1 Within certain limits, the bob of a simple pendulum of length l may be considered to move with simple harmonic motion of period T, where

$$T = 2\pi\sqrt{\frac{l}{g}}$$

(a) State **one** limitation that applies to the pendulum when this equation is used.

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(1)

(b) Describe an experiment to determine the value of the Earth's gravitational field strength g using a simple pendulum and any other appropriate apparatus.

In your answer you should:

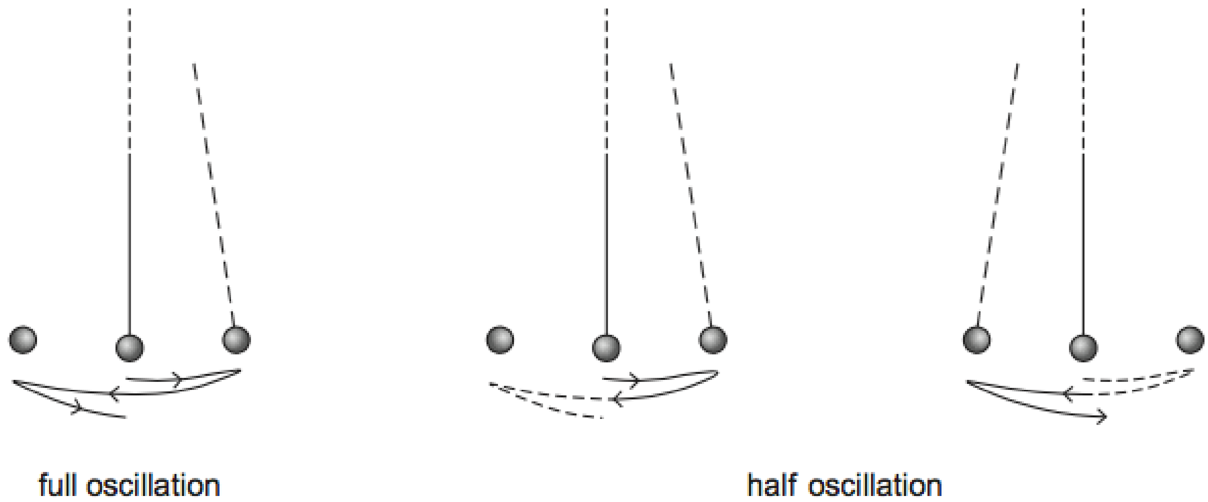
- describe how you would arrange the apparatus
- indicate how you would make the measurements
- explain how you would calculate the value of g by a graphical method
- state the experimental procedures you would use to ensure that your result was accurate.

You may draw a diagram to help you with your answer.

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

(6)

(c) When carrying out the experiment in part **(b)**, a student measures the time period incorrectly. Mistakenly, the student thinks that the time period is the time taken for half of an oscillation instead of a full oscillation, as illustrated in the diagram.



Deduce the effect this will have on the value of g obtained from the experiment, explaining how you arrive at your answer.

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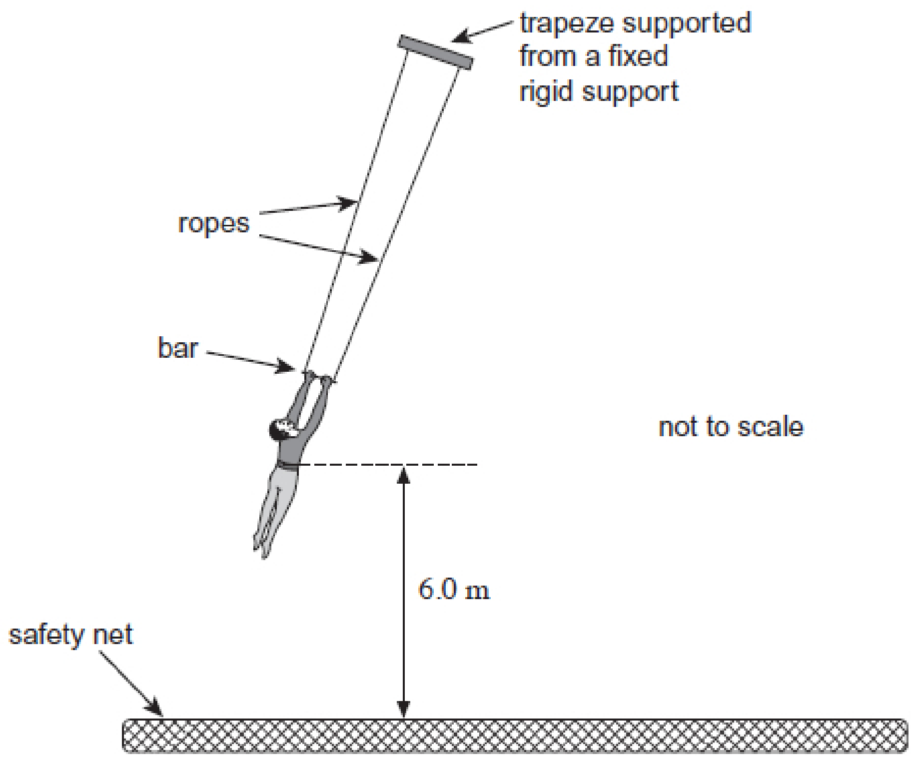
(3)

(Total 10 marks)

2 **Figure 1** shows an acrobat swinging on a trapeze.

Figure 1



(a) (i) State and explain how the tension in the ropes of the trapeze varies as the acrobat swings on the trapeze.

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(3)

(ii) The period of the oscillation of the acrobat on the trapeze is 3.8 s.

Calculate the distance between the point of suspension of the trapeze and the centre of mass of the acrobat.

Assume that the acrobat is a point mass and that the system behaves as a simple pendulum.

distance ____________________ m

(2)

(b) At one instant the amplitude of the swing is 1.8 m. The acrobat lets go of the bar of the trapeze at the lowest point of the swing. He lands in a safety net when his centre of mass has fallen 6.0 m.

(i) Calculate the speed of the acrobat when he lets go of the bar.

speed ____________________ m s^{-1}

(3)

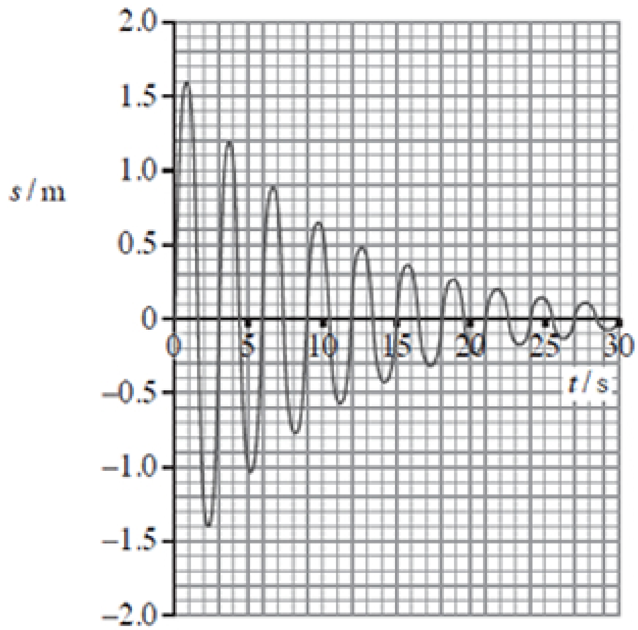
(ii) Calculate the horizontal distance between the point of suspension of the trapeze and the point at which the acrobat lands on the safety net.

horizontal distance ____________________ m

(3)

(c) **Figure 2** shows the displacement−time (s–t) graph for the bar of the trapeze after the acrobat has let go of the bar.

Figure 2



(i) Show that the amplitude of the oscillations decreases exponentially.

(3)

(ii) Explain why the period of the trapeze changes when the acrobat lets go of the bar.

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(2)

(Total 16 marks)

3 A roundabout in a fairground requires an input power of 2.5 kW when operating at a constant angular velocity of 0.47 rad s^{-1}.

(a) Show that the frictional torque in the system is about 5 kN m.

(3)

(b) When the power is switched off, the roundabout decelerates uniformly because the frictional torque remains constant. The roundabout takes a time of 34 s to come to rest.

(i) Calculate the moment of inertia of the roundabout.
Give an appropriate unit for your answer.

moment of inertia ____________________ unit __________

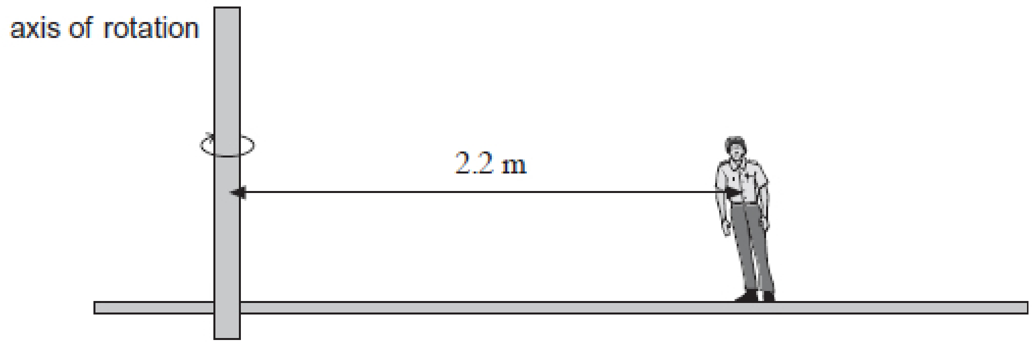
(3)

(ii) Calculate the number of revolutions that are made before the roundabout comes to rest.

number of revolutions ____________________

(3)

(c) An operator of mass 65 kg is standing on the roundabout when the roundabout is rotating at an angular velocity of 0.47 rad s^{-1}. His centre of mass is 2.2 m from the axis of rotation. The diagram shows that his body leans towards the centre of the path.



(i) Calculate the centripetal force needed for the operator to remain at this radius on the roundabout.

centripetal force ____________________ N

(2)

(ii) State the origin of this centripetal force and suggest why the operator has to incline his body towards the centre of rotation to avoid falling over.

You may draw the forces that act on the operator in the diagram to help your answer.

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(2)

(iii) While the roundabout is moving, the operator drops a coin.

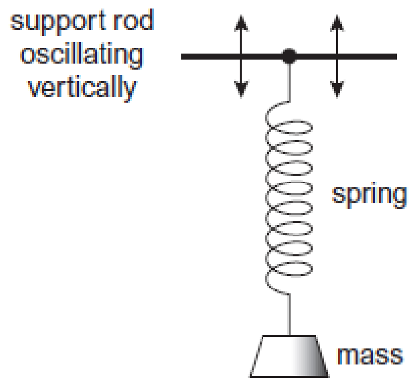
Which statement correctly describes and explains what happens to the coin?
Tick (✓) the correct answer in the right-hand column.

	Tick (✓)
There is no longer a centripetal force acting, so the coin falls vertically downwards and lands on the roundabout directly below the point at which it was dropped.	
The centripetal force causes the coin to have a horizontal component of velocity towards the centre of the roundabout, so that it follows a trajectory towards the centre of the roundabout.	
There is no longer a centripetal force acting, so there is a horizontal component of the coin's velocity directed away from the centre of the roundabout and it follows a trajectory directly away from the centre.	
There is no longer a centripetal force acting, so the coin has a horizontal component of its velocity tangential to its original path on the roundabout and it follows a trajectory along this tangent.	

(1)
(Total 14 marks)

4 (a) A mass is attached to one end of a spring and the other end of the spring is suspended from a support rod, as shown in **Figure 1**.

Figure 1



The support rod oscillates vertically, causing the mass to perform forced vibrations. Under certain conditions, the system may demonstrate resonance.

Explain in your answer what is meant by forced vibrations and resonance. You should refer to the frequency, amplitude and phase of the vibrations.

forced vibrations ____

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resonance ____

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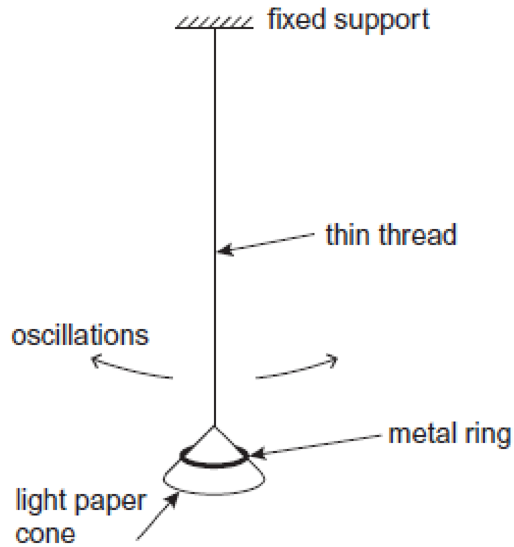
(4)

(b) A simple pendulum is set up by suspending a light paper cone (acting as the pendulum bob) on the end of a length of thin thread. A metal ring may be placed over the cone to increase the mass of the bob, as shown in **Figure 2**.

Figure 2



The bob is displaced and released so that it oscillates in a vertical plane. The oscillations are subject to damping.

(i) Are the oscillations of the pendulum more heavily damped when the cone oscillates with the metal ring on it, when it oscillates without the ring, or does the presence of the ring have no effect on the damping of the oscillations? Tick (✓) the correct answer.

cone oscillates with ring	
cone oscillates without ring	
ring has no effect	

(1)

(ii) Explain your answer to part (i).

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(3)

(Total 8 marks)

5 A lead ball of mass 0.25 kg is swung round on the end of a string so that the ball moves in a horizontal circle of radius 1.5 m. The ball travels at a constant speed of 8.6 m s^{-1}.

(a) (i) Calculate the angle, in degrees, through which the string turns in 0.40 s.

angle ____________________ degree

(3)

(ii) Calculate the tension in the string.
You may assume that the string is horizontal.

tension ____________________ N

(2)

(b) The string will break when the tension exceeds 60 N.
Calculate the number of revolutions that the ball makes in one second when the tension is 60 N.

number of revolutions ____________________

(2)

(c) Discuss the motion of the ball in terms of the forces that act on it. In your answer you should:

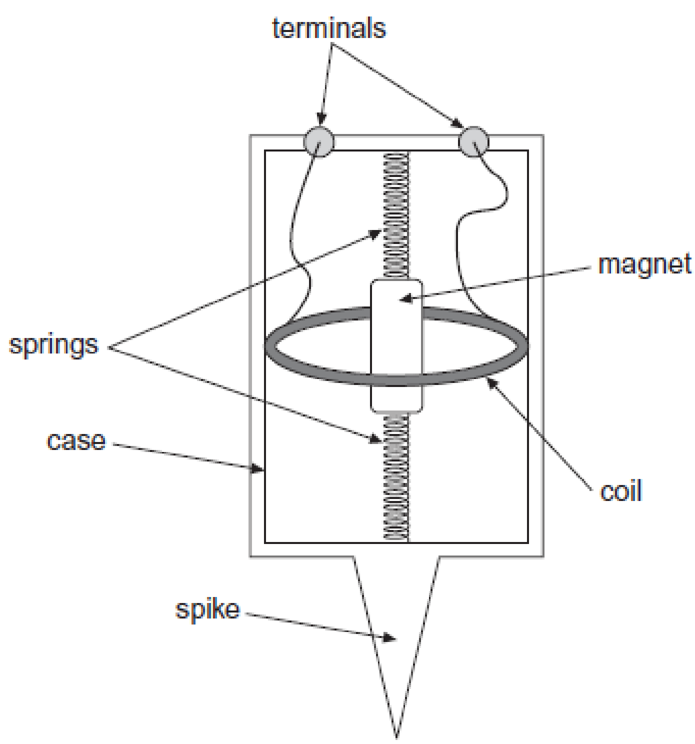
- explain how Newton's three laws of motion apply to its motion in a circle
- explain why, in practice, the string will not be horizontal.

You may wish to draw a diagram to clarify your answer.

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

(6)
(Total 13 marks)

6 The diagram below shows the main parts of a geophone.



The spike attaches the geophone firmly to the ground. At the instant an earthquake occurs, the case and coil move upwards due to the Earth's movement. The magnet remains stationary due to its inertia. In 3.5 ms, the coil moves from a position where the flux density is 9.0 mT to a position where the flux density is 23.0 mT.

(a) The geophone coil has 250 turns and an area of 12 cm^2.

Calculate the average emf induced in the coil during the first 3.5 ms after the start of the earthquake.

emf ____________________ V

(3)

(b) Explain how the initial emf induced in the coil of the geophone would be affected:

if the stiffness of the springs were to be increased

___

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if the number of turns on the coil were to be increased.

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(2)

(c) (i) The geophone's magnet has a mass of 8.0×10^{-3} kg and the spring stiffness of the system is 2.6 N m^{-1}.

Show that the natural period of oscillation of the mass−spring system is approximately 0.35 s.

(2)

(ii) At the instant that the Earth stops moving after one earthquake, the emf in the coil is at its maximum value of +8 V. The magnet continues to oscillate.

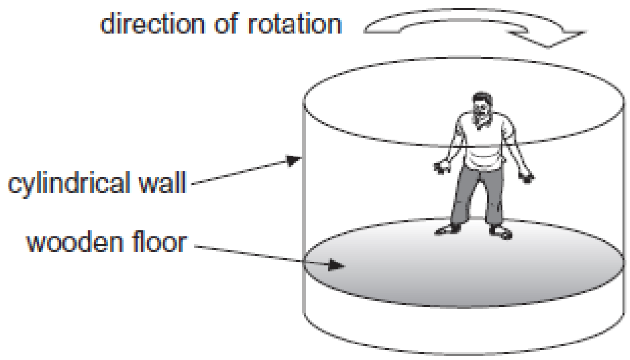
On the grid below, sketch a graph showing the variation of emf with time as the magnet's oscillation decays.
Show at least **three** oscillations.

(3)

(Total 10 marks)

7 **Figure 1** shows a fairground ride called a Rotor. Riders stand on a wooden floor and lean against the cylindrical wall.

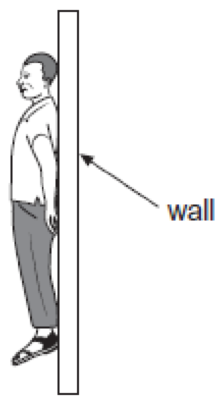
Figure 1



The fairground ride is then rotated. When the ride is rotating sufficiently quickly the wooden floor is lowered. The riders remain pinned to the wall by the effects of the motion. When the speed of rotation is reduced, the riders slide down the wall and land on the floor.

(a) (i) At the instant shown in **Figure 2** the ride is rotating quickly enough to hold a rider at a constant height when the floor has been lowered.

Figure 2



Draw onto **Figure 2** arrows representing all the forces on the rider when held in this position relative to the wall.
Label the arrows clearly to identify all of the forces.

(3)

(ii) Explain why the riders slide down the wall as the ride slows down.

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(2)

A Rotor has a diameter of 4.5 m. It accelerates uniformly from rest to maximum angular velocity in 20 s.
The total moment of inertia of the Rotor and the riders is 2.1×10^5 kg m^2.

(b) (i) At the maximum speed the centripetal acceleration is 29 m s^{-2}.

Show that the maximum angular velocity of a rider is 3.6 rad s^{-1}.

(2)

(ii) Calculate the torque exerted on the Rotor so that it accelerates uniformly to its maximum angular velocity in 20 s.
State the appropriate SI unit for torque.

torque ____________________ SI unit for torque __________

(3)

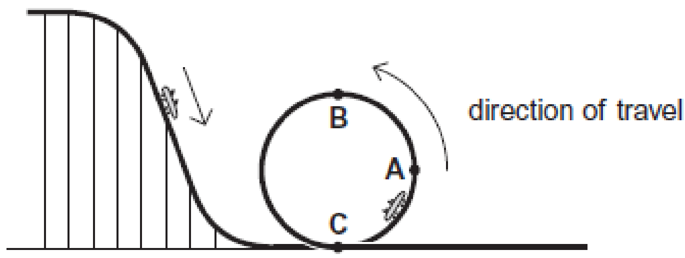
(iii) Calculate the centripetal force acting on a rider of mass 75 kg when the ride is moving at its maximum angular velocity.
Give your answer to an appropriate number of significant figures.

centripetal force ____________________ N

(1)

(c) **Figure 3** shows the final section of a roller coaster which ends in a vertical loop. The roller coaster is designed to give the occupants a maximum acceleration of 3*g*. Cars on the roller coaster descend to the start of the loop and then travel around it, as shown.

Figure 3



(i) At which one of the positions marked **A**, **B** and **C** on **Figure 3** would the passengers experience the maximum reaction force exerted by their seat?
Circle your answer below.

A **B** **C**

(1)

(iii) Explain why the maximum acceleration is experienced at the position you have chosen.

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(2)
(Total 14 marks)

8 (a) (i) Name the **two** types of potential energy involved when a mass–spring system performs vertical simple harmonic oscillations.

___

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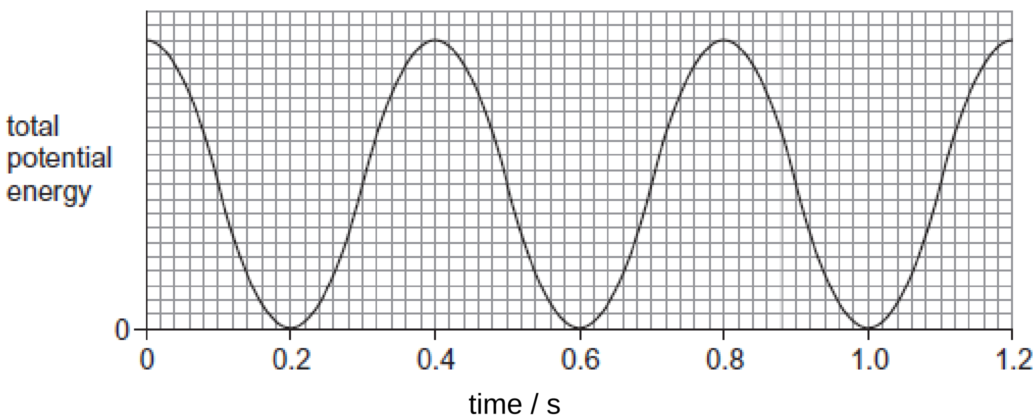
(1)

(ii) Describe the energy changes which take place during one complete oscillation of a vertical mass-spring system, starting when the mass is at its lowest point.

(2)

(b) **Figure 1** shows how the **total** potential energy due to the simple harmonic motion varies with time when a mass-spring system oscillates vertically.

Figure 1

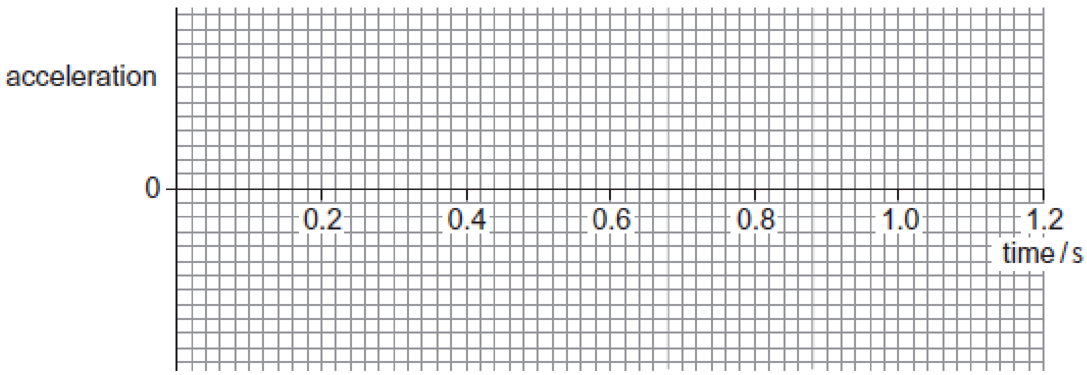


(i) State the time period of the simple harmonic oscillations that produces the energy–time graph shown in **Figure 1**, explaining how you arrive at your answer.

(2)

(ii) Sketch a graph on **Figure 2** to show how the acceleration of the mass varies with time over a period of 1.2 s, starting with the mass at the highest point of its oscillations. On your graph, upwards acceleration should be shown as positive and downwards acceleration as negative. Values are not required on the acceleration axis.

Figure 2



(2)

(c) (i) The mass of the object suspended from the spring in part (b) is 0.35 kg. Calculate the spring constant of the spring used to obtain **Figure 1**. State an appropriate unit for your answer.

spring constant ____________________ unit ___________

(3)

(ii) The maximum kinetic energy of the oscillating object is 2.0×10^{-2} J. Show that the amplitude of the oscillations of the object is about 40 mm.

(4)

(Total 14 marks)

9 (a) A simple pendulum is given a small displacement from its equilibrium position and performs *simple harmonic motion*.

State what is meant by simple harmonic motion.

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(2)

(b) (i) Calculate the frequency of the oscillations of a simple pendulum of length 984 mm. Give your answer to an appropriate number of significant figures.

frequency ____________________ Hz

(3)

(ii) Calculate the acceleration of the bob of the simple pendulum when the displacement from the equilibrium position is 42 mm.

acceleration ____________________ ms^{-2}

(2)

(c) A simple pendulum of time period 1.90 s is set up alongside another pendulum of time period 2.00 s. The pendulums are displaced in the same direction and released at the same time.

Calculate the time interval until they next move in phase. Explain how you arrive at your answer.

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time interval ____________________ s

(3)

(Total 10 marks)

10 (a) (i) State **two** situations in which a charged particle will experience no magnetic force when placed in a magnetic field.

first situation____

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second situation____

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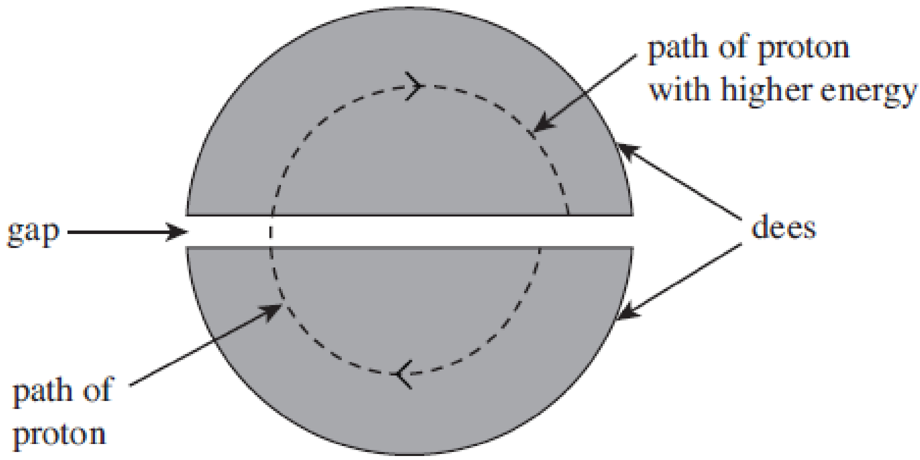
(2)

(ii) A charged particle moves in a circular path when travelling perpendicular to a uniform magnetic field. By considering the force acting on the charged particle, show that the radius of the path is proportional to the momentum of the particle.

(2)

(b) In a cyclotron designed to produce high energy protons, the protons pass repeatedly between two hollow D-shaped containers called ‘dees’. The protons are acted on by a uniform magnetic field over the whole area of the dees. Each proton therefore moves in a semi-circular path at constant speed when inside a dee. Every time a proton crosses the gap between the dees it is accelerated by an alternating electric field applied between the dees. The diagram below shows a plan view of this arrangement.



(i) State the direction in which the magnetic field should be applied in order for the protons to travel along the semicircular paths inside each of the dees as shown in the diagram above.

____

(1)

(ii) In a particular cyclotron the flux density of the uniform magnetic field is 0.48 T. Calculate the speed of a proton when the radius of its path inside the dee is 190 mm.

speed ____________________ ms^{-1}

(2)

(iii) Calculate the time taken for this proton to travel at constant speed in a semicircular path of radius 190 mm inside the dee.

time ____________________ s

(2)

(iv) As the protons gain energy, the radius of the path they follow increases steadily, as shown in the diagram above. Show that your answer to part (b)(iii) does not depend on the radius of the proton's path.

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(2)

(c) The protons leave the cyclotron when the radius of their path is equal to the outer radius of the dees. Calculate the maximum kinetic energy, in Me V, of the protons accelerated by the cyclotron if the outer radius of the dees is 470 mm.

maximum kinetic energy ____________________ Me V

(3)

(Total 14 marks)

11 **Figure 1** shows (not to scale) three students, each of mass 50.0 kg, standing at different points on the Earth's surface. Student **A** is standing at the North Pole and student **B** is standing at the equator.

Figure 1

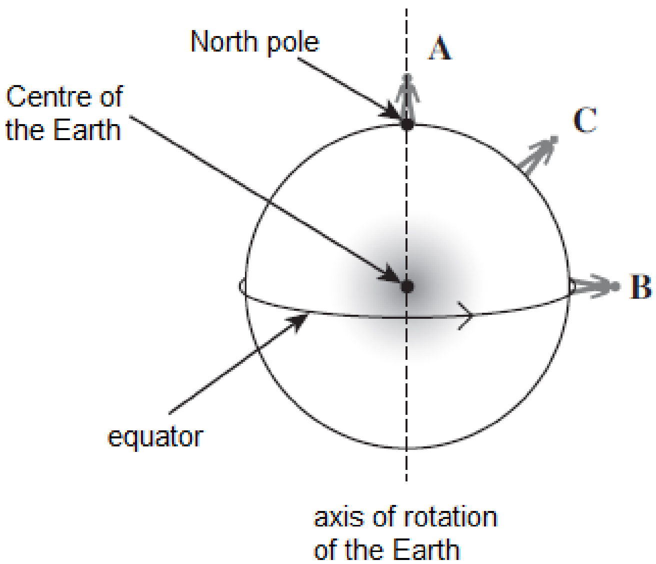
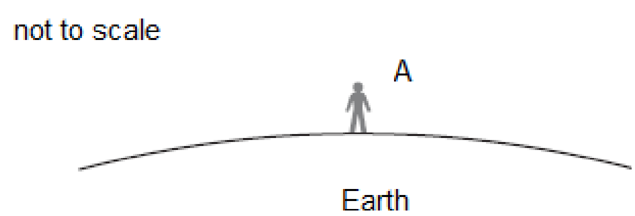


Figure 2



The radius of the Earth is 6370 km.
The mass of the Earth is 5.98×10^{22} kg.

In this question assume that the Earth is a perfect sphere.

(a) (i) Use Newton's gravitational law to calculate the gravitational force exerted by the Earth on a student.

force ____________________ N

(3)

(ii) **Figure 2** shows a closer view of student **A**.
Draw, on **Figure 2**, vector arrows that represent the forces acting on student **A**.

(2)

(b) (i) Show that the linear speed of student **B** due to the rotation of the Earth is about 460 ms^{-1}.

(3)

(ii) Calculate the magnitude of the centripetal force required so that student **B** moves with the Earth at the rotational speed of 460 ms^{-1}.

magnitude of the force ____________________ N

(2)

(iii) Show, on **Figure 1**, an arrow showing the direction of the centripetal force acting on student **C**.

(1)

(c) Student **B** stands on a bathroom scale calibrated to measure weight in newton (N). If the Earth were not rotating, the weight recorded would be equal to the force calculated in part (a)(i).

State and explain how the rotation of the Earth affects the reading on the bathroom scale for student **B**.

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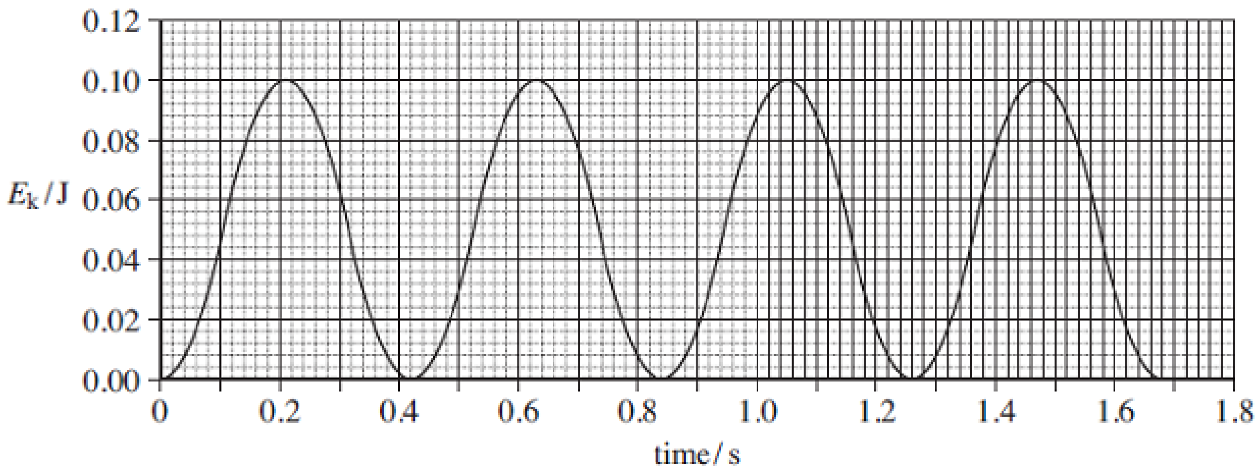
(3)

(Total 14 marks)

12

(a) **Figure 1** shows how the kinetic energy, E_k, of an oscillating mass varies with time when it moves with simple harmonic motion.

Figure 1



(i) Determine the frequency of the oscillations of the mass.

frequency of oscillation ____________________ Hz

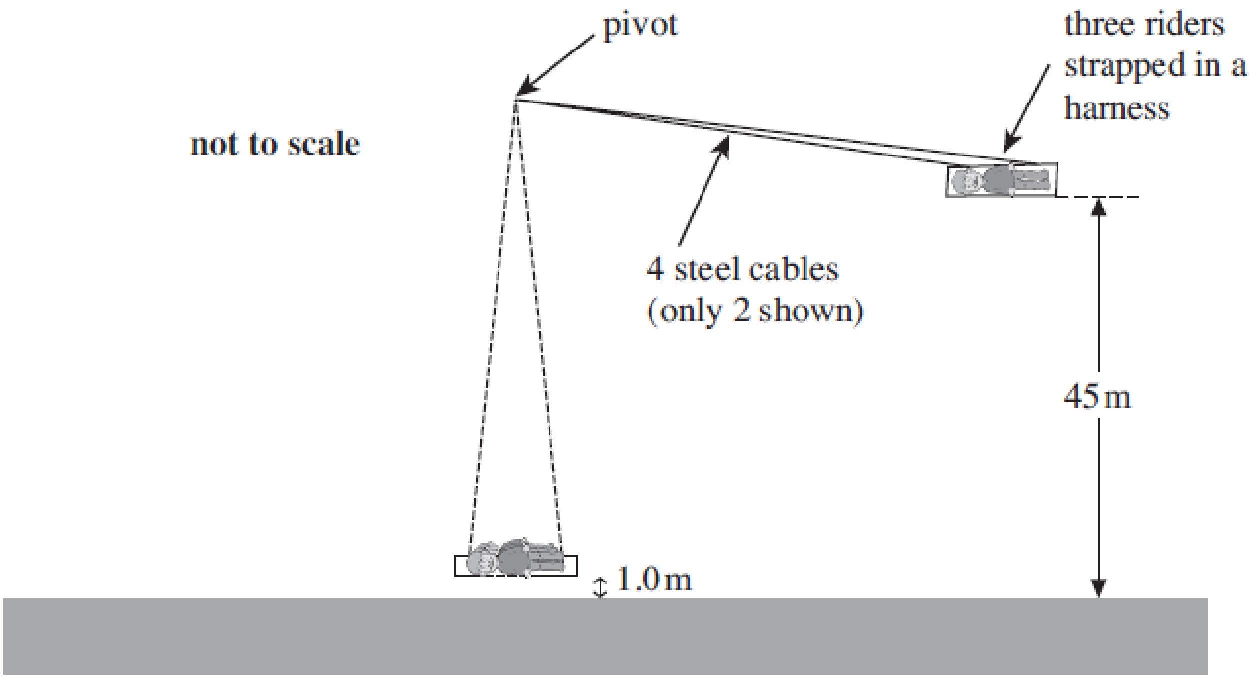
(2)

(ii) Sketch, on **Figure 1**, a graph showing how the potential energy of the mass varies with time during the first second.

(2)

(b) **Figure 2** shows a ride called a 'jungle swing'.

Figure 2



The harness in which three riders are strapped is supported by 4 steel cables. An advert for the ride states that the riders will be released from a height of 45 m above the ground and will then swing with a period of 14.0 s. It states that they will be 1.0 m above the ground at the lowest point and that they will travel at speeds of 'up to 120 km per hour'.

(i) Treating the ride as a simple pendulum, show that the distance between the pivot and the centre of mass of the riders is about 49 m.

(2)

(ii) The riders and their harness have a total mass of 280 kg.
Calculate the tension in each cable at the lowest point of the ride, assuming that the riders pass through this point at a speed of 120 km h^{-1}. Assume that the cables have negligible mass and are vertical at this point in the ride.

tension in each cable ____________________ N

(4)

(iii) Show that the maximum speed stated in the advert is an exaggerated claim.
Assume that the riders are released from rest and neglect any effects of air resistance.

(4)

(iv) The riders lose 50% of the energy of the oscillation during each half oscillation. After one swing, the speed of the riders as they pass the lowest point is 20 m s^{-1}.

Calculate the speed of the riders when they pass the lowest point, travelling in the same direction after two further complete oscillations.

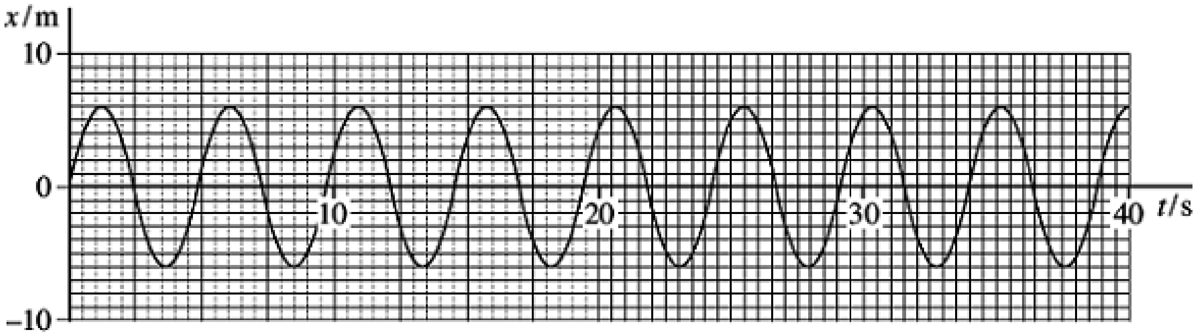
speed of riders ____________________ ms^{-1}

(3)

(Total 17 marks)

13 A pirate ship is a type of amusement park pendulum ride in which a gondola carrying passengers is made to oscillate. The ride can be modelled using a simple pendulum consisting of a mass on a string.

The figure below shows how the displacement x of the mass varies with time *t*.



(a) (i) Define amplitude.

____

____

(1)

(ii) Determine the amplitude of the oscillations of the mass.

amplitude ____________________ m

(1)

(iii) Calculate the period of the pendulum.

period ____________________ s

(2)

(b) Another model was constructed using a pendulum of frequency 0.25 Hz with the mass having an initial amplitude of 4.5 m.

(i) Calculate the maximum velocity of the mass.

maximum velocity ____________________ ms^{-1}

(2)

(ii) Calculate the maximum acceleration of the mass.

maximum acceleration ____________________ ms^{-2}

(2)

(iii) Calculate the length of the simple pendulum that has a frequency of 0.25 Hz.

length ____________________ m

(2)

(c) To simplify the driving mechanism of the actual ride it is suggested that the gondola should be pushed each time it reaches the centre moving in one direction.
Explain why this would lead to large amplitude oscillations.

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(2)

(d) When the force is no longer applied the gondola will naturally come to rest. The time for this to happen will usually be too long to satisfy the ride operators. External dampers are used to reduce the time taken to stop the gondola.
Explain why the gondola would come to rest naturally and what feature of an energy efficient ride design would make this a lengthy process.

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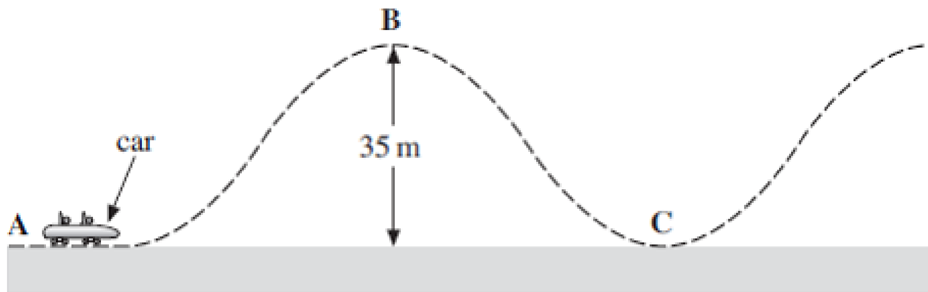
(3)
(Total 15 marks)

14 The figure below shows a car on a rollercoaster track. The car is initially at rest at **A** and is lifted to the highest point of the track, **B**, 35 m above **A**.



The car with its passengers has a total mass of 550 kg. It takes 25 s to lift the car from **A** to **B**. It then starts off with negligible velocity and moves unpowered along the track.

(a) Calculate the power used in lifting the car and its passengers from **A** to **B**.
Include an appropriate unit in your answer.

___

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___

power ___ unit ___

(3)

(b) The speed reached by the car at **C**, the bottom of the first dip, is 22 ms^{-1}. The length of the track from **B** to the bottom of the first dip **C** is 63 m.

Calculate the average resistive force acting on the car during the descent.

Give your answer to a number of significant figures consistent with the data.

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resistive force ___ N

(4)

(c) Explain why the resistive force is unlikely to remain constant as the car descends from **B** to **C**.

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(3)

(d) At **C**, a passenger of mass 55 kg experiences an upward reaction force of 2160 N when the speed is 22 ms^{-1}.

Calculate the radius of curvature of the track at **C**. Assume that the track is a circular arc at this point.

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radius of curvature of the track ____________________ m

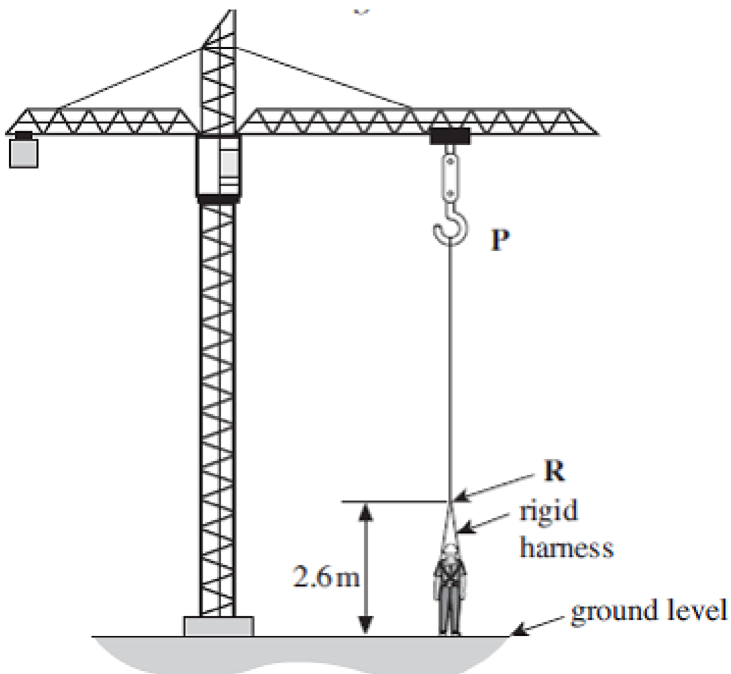
(3)

(Total 13 marks)

15 In a reverse bungee experience a 'rider' is catapulted high into the air.
A designer creates a less extreme version for more timid participants, as shown in the figure below.

The rider is strapped into a rigid harness attached to one end of an elastic rope **PR**. The rider and the rope behave in the same way as a mass-spring system.

The rider is initially held at rest at ground level. The top end of the rope, **P**, is raised to stretch the rope. The rider is then released and moves upwards, reaching a maximum height when the rope is at its unstretched (natural) length. The rider then oscillates vertically until eventually coming to rest, suspended above the ground.



The rope has an unstretched length of 20 m. When stretched, the rope obeys Hooke's law and has a stiffness of 92 Nm^{-1}. In the following questions ignore the mass of the rope.

(a) (i) The rider and harness have a total mass of 55 kg.
Calculate the overall length of the rope when the rider comes to rest, suspended above the ground, at the end of the ride.

___

___

___

___

___

overall length ____________________ m

(3)

(ii) At the start of the ride, the lower end of the rope **R** is attached to the rigid harness at a point which is 2.6 m above the ground.

The top end of the rope, **P**, has to be adjusted so that the rope just becomes unstretched when the rider is at the highest point of the ride.
Determine the height of **P** above the ground.
Neglect air resistance in this part of the question.

___

___

___

height of point **P** ______________________ m

(1)

(b) (i) Show that the frequency of oscillation of the rider on the end of the rope is about 0.2 Hz.

___

___

___

___

___

___

(3)

(ii) Calculate the maximum speed reached by the rider when the amplitude of the oscillation is 4.2 m.

___

___

___

___

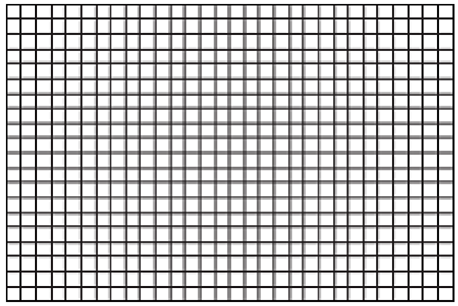
___

maximum speed ______________________ ms^{-1}

(2)

(iii) In practice, air resistance has an effect. Sketch below, a graph showing how you would expect the velocity to vary with time over the first two complete oscillations, from the instant the rider was released from ground level. Take an upward velocity as being positive.

Label the time axis with a suitable scale. No scale is required on the velocity axis.



(3)

(c) (i) A rider of greater mass now uses the ride. Explain how the height of **P** has to be changed to produce the same initial amplitude of oscillations as that for the previous rider.

___

___

___

___

(3)

(ii) A safety officer examines the design of the ride and thinks that, if the end **P** of the rope is raised too high so that the rope is stretched too much at the start, there is a risk that the rider could hit the ground after the first oscillation and suffer an injury. Describe what would happen to the rider during the ride in this case and explain why, even if air resistance is negligible, the safety officer's concerns are unfounded.

___

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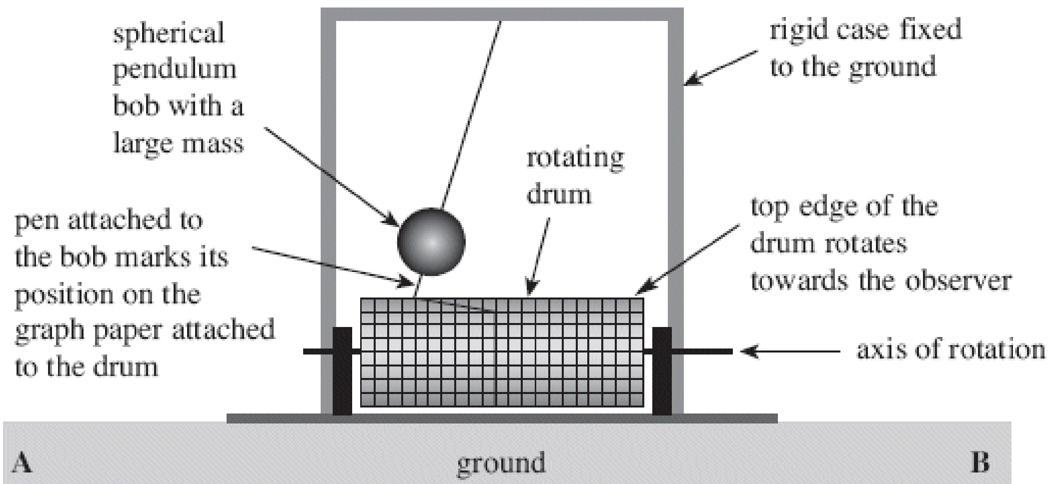
(3)

(Total 18 marks)

16 **Figure 1** shows a seismometer used for detecting the horizontal movement of the ground caused by an earthquake.

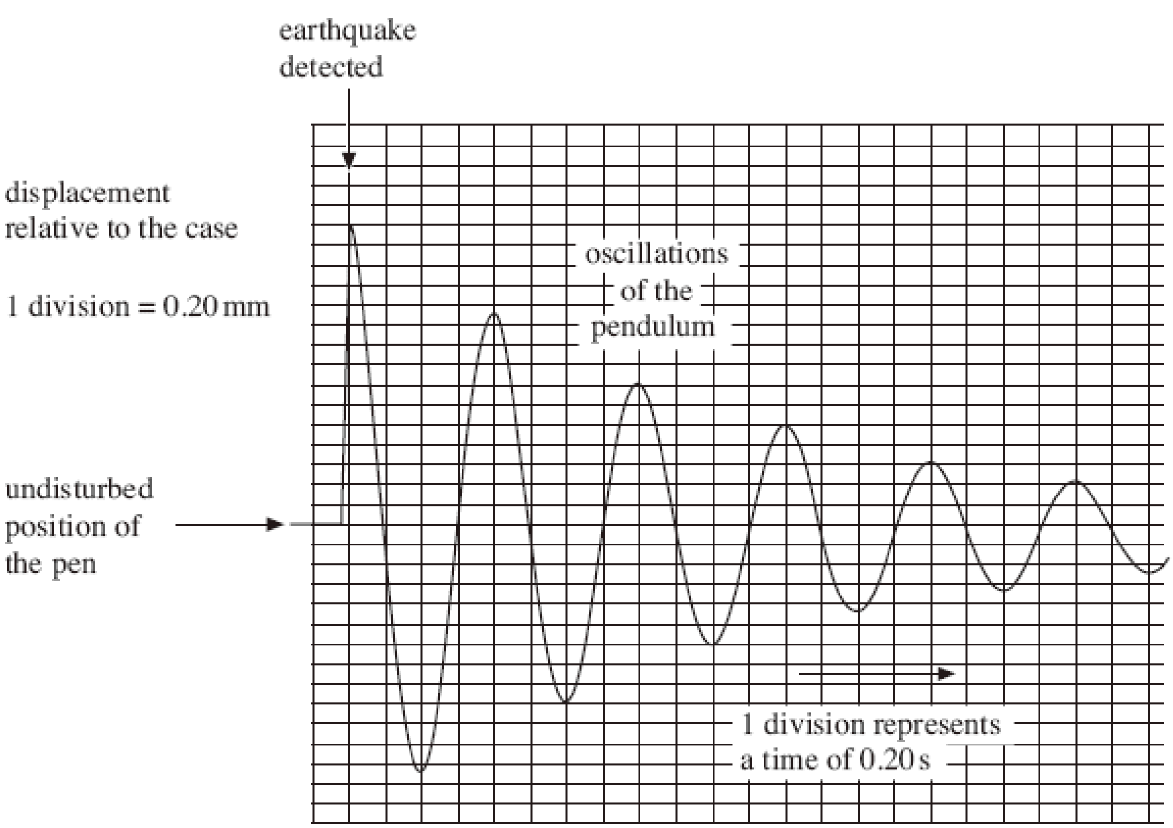
Figure 1



The rigid case is fixed to the ground. When an earthquake occurs, the ground moves horizontally so the rigid case also moves horizontally. Initially, the heavy pendulum bob remains in its original position due to its high inertia. **Figure 1** shows the pendulum immediately after an earthquake is detected.

The rotating drum moves at a steady speed. **Figure 2** shows the trace produced on the graph paper that is attached to the rotating drum following the earthquake.

Figure 2



(a) (i) State whether the ground has moved towards **A** or **B** to produce the situation shown in **Figure 1**.

____

(1)

(ii) Determine the magnitude of the initial displacement of the ground that caused the trace in **Figure 2**.

____

(1)

(b) (i) Use data from **Figure 2** to calculate the distance between the point of suspension of the pendulum and the centre of mass of the bob. Assume that the arrangement is a simple pendulum.

____

____

____

____

____

____

____

distance ______________________ m

(3)

(ii) State and explain the effect of using a bob of the same radius but smaller mass on the initial displacement of the bob,

____

____

____

the period of oscillation of the bob.

____

____

____

(4)

(c) (i) Determine whether the amplitude of the oscillations shown in **Figure 2** decreases exponentially.

___

___

___

___

___

___

___

(3)

(ii) Explain why the amplitude of the oscillations of the bob decreases following the initial displacement.

___

___

___

___

___

(2)

(iii) State and explain the effect of using a bob with the same radius but smaller mass on the time taken for the bob to come to rest following the initial disturbance.

___

___

___

___

(2)

(Total 16 marks)

17 The Hubble space telescope was launched in 1990 into a circular orbit near to the Earth. It travels around the Earth once every 97 minutes.

(a) Calculate the angular speed of the Hubble telescope, stating an appropriate unit.

answer = ______________________

(3)

(b) (i) Calculate the radius of the orbit of the Hubble telescope.

answer = ______________________ m

(3)

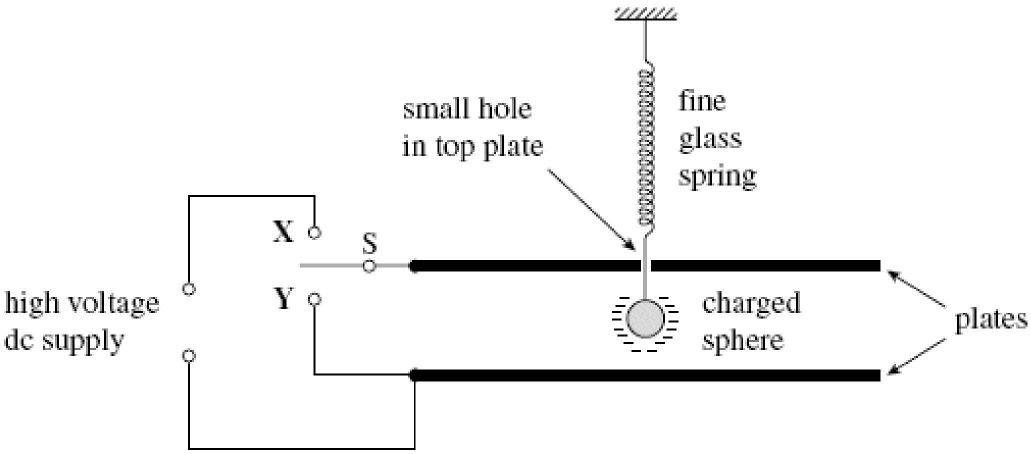
(ii) The mass of the Hubble telescope is 1.1×10^4 kg. Calculate the magnitude of the centripetal force that acts on it.

answer = ______________________ N

(2)

(Total 8 marks)

18 A small negatively charged sphere is suspended from a fine glass spring between parallel horizontal metal plates, as shown in the figure below.



(a) Initially the plates are uncharged. When switch S is set to position **X**, a high voltage dc supply is connected across the plates. This causes the sphere to move vertically upwards so that eventually it comes to rest 18 mm higher than its original position.

(i) State the direction of the electric field between the plates.

____

(1)

(ii) The spring constant of the glass spring is 0.24 N m^{-1}. Show that the force exerted on the sphere by the electric field is 4.3×10^{-3} N.

(1)

(iii) The pd applied across the plates is 5.0 kV. If the charge on the sphere is -4.1×10^{-8} C, determine the separation of the plates.

answer = ______________________ m

(3)

(b) Switch S is now moved to position **Y**.

(i) State and explain the effect of this on the electric field between the plates.

(2)

(ii) With reference to the forces acting on the sphere, explain why it starts to move with simple harmonic motion.

(3)

(Total 10 marks)

19 (a) Describe the energy changes that take place as the bob of a simple pendulum makes one complete oscillation, starting at its maximum displacement.

(2)

(b)

Figure 1

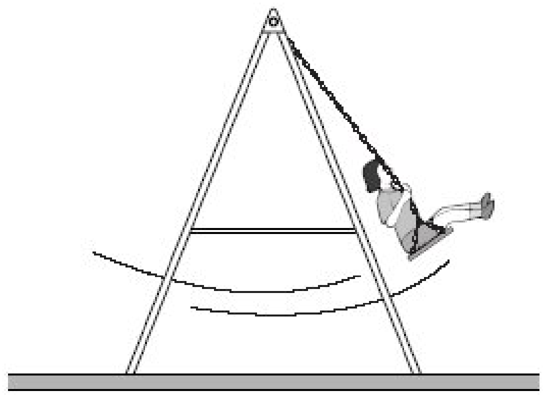


Figure 1 shows a young girl swinging on a garden swing. You may assume that the swing behaves as a simple pendulum. Ignore the mass of chains supporting the seat throughout this question, and assume that the effect of air resistance is negligible.
15 complete oscillations of the swing took 42s.

(i) Calculate the distance from the top of the chains to the centre of mass of the girl and seat. Express your answer to an appropriate number of significant figures.

answer = ____________________ m

(4)

(ii) To set her swinging, the girl and seat were displaced from equilibrium and released from rest. This initial displacement of the girl raised the centre of mass of the girl and seat 250 mm above its lowest position. If the mass of the girl was 18 kg, what was her kinetic energy as she first passed through this lowest point?

answer = ____________________ J

(2)

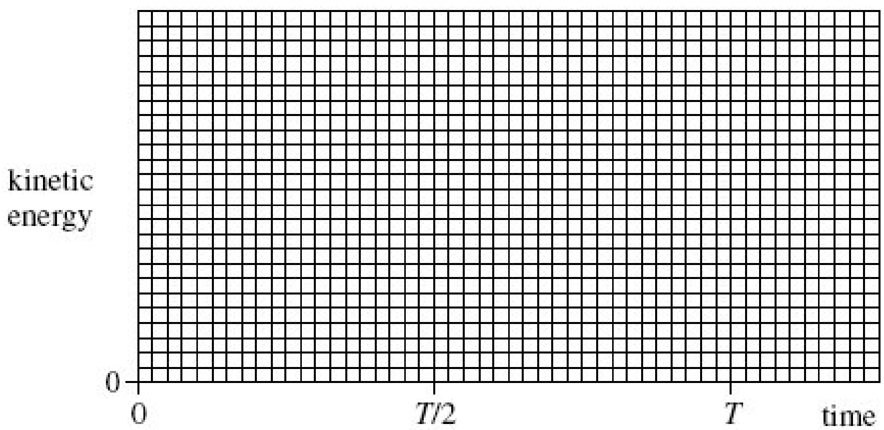
(iii) Calculate the maximum speed of the girl during the first oscillation.

answer = ____________________ m s^{-1}

(1)

(c)

Figure 2



On **Figure 2** draw a graph to show how the kinetic energy of the girl varied with time during the first complete oscillation, starting at the time of her release from maximum displacement. On the horizontal axis of the graph, *T* represents the period of the swing. You do not need to show any values on the vertical axis.

(3)

(Total 12 marks)

20 (a) Give an equation for the frequency, *f*, of the oscillations of a simple pendulum in terms of its length, *l*, and the acceleration due to gravity, *g*.

___

___

State the condition under which this equation applies.

___

___

(2)

(b) The bob of a simple pendulum, of mass 1.2×10^{-2} kg, swings with an amplitude of 51 mm. It takes 46.5 s to complete 25 oscillations. Calculate

(i) the length of the pendulum,

(ii) the magnitude of the restoring force that acts on the bob when at its maximum displacement.

(6)

(Total 8 marks)

21 (a) State, in words, Newton's law of gravitation.

(3)

(b) By considering the centripetal force which acts on a planet in a circular orbit, show that $T^2 \propto R^3$, where T is the time taken for one orbit around the Sun and R is the radius of the orbit.

(3)

(c) The Earth's orbit is of mean radius 1.50×10^{11} m and the Earth's year is 365 days long.

(i) The mean radius of the orbit of Mercury is 5.79×10^{10} m. Calculate the length of Mercury's year.

(ii) Neptune orbits the Sun once every 165 Earth years.

Calculate the ratio $\frac{\text{distance from Sun to Neptune}}{\text{distance from Sun to Earth}}$.

(4)

(Total 10 marks)

22 (a) A body is moving with simple harmonic motion. State **two** conditions that must be satisfied concerning the *acceleration* of the body.

condition 1

condition 2

(2)

(b) A mass is suspended from a vertical spring and the system is allowed to come to rest. When the mass is now pulled down a distance of 76 mm and released, the time taken for 25 oscillations is 23 s.

Calculate

(i) the frequency of the oscillations,

(ii) the maximum acceleration of the mass,

____

____

(iii) the displacement of the mass from its rest position 0.60 s after being released. State the direction of this displacement.

____

____

____

____

(6)

(c)

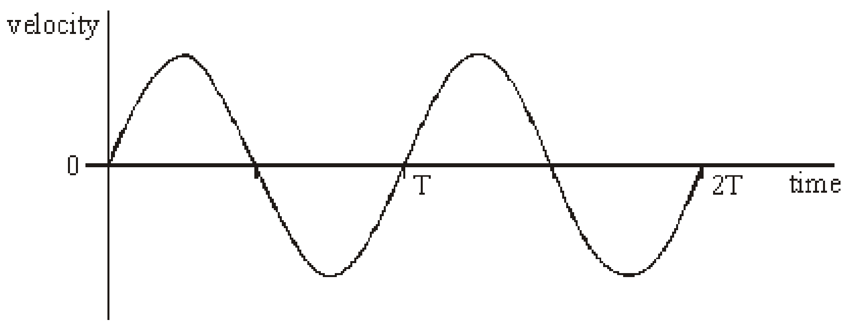


Figure 1

Figure 1 shows qualitatively how the velocity of the mass varies with time over the first two cycles after release.

(i) Using the axes in **Figure 2**, sketch a graph to show qualitatively how the displacement of the mass varies with time during the same time interval.

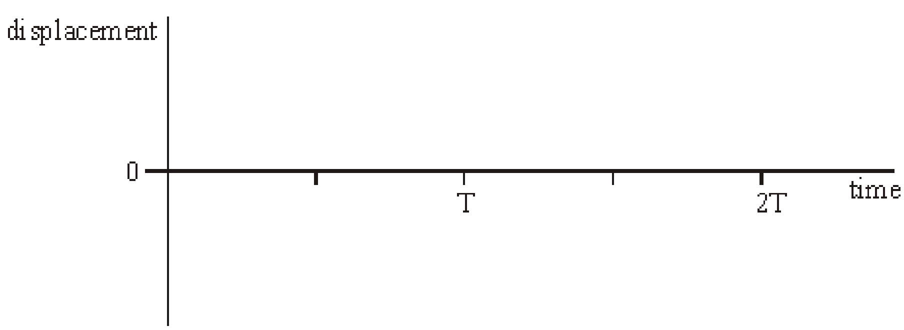


Figure 2

(ii) Using the axes in **Figure 3**, sketch a graph to show qualitatively how the potential energy of the mass-spring system varies with time during the same time interval.

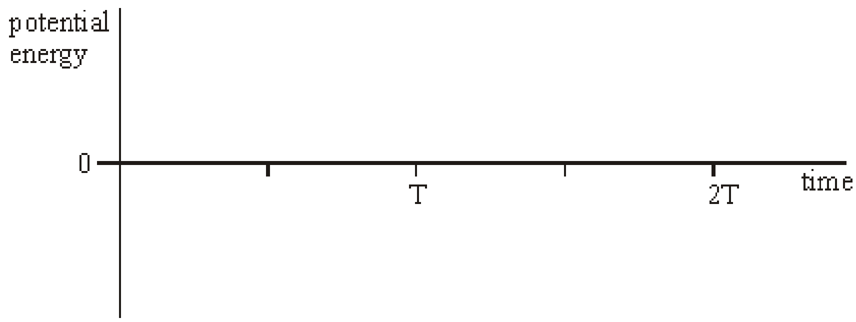


Figure 3

(4)
(Total 12 marks)

23 In a football match, a player kicks a stationary football of mass 0.44 kg and gives it a speed of 32 m s^{-1}.

(a) (i) Calculate the change of momentum of the football.

____

(ii) The contact time between the football and the footballer's boot was 9.2 m s. Calculate the average force of impact on the football.

____

____

____

(3)

(b) A video recording showed that the toe of the boot was moving on a circular arc of radius 0.62 m centred on the knee joint when the football was struck. The force of the impact slowed the boot down from a speed of 24 m s^{-1} to a speed of 15 m s^{-1}.

Figure 1

(i) Calculate the deceleration of the boot along the line of the impact force when it struck the football.

___

___

___

(ii) Calculate the centripetal acceleration of the boot just before impact.

___

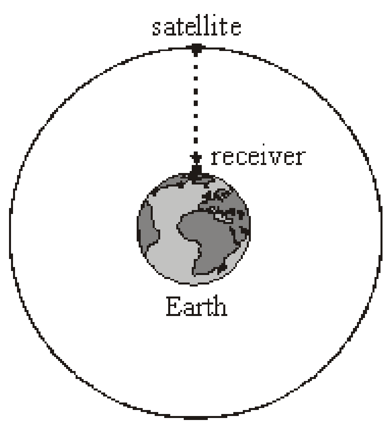
___

___

(iii) Discuss briefly the radial force on the knee joint before impact and during the impact.

(4)
(Total 7 marks)

24 The Global Positioning System (GPS) is a system of satellites that transmit radio signals which can be used to locate the position of a receiver anywhere on Earth.



(a) A receiver at sea level detects a signal from a satellite in a circular orbit when it is passing directly overhead as shown in the diagram above.

(i) The microwave signal is received 68 ms after it was transmitted from the satellite. Calculate the height of the satellite.

(ii) Show that the gravitational field strength of the Earth at the position of the satellite is 0.56 N kg^{-1}.

mass of the Earth = 6.0×10^{24} kg
mean radius of the Earth = 6400 km

(4)

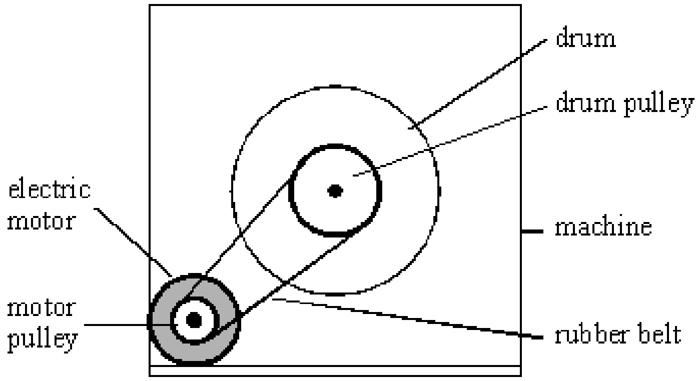
(b) For the satellite in this orbit, calculate

(i) its speed,

(ii) its time period.

(5)
(Total 9 marks)

25 An electric motor in a machine drives a rotating drum by means of a rubber belt attached to pulleys, one on the motor shaft and one on the drum shaft, as shown in the diagram below.



(a) The pulley on the motor shaft has a diameter of 24 mm. When the motor is turning at 50 revolutions per second, calculate

(i) the speed of the belt,

(ii) the centripetal acceleration of the belt as it passes round the motor pulley.

(5)

(b) When the motor rotates at a particular speed, it causes a flexible metal panel in the machine to vibrate loudly. Explain why this happens.

(2)

(Total 7 marks)

Mark schemes

1 (a) amplitude (of bob) is small
[**or** (angular) amplitude is less than or = 10°]
[**or** sin $\theta \approx \theta$ with θ explained] ✓

__or__ string is inextensible (or of negligible mass)

__or__ bob is a point mass

Ignore references to “air resistance”.

1

(b) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate describes the arrangement of the apparatus clearly. They identify correctly the measurements to be made, and indicate how these measurements would be made. They describe a valid method by which a straight line graph may be obtained and show how g would be calculated from their graph. They are also aware of precautions that should be taken during the experiment to ensure that the result is accurate.

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate is less clear about the experimental arrangement, gives a reasonable account of the measurements to be made and indicates a valid method by which a straight line graph may be obtained. They are less clear about how the result would be calculated from the graph, and they know the precautions less well.

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate gives a superficial account of the experimental arrangement, has some knowledge of the measurements to be made, but has only limited ability to show how a graphical method could be used to calculate the result. Some precautions may be known.

The description expected in a competent answer should include a coherent selection of the following points.

- Diagram or description showing a bob suspended from a fixed point, on which the length l may be labelled correctly.
- Length l of pendulum measured by ruler from fixed point of support to centre of mass of bob.
- Period T measured by stopwatch, by timing a number of oscillations.
- Measurement of T repeated for the same l and a mean value of T calculated.
- Measurements repeated for at least five different values of l.
- Graph of T^2 against l (or any other suitable linear graph) would be plotted.
- Graph is a straight line through origin, gradient is $4\pi2/g$ (or correct expression for g from their graph).

Experimental measures such as the following are likely to be given:

- Small amplitude oscillations.
- Measure l to centre of mass of bob.
- Measure T from a large number of oscillations.

- Repeat timing for each length.
- Begin counting oscillations at nought when $t = 0$.
- Measure complete oscillations.
- Use of fiducial mark at centre of oscillations.
- Pendulum should swing in a vertical plane.
- Avoid very small values of l when repeating the experiment.

Credit may be given for any of these points which are described by reference to an appropriate labelled diagram.

*A **high level** answer must include*

1. a description of the apparatus,

2. a correct statement of the measurements to be made,

3. a correct graph plot,

4. a correct indication of how g would be found from the graph,

5. at least two precautions.

*An **intermediate level** answer must include (at least)*

*1 and 2, **or** 1 and 3, **or** 2 and 3, above and at least one precaution.*

*A **low level** answer must include (at least) any one of 1,2,3,4 above.*

*An inappropriate, irrelevant or physically incorrect answer should be awarded **a mark of zero**.*

*If the experiment described relates to a **compound pendulum**, mark to max 2.*

If a log graph is plotted and explained, it may gain credit.

*If a correct graph is **not** used, then maximum mark awarded is 3.*

max 6

(c) measured value of g will be 4× true value of g ✓

gradient of T^2 against l graph will be ¼ of expected value [**or** reference to g ∞ $1/T^2$ or equivalent] ✓

(T is halved so) T^2 is ¼ of true value ✓

2nd and 3rd marks may be covered by an analysis of the period equation.

3

[10]

2 (a) (i) Tension minimum at extremities or maximum at middle / bottom

Tension depends on (component of) weight and required centripetal force / velocity

Increases as acrobat moves downwards

Tension at bottom = $mg + mv^2/r$ or Tension = weight + centripetal force

Tension at extremity = $mg/\cos\theta$ (θ is angle between rope and vertical)

Max 3

3

(ii) Use of $T = 2\pi\sqrt{(l/g)}$

3.6 (3.59) (m)

Allow for change of subject for use

2

(b) (i) Frequency of swing = 0.26 Hz

Use of $v = 2\pi fA$

3.0 or 2.97 (m s^{-1})

alternative method

Change in pe = gain in ke

Calculating Δh by geometry from swing = 0.48 m

3.1 or 3.06 (m s^{-1})

3

(ii) Use of $s = ½ at^2$

time to reach safety net = 1.11 s

s = their answer to **(b)(i)** × their time to reach the net = answer

(answer is 3.3 m if all correct)

Allow for change of subject for use

3

(c) (i) Attempt at valid test:

Fractional change in amplitude for same time interval

or use of 'half life' method

or use of exponential formula ($A = A_o e^{-kt}$) to show that k is constant

Correct calculation for one pair of amplitudes

Correct for second pair and conclusion

for half life method must see curve through peaks or other indication to find values between peaks

3

(ii) Period shorter

Centre of mass of trapeze artist was lower than the bar

Effective length of the pendulum is lower

Bar likely to be low mass now have a pendulum with distributed mass / no longer a simple pendulum / centre of mass is half way along suspending rope

Calculates new effective length of the pendulum (2 m)

Max 2

2

[16]

3 (a) T = power/ω

Torque = 2500/0.47

5320 N m value to 2 or more sf needed

3

(b) (i) Deceleration= 0.47/34= 0.0138 (rad s^{-2})

moment of inertia = torque / angular deceleration
=5000/0.0138 = 3.57×10^5

kg m^2 (Allow N m s^2)

3.8×10^5 if 5320 used

3

(ii) Suitable equation of motion used with correct data but omitted minus sign

8.0 radian Allow (their $\omega/2\pi$)

1.27 revolutions

Condone 1 revolution

(allowed for thinking question refers to complete revolutions)

3

(c) (i) $F = 65 \times 2.2 \times 0.47^2$

32(31.6 N)

2

(ii) Force produced by friction between the feet and the roundabout

Centripetal force has to act through the centre of mass of the operator
or
The resultant of the frictional force and normal reaction has to pass through the centre of mass

Any indication (eg on diagram) of wrong direction = 0

2

(iii) Ticks 4th box

1

[14]

4 (a) *forced vibrations:*

repeated upwards and downwards movement ✓
vibrations at frequency of support rod ✓
amplitude is small at high frequency **or** large at low frequency ✓
correct reference to phase difference between displacements of driving and forced vibrations ✓

Acceptable references to phase differences:

*Forced vibrations − when frequency of driver » frequency of driven, displacements are out of phase by (almost) π radians or 180° (**or** ½ a period) **or** when frequency of driver « frequency of driven, displacements are (almost) in phase. [Accept either].*

[Condone >, < for », «].

resonance:

frequency of support rod **or** driver is equal to natural frequency of (mass-spring) system ✓
large (or maximum) amplitude vibrations of mass ✓
maximum energy transfer (rate) (from support rod to mass-spring system) ✓
correct reference to phase difference between displacements of driving and driven vibrations at resonance ✓

*Resonance − displacement of driver leads on displacement of driven by π / 2 radians or 90° **or** ¼ of a period (or driven lags on driver by π / 2 radians or 90° **or** ¼ of a period).*

[Condone phase difference is π / 2 radians or 90°].

max 4

(b) (i) cone oscillates without ring *(ticked)*

Only one box to be ticked.

1

(ii) damping is caused by air resistance ✓

area is the same whether loaded or not loaded ✓

loaded cone has more kinetic energy **or** potential energy **or** momentum (at same amplitude) ✓

smaller <u>proportion</u> (or <u>fraction</u>) of (condone less) energy removed per oscillation from loaded cone (or vice versa) ✓

inertia of loaded cone is greater ✓

Award marks for correct physics even when answer to (b)(i) is incorrect.

max 3

[8]

5

(a) (i) $\omega\left(=\frac{v}{r}\right)=\frac{8.6}{1.5}$ (= 5.73 rad s^{-1}) ✓

$\theta(=\omega t)$ = 5.73 × 0.40 = 2.3 (2.29) (rad) ✓

$= \frac{2.29}{2\pi}$ × 360 = 130 (131) (degrees) ✓

[**or** $s((=vt)$ = 8.6 × 0.40 (= 3.44 m) ✓

$\theta = \frac{3.44}{2\pi \times 1.5}$ × 360 ✓ = 130 (131) (degrees) ✓]

Award full marks for any solution which arrives at the correct answer by valid physics.

3

(ii) tension $F(=m\omega^2 r)$ = 0.25 × 5.73^2 × 1.5 ✓ = 12(.3) (N) ✓

[**or** $F\left(=\frac{mv^2}{r}\right) = \frac{0.25\times 8.6^2}{1.5}$ ✓ = 12(.3) (N) ✓]

Estimate because rope is not horizontal.

2

(b) maximum $\omega \left(= \sqrt{\frac{F}{mr}} \right) = \sqrt{\frac{60}{0.25 \times 1.5}}$ (= 12.6) (rad s^{-1}) ✓

maximum $f \left(= \frac{\omega}{2\pi} \right) = \frac{12.6}{2\pi}$ = 2.01 (rev s^{-1}) ✓

[**or** maximum $v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{60 \times 1.5}{0.25}}$ (= 19.0) (m s^{-1}) ✓

maximum $f \left(= \frac{v}{2\pi r} \right) = \frac{19.0}{2\pi \times 1.5}$ = 2.01 (rev s^{-1}) ✓]

Allow 2 (rev s^{-1}) for 2nd mark.

Ignore any units given in final answer.

2

(c) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The student appreciates that the velocity of the ball is not constant and that this implies that it is accelerating. There is a comprehensive and logical account of how Newton's laws apply to the ball's circular motion: how the first law indicates that an inward force must be acting, the second law shows that this force must cause an acceleration towards the centre and (if referred to) the third law shows that an equal outward force must act on the point of support at the centre. The student also understands that the rope is not horizontal and states that the weight of the ball is supported by the vertical component of the tension.

A ***high level*** *answer must give a reasonable explanation of the application of at least two of Newton's laws, and an appreciation of why the rope will not be horizontal.*

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The student appreciates that the velocity of the ball is not constant. The answer indicates how at least one of Newton's laws applies to the circular motion. The student's understanding of how the weight of the ball is supported is more superficial, the student possibly failing to appreciate that the rope would not be horizontal and omitting any reference to components of the tension.

An ***intermediate level*** *answer must show a reasonable understanding of how at least one of Newton's laws applies to the swinging ball.*

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The student has a much weaker knowledge of how Newton's laws apply, but shows some understanding of at least one of them in this situation. The answer coveys little understanding of how the ball is supported vertically.

> *A **low level** answer must show familiarity with at least one of Newton's laws, but may not show good understanding of how it applies to this situation.*
>
> *References to the effects of air resistance, and/or the need to keep supplying energy to the system would increase the value of an answer.*

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

- *First law:* ball does not travel in a straight line, so a force must be acting on it
- although the ball has a constant speed its velocity is not constant because its direction changes constantly
- because its velocity is changing it is accelerating
- *Second law*: the force on the ball causes the ball to accelerate (or changes the momentum of it) in the direction of the force
- the acceleration (or change in momentum) is in the same direction as the force
- the force is centripetal: it acts towards the centre of the circle
- *Third law*: the ball must pull on the central point of support with a force that is equal and opposite to the force pulling on the ball from the centre
- the force acting on the point of support acts outwards
- *Support of ball*: the ball is supported because the rope is not horizontal
- there is equilibrium (or no resultant force) in the vertical direction
- the weight of the ball, mg, is supported by the vertical component of the tension, $F \cos \theta$, where θ is the angle between the rope and the vertical and F is the tension
- the horizontal component of the tension, $F \sin \theta$, provides the centripetal force $m \omega^2 r$

Credit may be given for any of these points which are described by reference to an appropriate labelled diagram.

> *A reference to Newton's 3 rd law is not essential in an answer considered to be a high level response. 6 marks may be awarded when there is no reference to the 3rd law.*

max 6

[13]

6 (a) emf = $\Delta(BAN) / t$

Change in flux = $A \times \Delta B$ or 12 × (23 − 9) seen

C1

Substitution ignoring powers of 10

C1

1.2 V

A1

3

(b) Reduced

M0

Magnet will move (with the case)

A1

Increased

M0

Flux linkage increases or emf is proportional to N

A1

2

(c) (i) Formula used

$$2\pi\sqrt{\frac{8\times10^{-3}}{2.6}}$$ seen

B1

0.348 / 0.349 seen to at least 3 sf

B1

2

(ii) Period consistent at 0.35 s or V_o = 8 V

B1

Shape shows decreasing amplitude

M1

At least 3 cycles starting at 8 V

A1

3

[10]

7 (a) (i) Weight / *W* / *mg* − vertically downwards from some point on the body

B1

Friction − vertically upwards and touching both the wall and the body

B1

Centripetal force / normal reaction / R − horizontally to the left from the body
Each must be correct and correctly labelled
Minus one for each additional inappropriate force

B1

3

(ii) Centripetal force / reaction / R is smaller

B1

Frictional force reduces
Frictional force is less than weight
Resultant force is downward
Friction is proportional to (normal) reaction

B1

2

(b) (i) $r\omega^2 = 29$ or
$v^2 / r = 29$

B1

Use of correct radius leading to 3.590 (rad s^{-1}) to at least 3 sig figs

2.54 using wrong r = 1 mark

B1

2

(ii) Angular acceleration, $\alpha = 3.6 / 20$ OR $3.59 / 20$ or 0.18 or 0.1795

C1

3.8 (3.77, 3.78) $\times 10^4$ cao

A1

N m or kg $m^2\ s^{-2}$

B1

3

(iii) 2200 N cao

B1

1

(c) (i) C

B1

1

(ii) Speed greatest (as all PE turned to KE)

B1

Total reaction force = $mr\omega^2 + mg$ or $v^2 / r + mg$ or R is largest or
$R = ma + mg$
OR
Acceleration = v^2 / r

B1

2

[14]

8 (a) (i) elastic potential energy **and** gravitational potential energy ✓

For elastic pe allow "pe due to tension", or "strain energy" etc.

1

(ii) elastic pe → kinetic energy → gravitational pe
→ kinetic energy → elastic pe ✓✓
[**or** pe→ke→pe→ke→pe is ✓ only]
[**or** elastic pe → kinetic energy → gravitational pe is ✓ only]

If kinetic energy is not mentioned, no marks.

Types of potential energy must be identified for full credit.

2

(b) (i) period = 0.80 s ✓
during one oscillation there are two energy transfer cycles
(or elastic pe→ke→gravitational pe→ke→elastic pe in 1 cycle)
or there are two potential energy maxima per complete oscillation ✓

Mark sequentially.

2

(ii) sinusoidal curve of period 0.80 s ✓
– cosine curve starting at $t = 0$ continuing to $t = 1.2$s ✓

For 1st mark allow ECF from T value given in (i).

2

(c) (i) use of $T = 2\pi\sqrt{\frac{m}{k}}$ gives $0.80 = 2\pi\sqrt{\frac{0.35}{k}}$ ✓

$\therefore k \left(= \frac{4\pi^2 \times 0.35}{0.80^2} \right) = 22\ (21.6)$ ✓ N m^{-1} ✓

Unit mark is independent: insist on N m^{-1}.
Allow ECF from wrong T value from (i): use of 0.40s gives 86.4 (N m^{-1}).

3

(ii) maximum ke = (½ mv_{max}^2) = 2.0 × 10^{-2} gives

$v_{max}^2 = \frac{2.0\times10^{-2}}{0.5\times0.35}$ ✓ (= 0.114 m^2s^{-2}) and v_{max} = 0.338 (m s^{-1}) ✓

$v_{max} = 2\pi fA$ gives $A = \frac{0.338}{2\pi\times1.25}$ ✓

and A = 4.3(0) × 10^{-2} m ✓ i.e. about 40 mm

[**or** maximum ke = (½ mv_{max}^2) = ½ $m\,(2\pi fA)^2$ ✓

½ × 0.35 × $4\pi^2$ × 1.25^2 × A^2 = 2.0 × 10^{-2} ✓

$\therefore A^2 = \frac{2\times2.0\times10^{-2}}{4\pi^2\times0.35\times1.25^2}$ ✓ (= 1.85 × 10^{-3})

and A = 4.3(0) × 10^{-2} m ✓ i.e. about 40 mm]

[**or** maximum ke = maximum pe = 2.0 × 10^{-2} (J)

maximum pe = ½ $k\,A^2$ ✓

∴ 2.0 × 10^{-2} = ½ × 21.6 × A^2 ✓

from which $A^2 = \frac{2\times2.0\times10^{-2}}{21.6}$ ✓ (= 1.85 × 10^{-3})

and A = 4.3(0) × 10^{-2} m ✓ i.e. about 40 mm]

First two schemes include recognition that f = 1 / T
i.e. f = 1 / 0.80 = 1.25 (Hz).

Allow ECF from wrong T value from (i) – 0.40s
gives A = 2.15 × 10^{-2}*m but mark to max 3.*

Allow ECF from wrong k value from (i) –86.4Nm^{-1} *gives*
A = 2.15 × 10^{-2}*m but mark to max 3.*

4

[14]

9 (a) acceleration is proportional to displacement (from equilibrium) ✓

Acceleration proportional to negative displacement is 1st mark only.

acceleration is in opposite direction to displacement
or towards a fixed point / equilibrium

Don't accept "restoring force" for accln.

position ✓

2

(b) (i) $f\left(=\frac{1}{2\pi}\sqrt{\frac{g}{l}}\right)=\frac{1}{2\pi}\sqrt{\frac{9.81}{0.984}}$ ✓ $= 0.503\ (0.5025)\ \text{(Hz)}$ ✓

3SF is an independent mark.

[**or** $T\left(=2\pi\sqrt{\frac{l}{g}}\right)=2\pi\sqrt{\frac{0.984}{9.81}}$ ✓ (= 1.9(90) (s))

When g = 9.81 is used, allow either 0.502 or 0.503 for 2nd and 3rd marks.

$f\left(=\frac{1}{T}\right)=\frac{1}{1.990}$ = 0.503 (0.5025) (Hz) ✓]

Use of g = 9.8 *gives 0.502 Hz: award only 1 of first 2 marks if quoted as 0.502, 0.503 0.50 or 0.5 Hz.*

answer to **3SF** ✓

3

(ii) $a\left(=-(2\pi f)^2 x\right)=(-)(2\pi\times 0.5025)^2\times 42\times 10^{-3}$ ✓

Allow ECF from ***any*** *incorrect f from (b)(i).*

= 0.42 (0.419) (m s^{-2}) ✓

2

(c) recognition of 20 oscillations of (shorter) pendulum

and / or 19 oscillations of (longer) pendulum ✓

Explanation: difference of 1 oscillation or phase change of 2π

or Δt = 0.1 so n = 2 / 0.1 =20, **or** other acceptable point ✓

time to next in phase condition = 38 (s) ✓

Allow "back in phase (for the first time)" as a valid explanation.

[**or** (T = 1.90 s so) (n + 1) × 1.90 = n × 2.00 ✓

gives n = 19 (oscillations of longer pendulum) ✓

minimum time between in phase condition = 19 × 2.00 = 38 (s) ✓]

3

[10]

10 (a) (i) *Two examples (any order)*:

- when charged particle is at rest **or** not moving relative to field ✓
- when charged particle moves parallel to magnetic field ✓

2

(ii) $BQv = \frac{mv^2}{r}$ ✓ (gives $BQr = mv$)

Acceptable answers must include correct force equation (1st point).

B and *Q* are constant so $r \propto$ momentum (mv) ✓

Insist on a reference to B and Q constant for 2nd mark.

2

(b) (i) upwards (perpendicular to plane of diagram) ✓

Accept "out of the page" etc.

1

(ii) $v\left(=\frac{BQr}{m}\right) = \frac{0.48 \times 1.60 \times 10^{-19} \times 0.19}{1.67 \times 10^{-27}}$ ✓ $= 8.7(4) \times 10^{6}\ (\mathrm{m\,s^{-1}})$

2

(iii) length of path followed (= length of semi-circle) = πr ✓

time taken $t\left(=\frac{\pi r}{v}\right) = \frac{\pi \times 0.19}{8.74 \times 10^{6}} = 6.8(3) \times 10^{-8}$ (s) ✓

Allow ECF from incorrect v from (b)(ii).

[**or** $\frac{v}{r} = \frac{BQ}{m}$ gives $t = \frac{\pi r}{v} = \frac{\pi m}{BQ}$ ✓

$= \frac{\pi \times 1.67 \times 10^{-27}}{0.48 \times 1.60 \times 10^{-19}} = 6.8(3) \times 10^{-8}$ (s) ✓]

Max 1 if path length is taken to be $2\pi r$ (gives 1.37×10^{-7}s).

2

(iv) $v \propto r$ (and path length $\propto r$) ✓

t = (path length / v) **or** (πr / v)

so r cancels (∴time doesn't depend on r) ✓

[**or** $t\left(=\frac{\pi r}{v}\right) = \frac{\pi rm}{BQr}$ ✓ $= \frac{\pi m}{BQ}$ (because r cancels) ✓]

[**or** $BQv = m\omega^2 r$ gives $BQ\omega r = m\omega^2 r$ and $BQ = m\omega = 2\pi fm$ ✓

∴ frequency is independent of r ✓]

2

(c) $v_{max} = 8.74 \times 10^6 \times \left(\frac{0.47}{0.19}\right) = 2.16 \times 10^7 \text{ (m s}^{-1}\text{)}$ ✓

1st mark can be achieved by full substitution, as in (b)(ii), or by use of data from (b)(i) and / or (b)(ii).

E_k (= ½ $mv_{max}{}^2$) = ½ × 1.67 × 10^{-27} × (2.16 × 10^7)^2 ✓

. (= 3.90 × 10^{-13} J)

$= \frac{3.90 \times 10^{-13}}{1.60 \times 10^{-13}} = 2.4(4) \text{ (MeV)}$ ✓

Allow ECF from incorrect v from (b)(ii), or from incorrect t from (b)(iii).

3

(Total 14 marks)

11 (a) (i) Use of $F – GMm/r^2$

C1

Allow 1 for
-correct formula quoted but forgetting square in substitution

Correct substitution of data

M1

-missing m in substitution

491 (490)N

A1

-substutution with incorrect powers of 10

Condone 492 N,

(ii) Up and down vectors shown (arrows at end) with labels

B1

allow W, mg (not gravity); R
allow if slightly out of line / two vectors shown at feet

up and down arrows of equal lengths

B1

condone if colinear but not shown acting on body

In relation to surface W ≤ R (by eye) to allow for weight vector starting in middle of the body

Must be colinear unless two arrows shown in which case R vectors ½ W vector(by eye)

(b) (i) Speed = $2\pi r / T$

B1

Max 2 if not easy to follow

$2\pi 6370000 / (24 \times 60 \times 60)$

B1

463 m s^{-1}

B1

Must be 3sf or more

(ii) Use of $F = mv^2/r$

C1

Allow 1 for use of $F = mr\omega^2$ with ω= 460

1.7 (1.66 – 1.68) N

A1

(iii) Correct direction shown
(Perpendicular to and toward the axis of rotation)
NB – not towards the centre of the earth

B1

(c) Force on scales decreases / apparent weight decreases
Appreciates scale reading = reaction force

C1

The reading would become 489 (489.3)N or reduced by 1.7 N)

A1

Some of the gravitational force provides the necessary centripetal force

B1

or $R = mg - mv^2/r$

[14]

12 (a) (i) correct period read from graph or use of $f=1/T$ 0.84±0.01

C1

2.4 Hz gets C1

correct frequency 1.2 (1.18 − 1.25 to 3 sf)

A1

(ii) correct shape (inverse)

B1

Crossover PE = KE

B1

(b) (i) Use of $T = 2\pi\sqrt{\frac{l}{g}}$

C1

48.7 (49) m

A1

(ii) v = 120 000 / 3600 = 33(.3) m s^{-1}

B1

Use of $F = m\,v^2/r$ (allow v in km h^{-1})

B1

Total tension = 6337 + (280 × 9.81) = 9.083 × 10^3 N
Allow their central force

B1

Divide by 4 2.27 × 10^3 N
Allow their central force

B1

(iii) $mgh = ½\,mv^2$

B1

Condone: Use of $v = 2\pi fA$ (max2)

9.8×44 = 0.5 v^2 Allow 45 in substitution

B1

Condone 22 m s^{-1}

29.4 m s^{-1} (Use of 45 gives 29.7)

B1

106 km h^{-1} (their m s^{-1} correctly converted)
Or compares with 33 m s^{-1}

B1

(iv) 1/16th(0.625) % of KE left if correct

M1

Allow 1/8 (0.125)or 1/32(0.313)

KE at start = 5.6×10^4 J or states energy $\propto$ speed^2 so speed is ¼

M1

Allow for correct sub^n $E = ½\ 280 \times 20^2$ x factor from incorrect number of swings calculated correctly

Final speed calculated = 5 m s^{-1}

A1

Must be from correct working

[17]

13 (a) (i) Maximum **displacement** (of carriage/pendulum from rest position)

B1

1

(ii) 6.0 (m)

B1

1

(iii) Clear evidence of what constitutes period

C1

4.8–4.9 (s)

A1

2

(b) (i) Use of $v = 2\pi fA$

C1

7.07 (ms^{-1})

A1

2

(ii) Use of $a = 4\pi^2 f^2 A$

C1

11.1 (ms^{-2}) ecf

A1

2

(iii) Substitution into or rearrangement of $T = 2\pi\sqrt{l/g}$

C1

3.98 (m)

A1

2

(c) Applied frequency = natural frequency

B1

Mention or clear description of resonance

B1

2

(d) Resistive/frictional/damping/air resistance forces

C1

due to friction in named place (eg in bearings)/air resistance acting on named part (allow ride/gondola here)

A1

low friction/large mass or inertia /streamline/smooth surface etc.

B1

3

[15]

14 (a) attempt to use power = *mgh/t* or $P = Fv$ and $v = s/t$

C1

7546/7550/7600

A1

W (allow J s^{-1} and condone N ms^{-1})

B1

3

(b) loss of GPE = 550 × 9.81 × 35 = 189 kJ

C1

gain in KE = 0.5 × 550 × 22^2 = 133 kJ

C1

resistance force = their difference/63 (890 N if correct)

A1

answer to 2 sf (allow if answer is from working even if incorrect)

B1

4

(c) air resistance varies/increases

B1

frictional force varies/increases

B1

further detail: air resistance increases with speed/v or normal reaction force varies with angle of the slope

B1

3

(d) use of $F = mv^2/r$

C1

arrives at r = 12 m (ignoring the weight)

C1

16.4 m

A1

3

[13]

15 (a) (i) use of $mg = k\Delta L$ or $F = k\Delta L$ **and** $F = mg$

C1

extension = 5.9 m

A1

total length = 25.9 m (allow 20 + their extension)

B1

3

(ii) 20 + twice (5.9) amplitude + 2.6; 34.4 m;
allow ecf from ai

B1

1

(b) (i) $T = 2\pi\sqrt{m/k}$ and $T = 1/f$ or $f = 1/2\pi\ \sqrt{k/m}$

B1

correct substitution: allow for calculation
of T (4.85 s)

B1

0.21 or 0.206 (Hz)

B1

3

(ii) substitutes data in $v_{max} = 2\pi fA$

C1

5.4 ms^{-1} (5.28 to 5.53)

A1

2

(iii) two complete oscillations shown with positive and negative velocities and acceptable shape (condone more than 2)

B1

and two from
period of 5 s used in graph (allow ecf for T from earlier part)

B1

start at 0 and positive velocity change at T = 0 with positive and negative velocities shown

B1

max velocity shown decreasing

B1

3

(c) (i) it would have to raised

B1

rest extension would be greater/rider would be nearer the ground if extension unchanged

B1

the rider has to move down a distance = to the amplitude (5.9 m) from the new rest position

or with same initial extension/energy stored in rope, the rider would reach a lower height
amplitude would be lower
or due to the larger mass more energy (= mgh) is needed to reach the same height

so initial extension would have to be increased

B1

3

(ii) the rope would become slack at the top of the ride so the rider would go into free flight/rider would overshoot the highest point

B1

the rider would fall and, with negligible air resistance, the rope would again absorb the energy arriving back at the start point **or** rider is more likely to fail to reach the ground after one oscillation due to energy losses/air resistance

B1

the PE gained (at the top of the flight) can (at most) only be converted back to the elastic energy that was stored in the rope at the start

(allow a statement to the effect that to hit the floor would contravene conservation of energy or require an energy input)

B1

3

[18]

16 (a) (i) toward B

B1

1

(ii) $15 \times 0.20 = 3$ mm

B1

1

(b) (i) period = 0.8 s

C1

use of $T = 2\pi\sqrt{L/g}$

C1

0.16 (0.159) m

A1

3

(ii) lower initial displacement

B1

lower inertia/more likely to begin moving as the Earth moves

B1

no effect

B1

period of a simple pendulum is independent of the mass of the bob/mass of bob is not in the formula for the period of a simple pendulum/period only depends on length (and *g*)

B1

4

(c) (i) clearly states consistency of ratios of successive amplitudes as the test

B1

one ratio of successive amplitudes correctly determined

B1

two ratios correctly determined and conclusion

B1

3

(ii) the oscillations are damped/air resistance mentioned/friction of pen against paper

B1

energy is lost because of air resistance/work is done against air resistance/energy lost moving air out of the way/giving air kinetic energy

B1

2

(iii) it will come to rest quicker

M1

the bob loses a greater proportion of its energy during each oscillation

A1

2

or pendulum has lower inertia so damping force has greater effect

or oscillating pendulum (initially) has less energy

or air resistance (initially) is unchanged

[16]

17 (a) $\omega \left(= \frac{2\pi}{T}\right) = \frac{2\pi}{97 \times 60}$ [or $\omega \left(= \frac{360}{T}\right) = \frac{360}{97 \times 60}$]

$= 1.1 \times 10^{-3}$ (1.08×10^{-3}) **(1)** [$= 6.2$ (6.19) $\times 10^{-2}$]

rad s^{-1} [accept s^{-1}] **(1)** [degree s^{-1}]

3

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **or** $r^3 = \frac{GM}{\omega^2}$ **(1)**

gives $r^3 = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.08 \times 10^{-3})^2}$ **(1)**

$\therefore r = 6.99 \times 10^6$ (m) **(1)**

3

(ii) F (= $m\omega^2 r$) = $1.1 \times 10^4 \times (1.08 \times 10^{-3})^2 \times 6.99 \times 10^6$ **(1)**

$= 9.0 \times 10^4$ (8.97×10^4) (N) **(1)**

[**or** $F\left(= \frac{GMm}{r^2}\right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 1.1 \times 10^4}{(6.99 \times 10^6)^2}$ **(1)**

$= 9.0 \times 10^4$ (8.98×10^4) (N) **(1)**]

2

[8]

18 (a) (i) (vertically) downwards [**or** top to bottom, or down the page] **(1)**

1

(ii) force on sphere F (= kx) = $0.24 \times 18 \times 10^{-3}$ **(1)** (= 4.32×10^{-3} N)

1

(iii) **use of** $F = EQ$ gives $E = \dfrac{4.32 \times 10^{-3}}{41 \times 10^{-9}}$ **(1)** (= 1.05×10^{5} V m^{-1})

use of $E = \dfrac{V}{d}$ gives separation $d = \dfrac{5.0 \times 10^{-3}}{1.05 \times 10^{5}}$ **(1)**

= 4.8×10^{-2} (m) **(1)** (4.76×10^{-2})

3

(b) (i) electric field becomes zero (or ceases to exist) **(1)**

flow of charge (or electrons) from one plate to the other
[**or** plates discharge] **(1)**

(until) pd across plates becomes zero [**or** no pd across plates,
or plates at same potential] **(1)**

max 2

(ii) net downward force on sphere (when E becomes zero)
[**or** gravitational force acts on sphere, **or** force is weight] **(1)**

this force extends spring **(1)**

force (or acceleration) is proportional to (change in)
extension of spring **(1)**
acceleration is in opposite direction to displacement
(or towards equilibrium) **(1)**

for shm, acceleration $\propto$ (−) displacement
[**or** for shm, force $\propto$ (−) displacement] **(1)**

max 3

[10]

19 (a) (grav) potential energy → kinetic energy → (grav) potential energy
→ kinetic energy → gravitational potential energy **(1)**

energy lost to surroundings in overcoming air resistance **(1)**

2

(b) (i) period $T = \left(\dfrac{42}{15}\right)$ = 2.8 s **(1)**

use of $T = 2\pi\sqrt{\dfrac{l}{g}}$ gives length $l = \left(= \dfrac{T^2 g}{4\pi^2}\right) = \dfrac{2.8^2 \times 9.81}{4\pi^2}$ **(1)**

giving distance from pt of support to c of m, l = 1.9 (m)
or 1.95 (m) **(1)**

answer must be to **2 or 3 sf** only **(1)**

4

(ii) $E_k = mg\Delta h$ stated or used **(1)**

gives E_k of girl at lowest point = 18 × 9.81 × 0.25 = 44 (J) **(1)**

2

(iii) $\frac{1}{2} mv^2 = 44.1$ gives max speed of girl $v = \sqrt{\frac{2 \times 44.1}{18}}$ = 2.2 (m s^{-1}) **(1)**

[**alternatively**: $A^2 = (3.9 - 0.25) \times 0.25$ gives $A = 0.955$ (m)
and $v_{max} = 2\pi f A = (2\pi/2.8) \times 0.955 = 2.1$ (m s^{-1}) **(1)**]

1

(c) graph drawn on **Figure 2** which:

shows $E_k = 0$ at $t = 0$, $T/2$ and T **(1)**

has 2 maxima of similar size (some attenuation allowed)
at $T/4$ and $3T/4$ **(1)**

is of the correct general shape **(1)**

3

[12]

20 (a) $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$ **(1)**

Oscillations must be of small amplitude **(1)**

2

(b) (i) $f = \frac{25}{46.5} = 0.53(8)(s^{-1})$ **(1)**

[or $T = \frac{46.5}{25} = 1.8(6)$ (s)]

$l\left(= \frac{g}{4\pi^2 f^2}\right) = \frac{9.81}{4\pi^2 0.538^2}$ [or $l\left(= \frac{T^2 g}{4\pi^2}\right) = \frac{1.86^2 \times 9.81}{4\pi^2}$] **(1)**

$l = 0.85(9)$m **(1)**

(allow C.E. for values of f or T)

(ii) $a_{max}\{= (–)(2\pi f)^2A\} = (2\pi \times 0.538)^2 \times 51 \times 10^{-3}$ **(1)**

($= 0.583$ ms^{-2})

(allow C.E. for value of f from (i))

$F_{max}(= ma_{max}) = 1.2 \times 10^{-2} \times 0.583$ **(1)**

$= 7.0 \times 10^{-3}$N **(1)**
(6.99×10^{-3}N)

[or $F_{max}(= mg \sin \theta_{max})$ where $\sin \theta_{max} = \dfrac{51}{859}$ **(1)**

$= 1.2 \times 10^{-2} \times 9.81 \times \dfrac{51}{859}$ **(1)**

$= 6.99 \times 10^{-3}$N **(1)**]

6

[8]

21 (a) attractive **force** between point masses **(1)**
proportional to (product of) the masses **(1)**
inversely proportional to square of separation/distance apart **(1)**

3

(b) $m\omega^2R = (–)\dfrac{GMm}{R^2}\left(\text{or} = \dfrac{mv^2}{R}\right)$ **(1)**

(use of $T = \dfrac{2\pi}{\omega}$ gives) $\dfrac{4\pi^2}{T^2} = \dfrac{GM}{R^3}$ **(1)**

G and M are constants, hence $T^2 \propto R^3$ **(1)**

3

(c) (i) (use of $T^2 \propto R^3$ gives) $\dfrac{365^2}{(1.50 \times 10^{11})^3} = \dfrac{T_m^2}{(5.79 \times 10^{10})^3}$ **(1)**

$T_m = 87(.5)$ days **(1)**

(ii) $\dfrac{1^2}{(1.50 \times 10^{11})^3} = \dfrac{165^2}{R_N^3}$ **(1)** (gives $R_N = 4.52 \times 10^{12}$ m)

ratio $= \dfrac{4.51 \times 10^{12}}{1.50 \times 10^{11}} = 30(.1)$ **(1)**

4

[10]

22 (a) acceleration is proportional to displacement **(1)**
acceleration is in opposite direction to displacement, or
towards a fixed point, or towards the centre of oscillation **(1)**

2

(b) (i) $f = \frac{25}{23}$ = 1.1 Hz (or s^{-1}) **(1)** (1.09 Hz)

(ii) (use of $a = (2\pi f)^2 A$ gives)
$a = (2\pi \times 1.09)^2 \times 76 \times 10^{-3}$ **(1)**
$= 3.6$ m s^{-2} **(1)** (3.56 m s^{-2})
(use of f = 1.1 Hz gives a = 3.63 m s^{-2})
(allow C.E. for incorrect value of f from (i))

(iii) (use of $x = A\cos(2\pi ft)$ gives)
$x = 76 \times 10^{-3} \cos(2\pi \times 1.09 \times 0.60)$ **(1)**
$= (–)4.3(1) \times 10^{-2}$m **(1)** (43 mm)
(use of f = 1.1 Hz gives
$x = (–)4.0(7) \times 10^{-2}$ m (41 mm))
direction: above equilibrium position or upwards **(1)**

6

(c) (i) graph to show:
correct shape, i.e. cos curve **(1)**
correct phase i.e. –(cos) **(1)**

(ii) graph to show:
two cycles per oscillation **(1)**
correct shape (even if phase is wrong) **(1)**
correct starting point (i.e. full amplitude) **(1)**

max 4

[12]

23 (a) (i) change of momentum (= 0.44 × 32) = 14(.1) kg m s^1 **(1)**

(ii) (use of $F = \frac{\Delta(mv)}{\Delta t}$ gives) $F = \frac{14.1}{9.2 \times 10^{-3}}$ **(1)**

$= 1.5(3) \times 10^3$N **(1)**

(allow C.E. for value of $\Delta(mv)$ from (i)

3

(b) (i) deceleration = $\frac{24 - 15}{9.2 \times 10^{-3}}$ = 9.8×10^2m s^{-2} **(1)**

(9.78×10^2m s^{-2})

(ii) (use of $a = \frac{v^2}{r}$ gives)

centripetal acceleration = $\frac{24^2}{0.62}$ = 9.3×10^2m s^{-2} **(1)**

(9.29×10^2 m s^{-2})

(iii) before impact: radial pull on knee joint due to centripetal acceleration of boot **(1)**
during impact: radial pull reduced **(1)**

4

[7]

24 (a) (i) h (= ct) (= $3.0 \times 10^8 \times 68 \times 10^{-3}$) = $2.0(4) \times 10^7$ m **(1)**

(ii) $g = (-)\dfrac{GM}{r^2}$ **(1)**

r (= $6.4 \times 10^6 + 2.04 \times 10^7$) = 2.68×10^7 (m) **(1)**
(allow C.E. for value of h from (i) for first two marks, but not 3rd)

$g = \dfrac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(2.68 \times 10^7)^2}$ **(1)** (= 0.56 N kg^{-1})

4

(b) (i) $g = \dfrac{v^2}{r}$ **(1)**

$v = [0.56 \times (2.68 \times 10^7)]^{½}$ **(1)**

= 3.9×10^3m s^{-1} **(1)** (3.87×10^3 m s^{-1})

(allow C.E. for value of r from a**(**ii**)**

[or $v^2 = \dfrac{GM}{r}$ = **(1)**

$v = \left(\dfrac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{2.68 \times 10^7}\right)^{1/2}$ **(1)**

= 3.9×10^3 m s^{-1} **(1)**]

(ii) $T\left(= \dfrac{2\pi r}{v}\right) = \dfrac{2\pi \times 2.68 \times 10^7}{3.87 \times 10^3}$ **(1)**

= $4.3(5) \times 10^4$s **(1)** (12.**(1)** hours)
(use of $v = 3.9 \times 10^3$ gives T = 4.3**(1)** × 10^4 s = 12.0 hours)
(allow C.E. for value of v from (I)

[alternative for (b):

(i) $v\left(\frac{2\pi r}{T}\right) = \frac{2\pi \times 2.68 \times 10^7}{4.36 \times 10^4}$ **(1)**

$= 3.8(6) \times 10^3$ m s^{-1} **(1)**]

(allow C.E. for value of *r* from (a)(ii) and value of *T*)

(ii) $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ **(1)**

$\left(= \frac{4\pi^2}{6.67 \times 10^{-11} \times 6.0 \times 10^{24}} \times (2.68 \times 10^7)^3\right) = (1.90 \times 10^9$ **(s^2) (1)**

$T = 4.3(6) \times 10^4$ s **(1)**

5

[9]

25 (a) (i) $r = 0.012$ (m) **(1)**
(use of $v = 2\pi fr$ gives) $v = 2\pi 50 \times 0.012$ **(1)**
$= 3.8$ m s^{-1} **(1)** (3.77 m s^{-1})

(ii) correct use of $a = \frac{v^2}{r}$ or $a = \frac{3.8^2}{0.012}$ **(1)**

$= 1.2 \times 10^3$ m s^{-2} **(1)**

[or correct use of $a = \omega^2 r$]
(allow C.E. for value of *v* from (i)

5

(b) panel resonates **(1)**
(because) motor frequency = natural frequency of panel **(1)**

2
QWC 2

[7]