Unit 3: Gravity and Motion

GRAVITATION AND SATELLITE MOTION

Question 1

The diagram shows object A falling at a constant speed of 2.00 m s^{-1} towards the ground and object B accelerating at 9.80 m s^{-2} towards the ground. What is the acceleration of object B relative to object A? Explain briefly.

(3)

Object A, v = 2.00 m s^{-1}

Object B, a = 9.80 m s^{-2}

Question 2 (16 marks)

Kepler-186f is a planet in orbit around the red dwarf star Kepler-186. A full public announcement about the planet was made by NASA on 17 April 2014. It is the first discovery of a planet with a similar radius to that of Earth in the habitable zone of another star.

Kepler-186f is a distance of 151 ± 18 parsecs from Earth (1 parsec = 3.26 Light Years). It has an orbital radius of 0.391 AU from its host star (The Astronomical Unit (AU) = Sun-Earth distance). It has an orbital period of 129.9 days.

a) Calculate the speed of Kepler-186f around its host star

(3)

b) Calculate the mass of the host star Kepler-186 based on the information given.

(4)

c) The mass of the planet Kepler-186f is difficult to estimate and is thought to be in a range of 32% to 377% the mass of the Earth. Explain whether or not this high degree of uncertainty affects estimates for the mass of the host star.

(2)

d) The radius of the planet Kepler-186f is 1.11 ± 0.14 times that of the Earth. Use this information and the uncertainty range for the mass of Kepler-186f to calculate the possible range for the gravitational field strength on the surface of the planet compared to "g" on Earth.

(3)

e) Calculate the percentage uncertainty (relative uncertainty) for the distance from Earth to Kepler-186f.

(1)

Question 3   (13 marks)

A **binary** planet system consists of two planets orbiting around their common centre of mass. This location is known as the *barycentre*. A binary planet system is shown below. Planet Talus has a mass of 2.04 x 10^{25} kg, Planet Trebor has a mass of 5.44 x 10^{24} Kg. The total separation between the 2 planets is **always** 210 500 km and the *barycentre* **always** lies on a straight line between Talus and Trebor, The distance between each planet and the barycentre is detailed in the diagram below (not to scale).
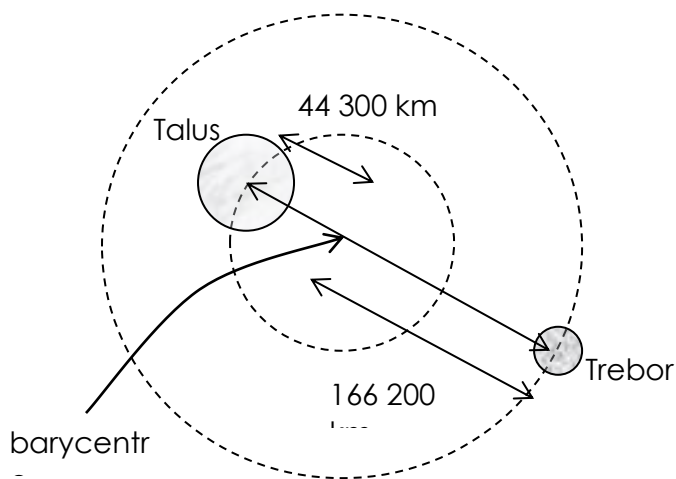
a) Calculate the gravitational force of attraction between Talus and Trebor.

(3)

b) Calculate the speed of Talus around the *barycentre*.

(3)

c) Calculate how many Earth hours it takes for Talus to orbit the *barycentre*.

(2)

d) Estimate the position of the planets after 32 hours of time from the initial position shown. Sketch them on the diagram and label them. Talus orbits in a clockwise direction about the *barycentre*. (If you could not determine the previous answer use 128 hours)

(2)

e) Show by algebraic proof that the following relationship must be true for any binary planet system that rotates around a *barycentre* in the pattern described in this question.
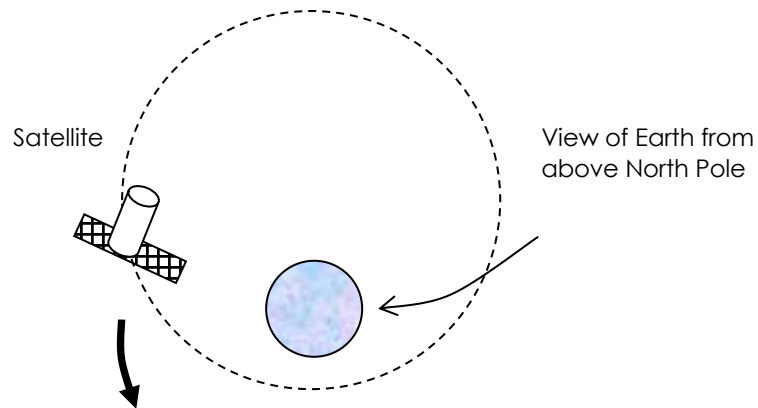
$$m_1 = \frac{m_2 \times r_2}{r_1}$$

m_1 = mass of planet 1 (kg) m_2 = mass of planet 2 (kg)

r_1 = distance of planet 1 to *barycentre* (m)

(3)

Question 4   (13 marks)

A satellite is in orbit around the equator of the Earth. It has a mass of 1495 kg and is at an altitude of 1.91×10^4 km above the Earth's surface.

Satellite

View of Earth from above North Pole

a) Calculate the **period** of this satellite and state your answer in hours.

(4)

b) Explain whether or not a satellite can be geostationary at this altitude.

(2)

c) Place **labelled** arrow(s) on the diagram to show the direction of the **net acceleration** of the satellite.

(1)

d) Give two examples of the uses of artificial satellites in everyday life.

(2)

The Earth is a natural satellite that orbits the Sun. (Assume a circular orbit for this question)

e) Calculate the orbital speed of the Earth as it goes around the Sun.

(3)

f) If the Sun was 90% of its current mass, describe how the orbital speed of the Earth would be affected if it remained at the same distance from Sun. *(A calculation is not required)*

(1)

Question 5   (13 marks)

The orbit of Venus lies between the Earth's orbit and the Sun. The radius of Venus is 6.05×10^6 m. The Magellan spacecraft was launched by NASA in 1995 for the purpose of radar mapping Venus. At one stage Magellan was put into a circular orbit of Venus at an altitude of 346 km. It took Magellan 94 minutes to complete this orbit. Magellan had a mass of 1035 kg.

a) Calculate the centripetal acceleration of the Magellan satellite in this orbit.

(3)

b) Calculate the mass of the planet Venus using the satellite data provided.

(3)

c) If the Magellan spacecraft was double the mass in this orbit explain how its orbital period would be affected.

(2)

d) There is a location between the Earth and the Sun where the net gravitational field strength due to the Earth and the Sun is zero. Calculate the distance from Earth to this location.

(5)

Question 6

A satellite provides information about the receding glaciers on the Earth's surface. It has a mass of 395 kg and is in a circular orbit of radius 1.45×10^4 km. By orbiting for 12 days it can map most of the Earth's glaciers.

(a)   Calculate the orbital speed of the satellite.   (3 marks)

b) At what **altitude** above the Earth is the satellite orbiting?   (3 marks)

c) List the force(s) that keep the satellite in its stable circular orbit.   (2 marks)

d)   On the diagram below draw one or more **labelled** arrows to show the direction of the force(s) on the satellite as it orbits the Earth.   (2 marks)
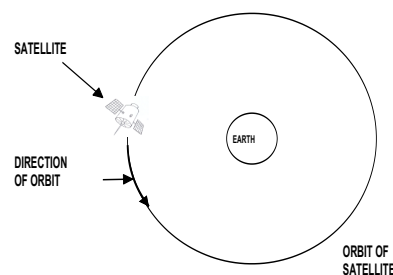
e) Would you expect this satellite to be in a geostationary orbit about the Earth? Explain your answer. (2 marks)

Question 7. (10 marks)

In your lifetime it is expected that there will be a manned mission to the planet Mars. One strategy is to launch the rocket from a base on the moon and that rocket will have a capsule that will be ejected and land on the surface of Mars. This is similar to the lunar missions 40 years ago. The capsule launches itself from the surface of Mars and reunites with the rocket. That is the plan.

(a) Why would they even consider a launch from the moon rather than Cape Canaveral in the USA? (1)

(b) Calculate the radius of Mars given the gravitational field strength on Mars is 3.73 m s-2 and its mass is 6.42 x 1023 kg. (3)

c) If the orbiting space craft will be at an altitude of 150km, what will be the time for one orbit around Mars? If you were unable to do part (b) assume a value of 4×10^6 as the radius of mars (4)

d) How many orbits will occur in one "earth day" of 24 hours (1)

PROJECTILE MOTION

Question 1 (13 marks)

A physics student observes a stone of mass 380 g being catapulted from the top of a cliff. The stone takes a time of 4.00 s to reach the ground. The stone is launched at 5.00 ms^{-1} at an angle of 20.0° below the horizontal. You may ignore air resistance for the calculations.

20° Initial launch speed is 5.00 m s^{-1}

Cliff   Height of
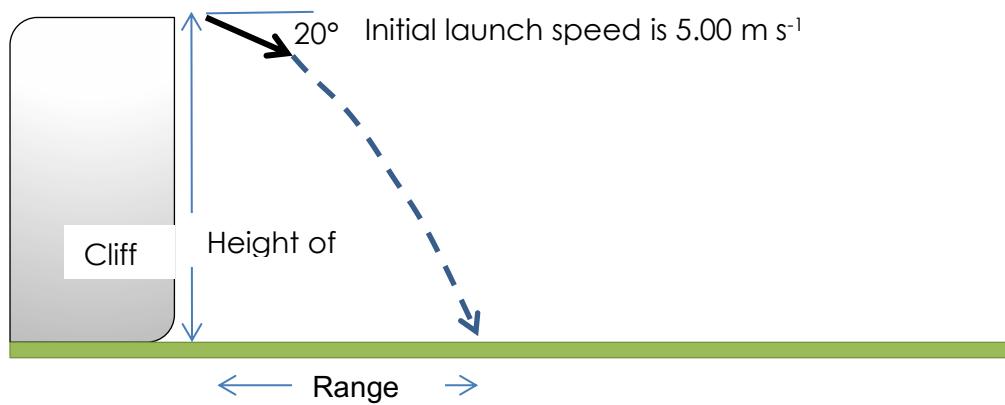
Range

a. Calculate the height of the cliff.

(3)

b. Calculate the horizontal range of the stone.

(3)

c. Calculate the kinetic energy of the stone after 3 seconds.

(4)

d. The final velocity of the stone is achieved as the stone reaches ground level. If the stone had been catapulted at the same launch speed but at an angle of 20° above the horizontal how would the magnitude of final velocity compare to a launch 20° below the horizontal. Circle a response and explain briefly.

(3)

final velocity greater   final velocity the same   final velocity less

Question 2   (13 marks)

A physics student observes a stone of mass 450 g being catapulted from the top of a cliff. The launch position at the top of the cliff is 6.00 m above ground level. The stone lands 20.0 m in front of the launch position. The initial launch speed u is at an angle of 40.0° to the horizontal. You may ignore air resistance for the calculations.
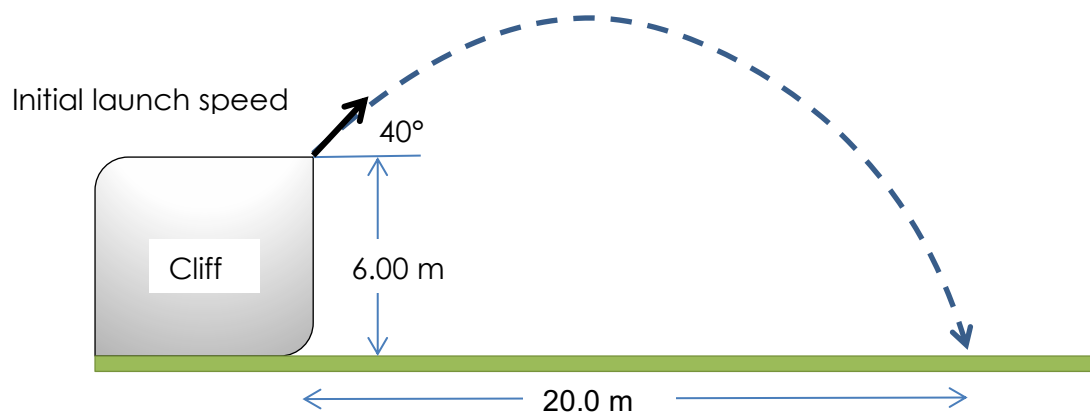
a. Calculate the initial launch speed **u** of the stone. You must show clear algebraic steps in your solution.

Hint: consider the flight time for both the horizontal and vertical components of motion.

(5)

b. Calculate the flight time of the stone. (If you were not able to solve part a), use a numerical value of 12.1 m s^{-1} for the initial launch speed **u**).

(3)

c. Calculate the minimum value of kinetic energy of the stone whilst in flight. (If you were not able to solve part a), use a numerical value of 12.1 m s^{-1} for the initial launch speed **u**).

(2)

d. Calculate the maximum height above ground level that the stone reaches on its flight path. (If you were not able to solve part a), use a numerical value of 12.1 m s^{-1} for the initial launch speed **u**).

(3)

Question 3   (12 marks)

A physics student observes a stone of mass 350 g being catapulted from the top of a cliff. The launch position at the top of the cliff is 15.0 m above ground level and it takes the stone a time of 5.00 seconds to reach the ground. The stone lands 88.0 m in front of the launch position. You may ignore air resistance for the calculations.
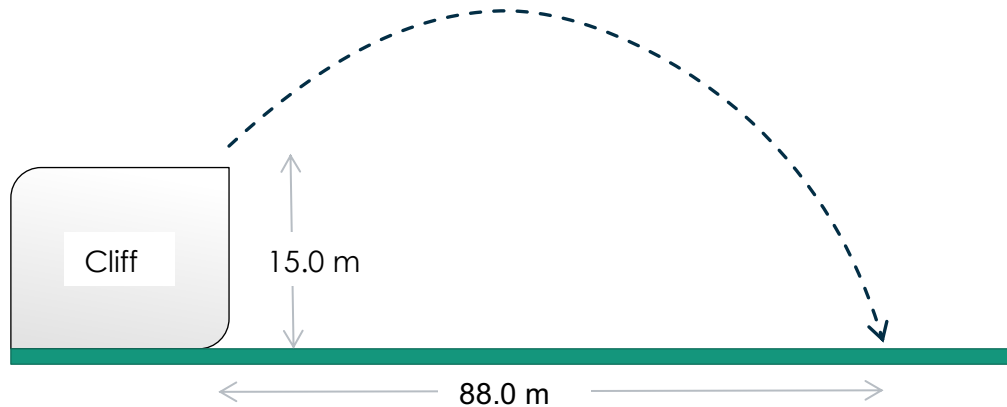
a) Calculate the vertical component of the velocity when the stone is launched.

(3)

b) Considering the kinetic energy of the stone along its flight path. Circle the best response for the following statement. The kinetic energy of the stone at maximum height is:

Maximum   50% of maximum   Zero   Minimum   Equal to all other
positions

(1)

c) Calculate the initial velocity of the stone.

(4)

d) Calculate the kinetic energy of the 350 g stone just before it hits the ground.

(4)

Question 4 (13 marks)

An eagle has captured a fish and is 14.7 m directly above the water when it releases the fish. The eagle is moving with a velocity of 5.20 m s⁻¹ at an angle of 36.6° above the horizontal when the fish is released. Ignore air resistance for calculations.

5.20 m s⁻¹

36.6°

This diagram is
NOT to scale

14.7 m
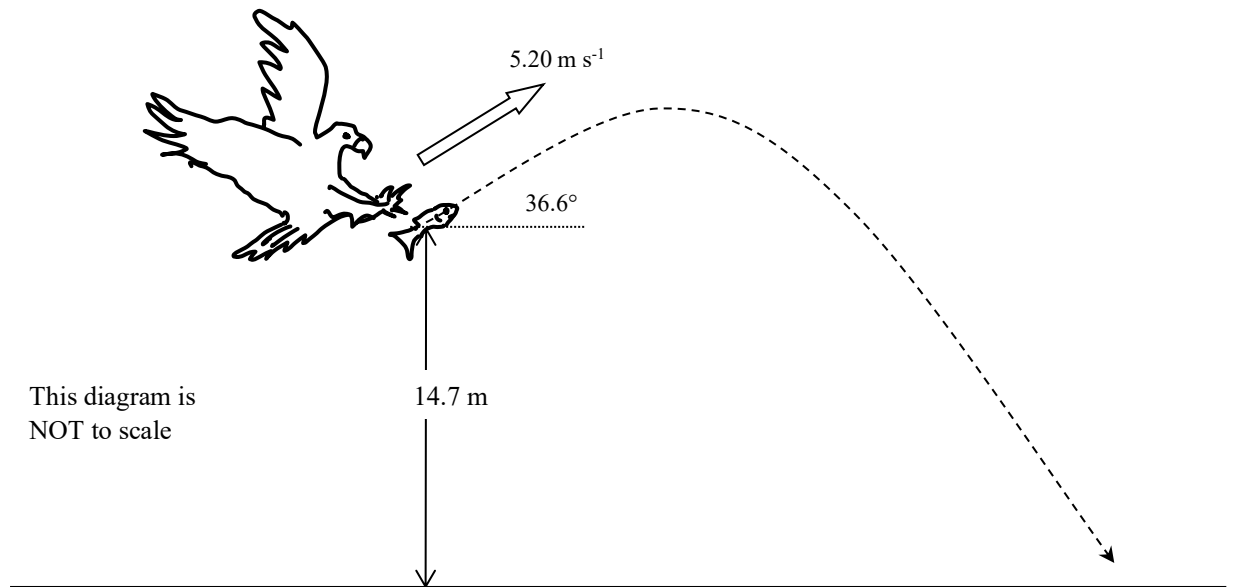
a) Calculate the time taken for the fish to reach the water.

(4)

b) Calculate the horizontal distance that the fish travels during its flight back to the water.

(3)

c) Calculate the maximum height above the water that the fish reaches during its flight.

(3)

If air resistance is taken into account then the flight path is altered.

d) Sketch the altered flight path onto the diagram.

(1)

e) Will the time of flight be longer or shorter when air resistance is taken into account? Discuss the factors that affect this.

(2)

Question 5 (12 marks)

A helicopter is required to drop emergency equipment to a group of walkers stranded in rugged bushland. A package is released from the helicopter at altitude (h) directly   above the group. The helicopter is moving with a velocity of 8 km h^{-1} at an angle of 40° above the horizontal when the package is released. The package lands on the ground 2.5 s after being released.
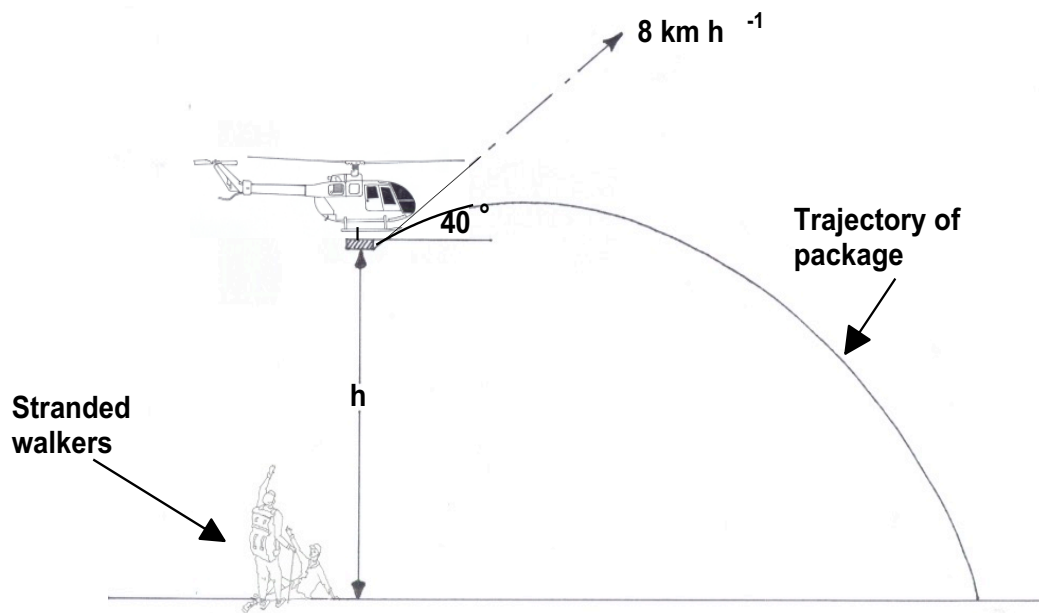
(a)   Calculate the value of h.   (4 marks)

(b)   If the helicopter continues to fly with its initial velocity, calculate the distance between the helicopter and the package at the instant the package hits the ground.   (4 marks)

(c)   On the axes below draw a graph that best represents the vertical speed of the   package as a function of time. Include actual values on the axes. Show   calculations that determine significant points on the graph.   (2 marks)
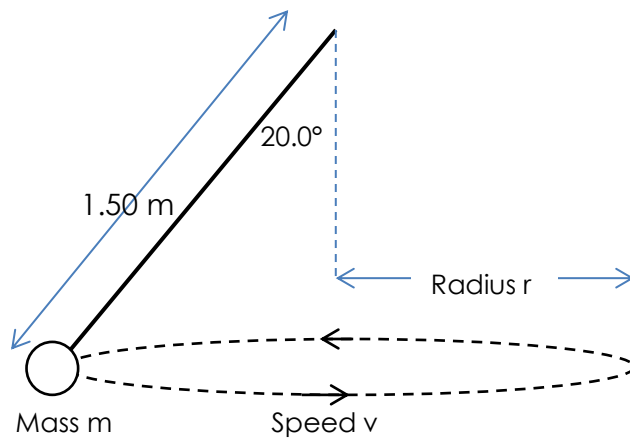
SPEED
m/s

time (s)
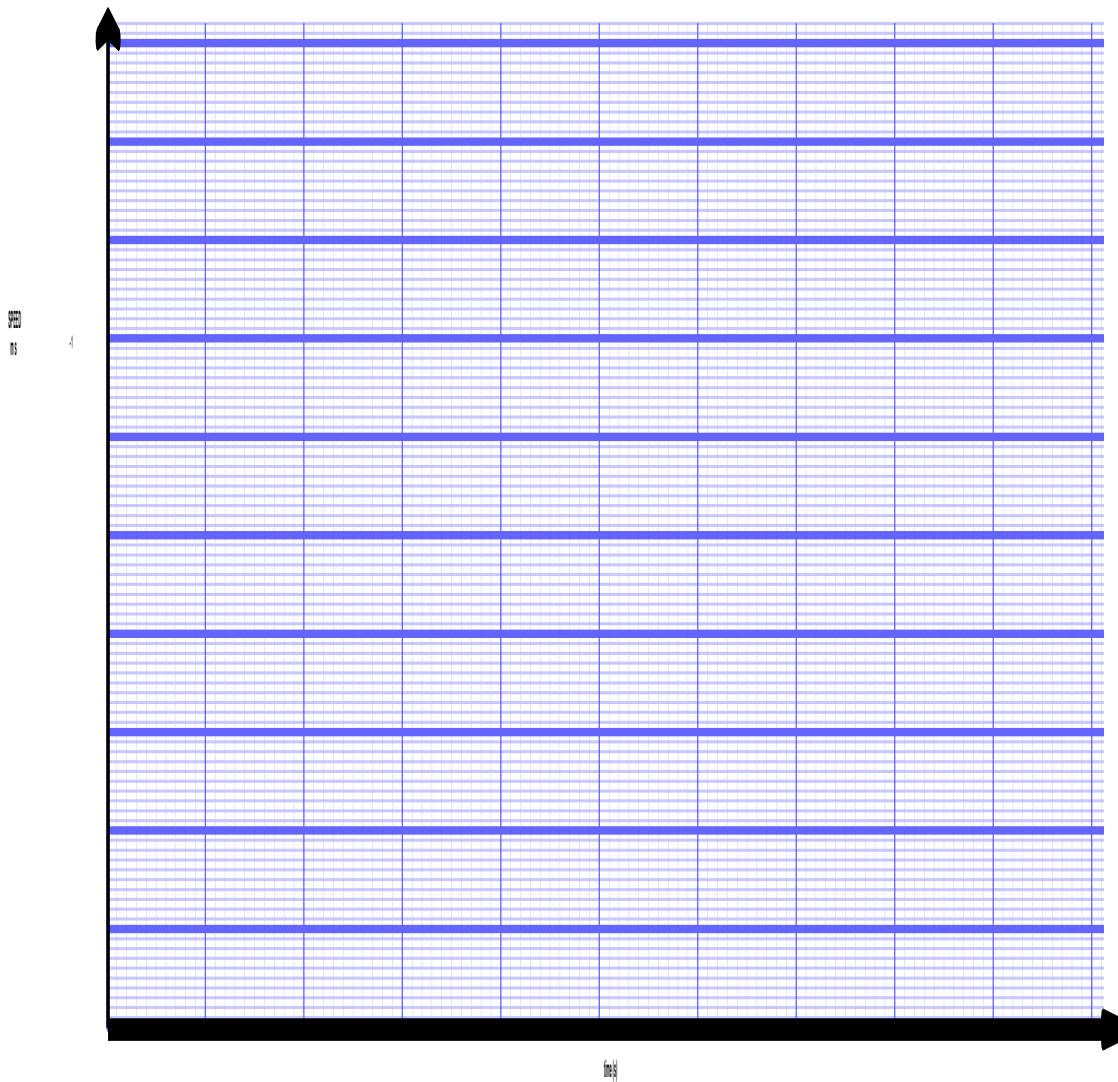
(d)If the helicopter was travelling **horizontally** at the same speed (8 km h^{-1}) and height (h) when it released the package, would you expect the package to land closer or further away from the group? Explain your answer. (2 marks)

CIRCULAR MOTION

Question 1

A ball of mass **m**, suspended from a ceiling moves along a horizontal circle of radius **r** at a constant speed **v**. The string connecting the mass to the ceiling makes an angle of 20.0° to the vertical. The string has a length of 1.50 metres.

Calculate the time taken for the ball to make one revolution.

20.0°

1.50 m

Radius r

Mass m   Speed v

(5)

Question 2

A roller coaster car of mass 800 kg is going over the apex of a circular section of track. The car has a speed of 6.00 m s⁻¹. Calculate the radius of the curve for the car to experience a normal reaction force of 4000 N from the track. You must refer to a vector diagram in your answer.
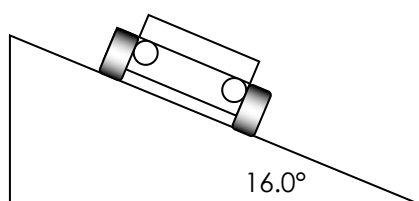
Vector diagram

Roller coaster car

Roller coaster track
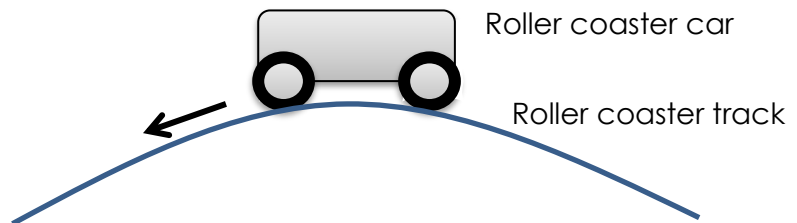
(4)

Question 3

A roller coaster car of mass 700 kg is upside down whilst doing a 'loop the loop'. The radius of the loop is 12.0 m. Calculate the speed required at the top of the loop for the car to experience a normal reaction force of 5000 N from the track. You must refer to a vector diagram in your answer.

Vector diagram

Roller coaster track

Roller coaster car
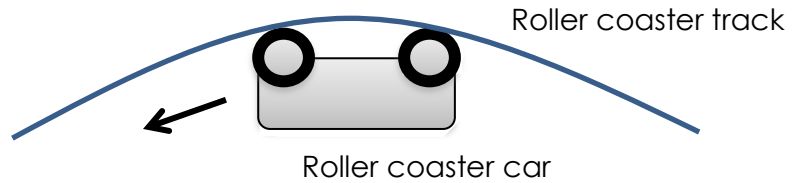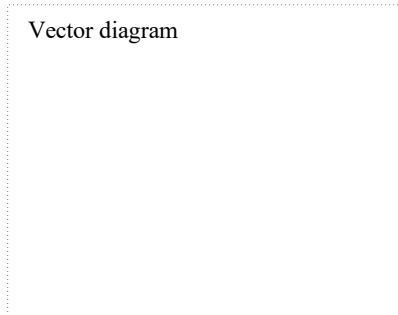
(4)

Question 4

By banking the curves of racetracks it is possible for vehicles to turn in a horizontal circle without relying on friction. For a car of mass 2100 kg the angle of banking is set at 16.0° above the horizontal. The car drives at a speed 24.0 m s^{-1} to maintain its height on the bank.

Vector diagram

16.0°

a) Draw a vector diagram in the space above showing the forces acting on the car and the sum of those forces.

(1)

b) Calculate the horizontal radius of the car's path.

(3)

c) The speed of the car increases to greater than 24.0 m s^{-1}. Explain what other change must occur if the magnitude of forces on your vector diagram remain the same on this frictionless track.

(2)

Question 5

A person is sitting on a swing that is moving through the arc of a circle. It has reached the lowest point and is moving at maximum speed. Explain with reference to a vector diagram how the person's apparent weight is different compared to being at rest on the swing.

Arc of swing
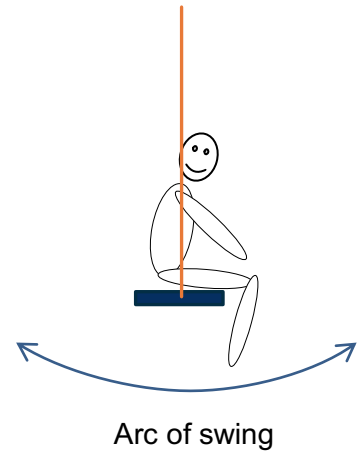
(4)

Question 6

A student is investigating the physics of the hammer throw event at the London Olympics. A hammer of mass 7.30 kg is describing uniform circular motion at a constant height. The length of the hammer is 1.21 m and the wire makes an angle of 77.2° with the vertical. Calculate the time taken for the hammer to make one revolution.

7.30 kg hamme

1.21 m

77.2°
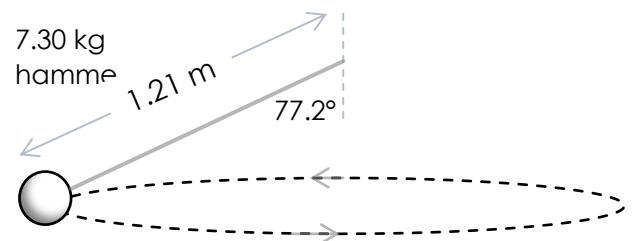
(5)

Question 7

By banking the curves of racetracks it is possible for vehicles to turn in a horizontal circle without relying on friction. For a car of mass 1 700 kg the angle of banking is set at 13.4° above the horizontal. The curve has a radius of 171 m and the car drives at a speed to maintain its height.

Vector diagram

13.4°
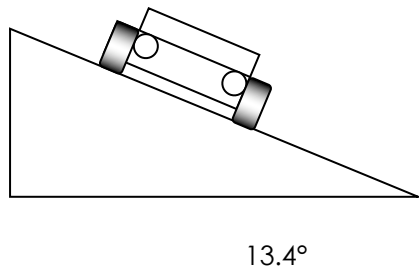
d) Draw a vector diagram showing the forces acting on the car and the sum of those forces in the space indicated above.
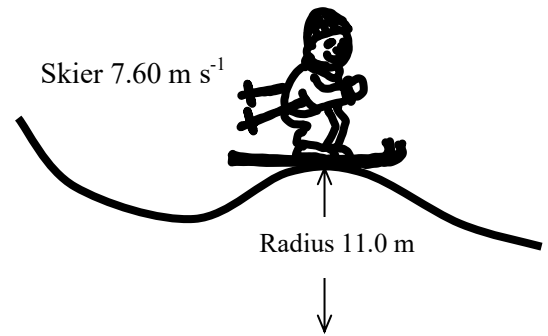
(1)

e) Calculate the centripetal force acting on the car.

(3)

Question 8

A 70 kg skier is on a frictionless slope. He follows a circular path of radius 11.0 m as he goes over a mound and has a speed of 7.60 m s^{-1} at the top of the circle.
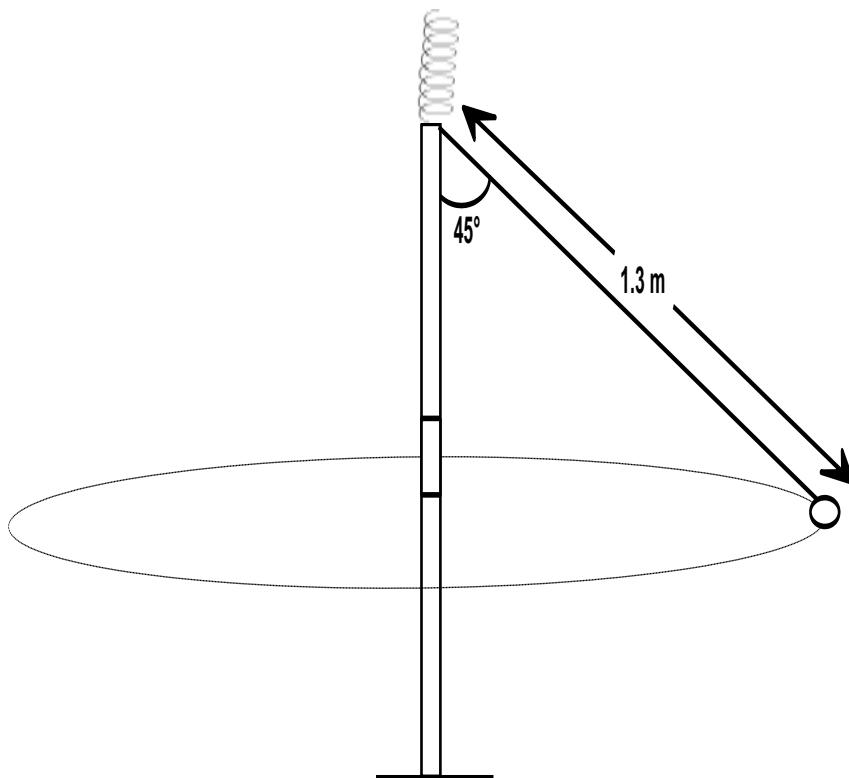
Skier 7.60 m s^{-1}

Radius 11.0 m

Calculate the normal reaction force he experiences from the mound at the top of the circle.

(4)

Question 9

During a game of totem tennis a ball of mass 60.0 g swings freely in a horizontal circular path. The string is 1.30 m long and is at an angle of 45° to the vertical as shown in the diagram.

45°

1.3 m

(a)   Calculate the radius of the ball's circular path.   (2 marks)
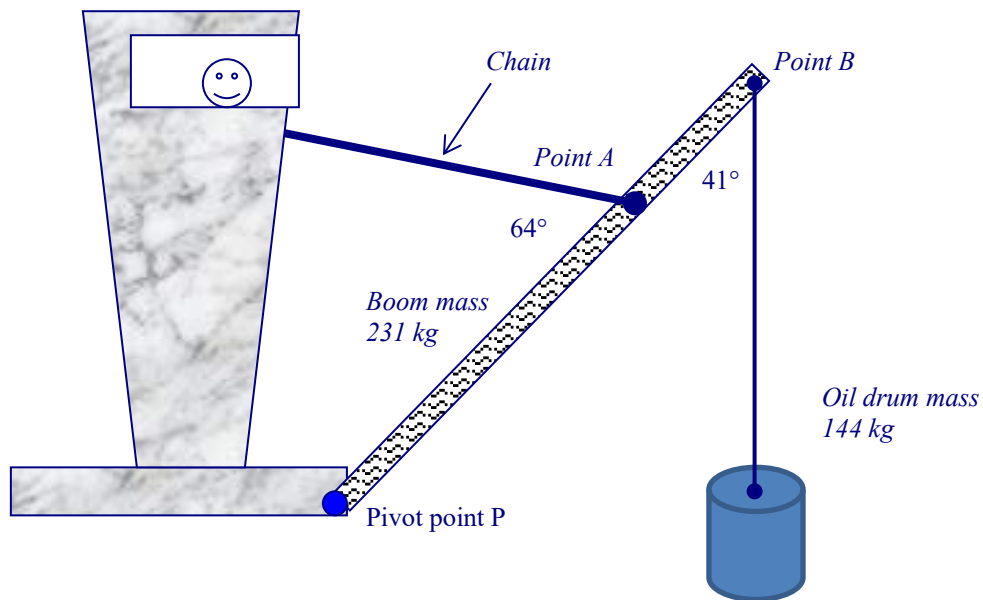
(b)   Calculate the net force acting on the ball   (3 marks)

TORQUE AND EQUILIBRIUM

Question 1   (9 marks)

A crane at Fremantle port is unloading an oil drum from a ship.

- The boom of the crane has a mass of 231 kg and is pivoted at point P.
- The oil drum of mass 144 kg is suspended from point B. Its rope makes an angle of 41° with the boom.
- A chain attached at point A is holding the boom in position. The distance from P to A is 3.80 m.
- The chain makes an angle of 64° with the boom.
- The boom has a length of 4.50 m from P to B with uniform mass distribution.

a. Demonstrate by calculation that the tension in the chain = 2.20 x 10³ N.

(4)

b. Calculate the magnitude of the **reaction force** acting on the boom from the pivot.

(3)

c. Calculate the direction of the **reaction force** acting on the boom from the pivot.

(2)

Question 2   (10 marks)

The 400 kg boom of a crane is pivoted at point A. The length of the uniform boom AC is 8.00 m. A crate of mass 700 kg is lifted by a rope attached at C. A flexible cable is attached at point B where the length AB is 6.00 m. The cable makes an angle of 22° with the boom. The rope lifting the crate makes an angle of 110° with the boom.
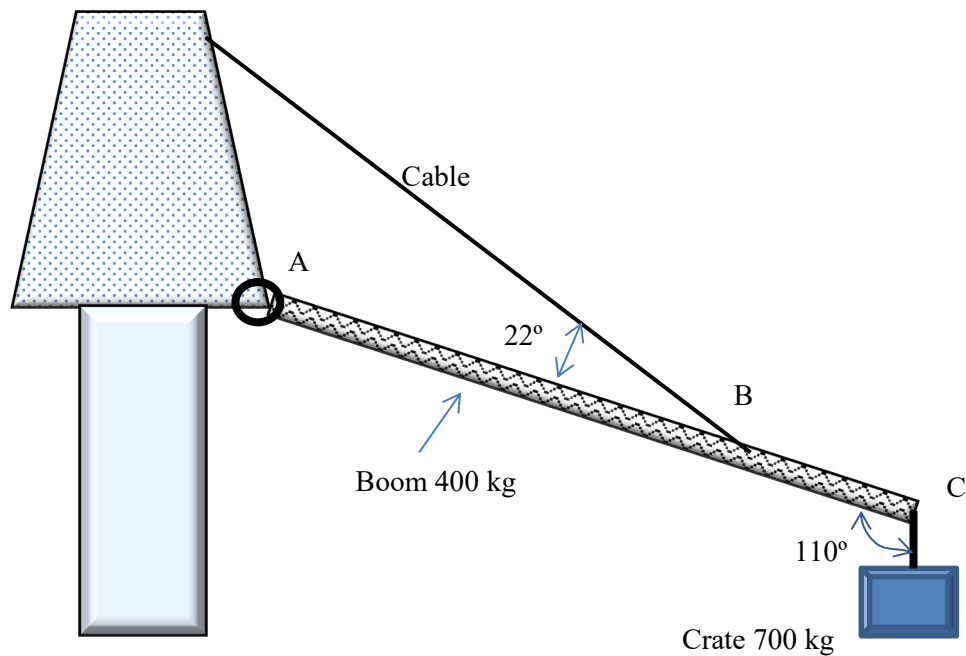
a. Demonstrate by calculation that the tension in the cable is 2.95 x 10⁴ N

(4)

b. Construct a vector diagram (approximately to scale) to show that $\Sigma F = 0$ when considering the weight of the boom, the weight of the crate, tension in the cable and reaction force from the pivot.

(1)

c. Calculate the magnitude of the reaction force from the pivot.

(3)

d. Calculate the direction of the reaction force relative to the vertical and show this angle on your vector diagram. (note that the reaction force acts below the horizontal)

(2)

Question 3

A rigid wooden plank of mass 2.5 kg is attached to a wall by a pivot and is supported by a rope in tension. A 3.5 kg bowling ball is suspended from the plank. The diagram is to scale. **Estimate** the tension in the rope. Express your answer to an appropriate number of significant figures.

Rope

Plank

Pivot

Bowling ball
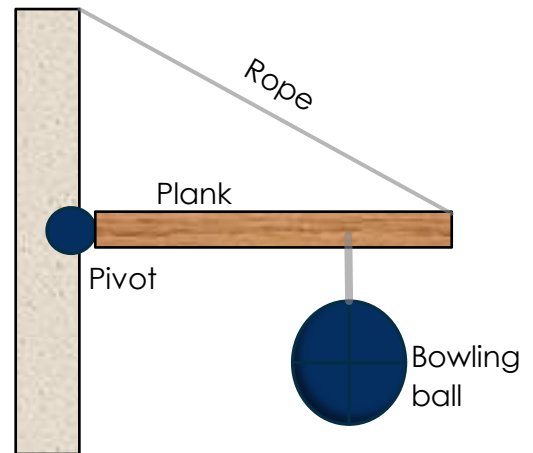
(4)

Question 4

A rigid boom of mass m is free to rotate about a frictionless pivot P. The boom is held in static equilibrium by a rope that is in tension. The boom is held in two different positions where the tension in position A is T_A and the tension in position B is T_B. The positions are shown in the diagram below.

T_A

T_B

position A
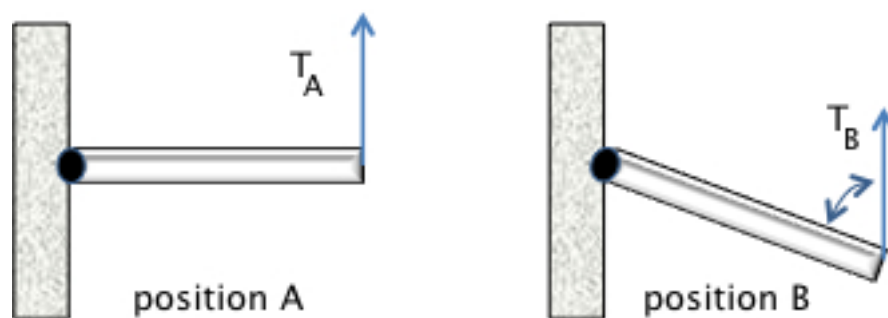
position B

a) When comparing the magnitude of tension in each position, circle the best response:

(1)

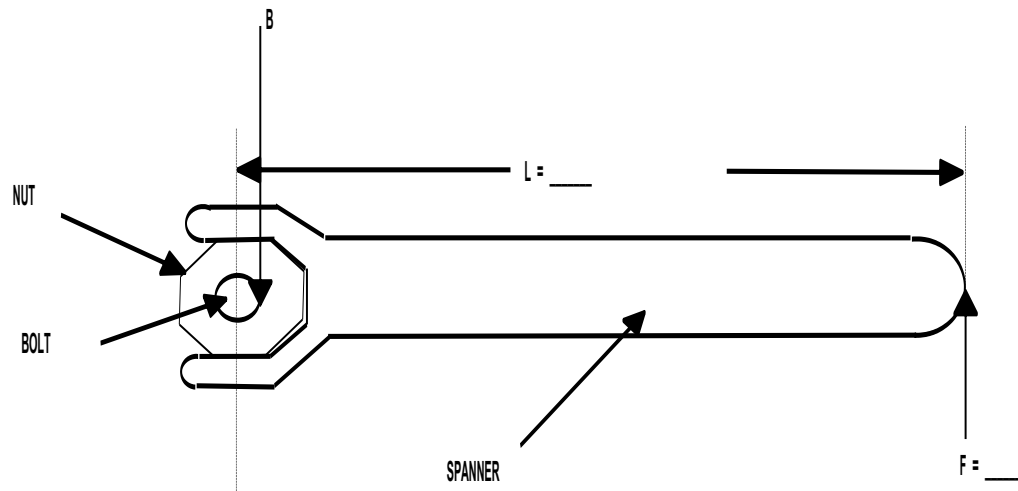$T_A = T_B$ $T_A > T_B$ $T_A < T_B$ Insufficient information for a response

b) Clearly explain your choice.

(3)

Question 5

A nut on a bolt on a bicycle requires a torque of 6 N m to just loosen it.

(a) Label the diagram below and estimate realistic values for the length (L) and force (F) that would just supply enough torque to loosen the nut. (4 marks)

B

NUT

BOLT

L : ___

SPANNER

F : ___

(b) ESTIMATE the binding force (B), between the nut and the bolt, which is just sufficient to stop the nut from coming loose. (2 marks)

B = _____