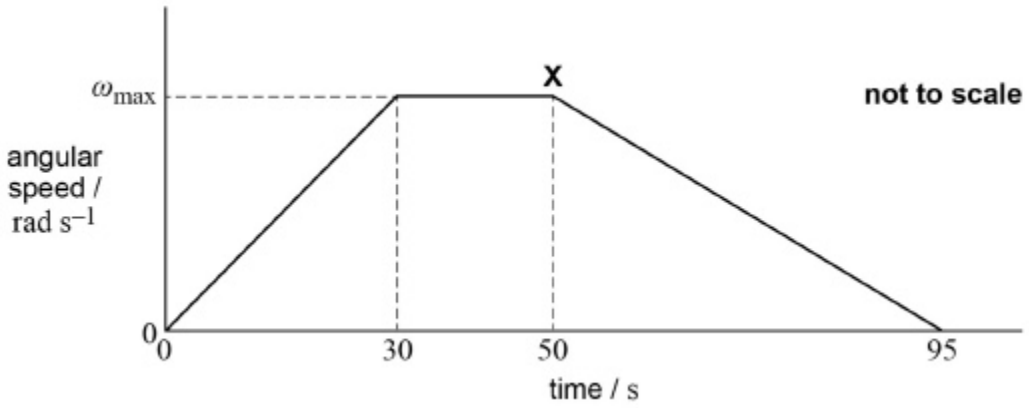
(b) The load is at a distance of 35 m from the axis of rotation.

Show that the total moment of inertia of the jib, and the trolley and load, about the axis of rotation is about 3×10^7 kg m^2.

(1)

(c) **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.

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

(2)

(d) 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.

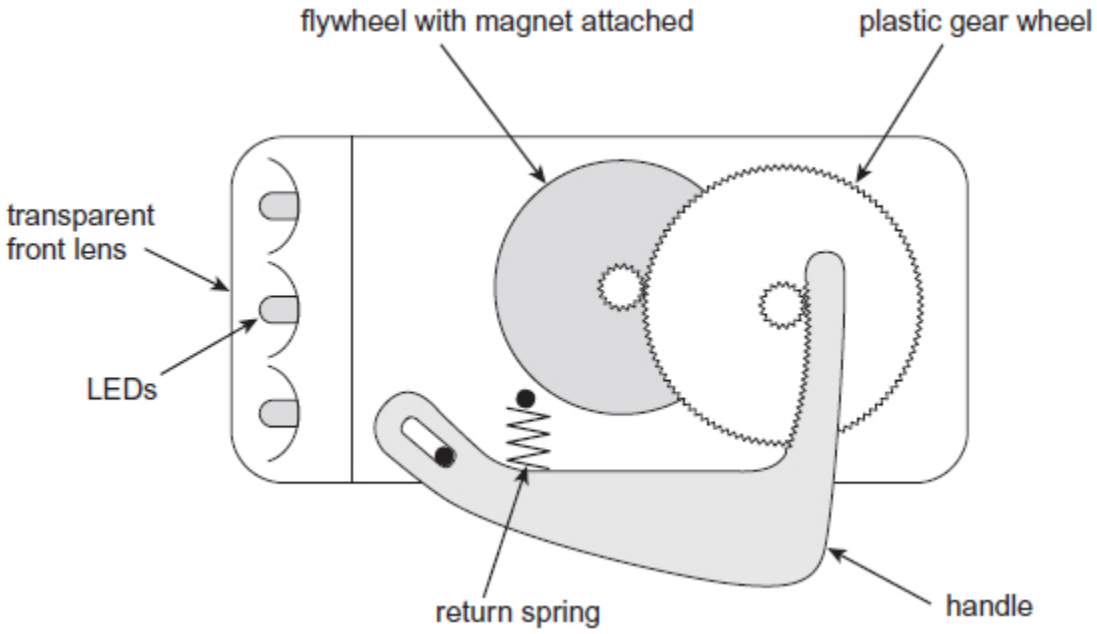
Assume the braking torque remains the same as before.

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

(3)

(Total 8 marks)

4. The diagram shows the mechanism of a dynamo torch for providing light without the use of batteries. When the handle is squeezed the gears rotate the flywheel increasing the kinetic energy stored in the flywheel. On the same axle as the flywheel is a magnet which generates an emf in surrounding coils as it rotates. The magnet, coils and electrical connections are not shown.



When the handle is released the mechanism disengages and a spring returns the handle to its original position. During this time the gears continue to turn. The energy of the flywheel enables it to continue to rotate for several seconds.

A designer wishes to enable the flywheel to store more energy and thus rotate for longer after the handle has been released.
The radius of the flywheel is limited by the overall size of the torch and cannot be increased.

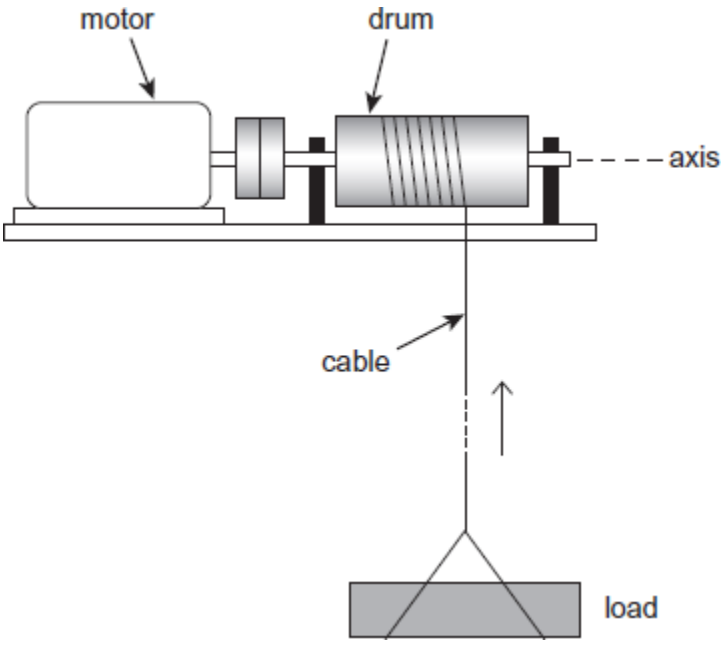
Describe and explain other changes that can be made to the mechanism and flywheel to store more energy. Your answer should include consideration of:

- the flywheel's shape
- the material from which it is made
- changes to the mechanism.

The quality of your written communication will be assessed in your answer.

(Total 6 marks)

5. 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)