**COMET BAY COLLEGE**

**Physics Unit 3 - Task 4**

**Motion and Gravity Test 2**

**Name: SOLUTION Total Marks /53**

**Question 1:**

**Question 14 (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 initial launch speed u is at an angle of 20.0° below the horizontal. You may ignore air resistance for the calculations.

Height of cliff

Range

Cliff

20°

Initial launch speed u = 5.00 m s-1

1. Calculate the height of the cliff.

(3)

Let up be positive (or alternative defined reference frame)

u (vertical) = u.sin θ (down) = -(5 x sin 20) = -1.71 m s-1

t (flight) = 4.00 s a = -9.80 m s-1 

s = ut + ½ at2

s = (-1.71 x 4) – (4.9 x 42) 

s = -85.24 m

Height of cliff = 85.2 m 

1. Calculate the horizontal range of the stone.

(3)

u (horizontal) = u.cosθ (right) = -(5 x cos 20) = 4.6984631 m s-1 right

t (flight) = 4.00 s a = 0 

s = u (horizontal) x t

s = (4.6984631 x 4) 

s = 18.79385 m

s (horizontal) = 18.8 m right 

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

(4)

u (horizontal) = 4.6984631 m s-1 right t = 3.00 s

v (vertical) = u + at

v = -1.71 + (-9.80 x 3) = -31.11 m s-1 down 

speed after 3 seconds = 

KE = ½ m v2 = ½ x 0.38 x 31.46292= 188 J 

1. 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)



1(a) Any reasonable combination of length and force whose product is 6 N m. However the length of the spanner should not exceed say 0.25 m

1(b) A reasonable estimate of the radius of the bolt would be between 0.002 m and 0.004 m. Using these values a force of between 3000 N and 1500 N would represent the frictional force between the bolt and nut.

(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 = \_\_\_\_\_\_\_\_\_\_\_\_\_

1. A 700.0 kg roller coaster car at the Royal Show starts 40.0 m above the ground, goes down a dip in the track and just manages to roll over the next hill which is 33.0 m above ground level.
2. Calculate the amount of energy the car has lost? (2 marks)

3(a) m = 700 kg

original height = 40 m

negotiated height (h) = 33 m

original potential energy = mgh = 700 x 9.8 x 40 = 2.74 x 105 J

energy to negotiate next hill = mgh = 700 x 9.8 x 33 = 2.26 x 105 J

loss of energy = (2.74 - 2.2) x 105 = 4.8 x 104 J

3(b) The energy has not been “lost”. It has been converted into friction, heat and sound.

3(c) The maximum height above the ground the roller coaster car can achieve as it negotiates successive hills and dips is 40 m. As the only energy it commences with is potential energy this limits the vertical distance the car can travel. The 40 m height can only be achieved if the track is frictionless which is unlikely.

1. What has happened to this “lost” energy? (1 mark)

(c) Neglecting energy losses, what is the maximum height above the ground the roller coaster car can achieve as it negotiates successive hills and dips?

Explain your answer. (2 marks)

1. 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 x 104 km. By orbiting for 12 days it can map most of the Earth’s glaciers.
   1. Calculate the orbital speed of the satellite. (3 marks)

1(a) r = 1.45 x 107 m

ms = 395 kg

G = 6.67 x 10-11 N m2 kg-2

Me = 5.98 x 1024

v2 = GMe/r

v2 = (6.67 x 10-11) x (5.98 x 1024)/(1.45 x 107)

v2 = 27.508 x 106

v = 5.20 x 103 m s-1

1(b) re = 6.37 x 106 m

rs = 1.45 x 107 m

altitude = rs – re

altitude = (1.45 x 107) – (6.37 x 106)

the altitude of the satellite = 8.13 x 106 m

1(c) The force that keeps the satellite in orbit is the centripetal force that acts towards the centre of the orbit. This force is provided by the gravitational attraction between the Earth and satellite.

1(d)



1(e) The satellite would not be in a geostationary orbit. If it was it would remain in orbit above the same location on the Earth and would not be able to map most of the glaciers on Earth. For the mapping to be complete the satellite would be in an orbit other than geostationary.

* 1. At what **altitude** above the Earth is the satellite orbiting? (3 marks)
  2. List the force(s) that keep the satellite in its stable circular orbit. (2 marks)
  3. 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 5**

An iron ball of mass 220 kg is suspended from the end of a rigid steel girder.

Diagram is not drawn to scale.

Steel wire

Pivot point

1.60 m

50º

Girder mass 180 kg

Rigid upright

Iron ball

mass 220 kg

65º

Action force from weight

= 220 × 9.8

Weight

= 180 × 9.8

Reaction from pivot

Tension

The girder has a mass of 180 kg and a length of 2.40 m.

The girder is pivoted to a rigid upright.

A steel wire is attached 1.60 m along the girder. It holds it in equilibrium with angles between components as shown in the diagram.

1. Identify all the forces acting on the girder by drawing them on the diagram.

Identifies all 4 forces✓

(1)

1. Demonstrate by calculation that the tension in the steel wire is 5.39 × 103 N.

(3)

Take moments about pivot ΣM = 0 M = r.F.sin θ

Σacwm = Σcwm

1.60×T×sin 50 = (1.20×180×9.8×sin 65) + (2.4×220×9.8×sin 65)

correct lever arms ✓ recognises sin θ for all torques ✓

T = 6608.071 / (1.60 × sin 50) = 5391.39

T = 5.39 × 103 N ✓ (along the wire)

**Question 6**

Refer to the diagram and description in **Question 5**. If the tension in the steel wire is 5.39 × 103 N calculate the magnitude and direction of the reaction force from the pivot acting on the steel girder.

Combined action of weights down

(220 +180) × 9.8 N

3920 N

Tension

5.39 × 103 N

Reaction Force

65°

Φ

Φ

(4)

Consider that ΣF = 0

Correct vector diagram (or component analysis)✓

Solve for R by cosine rule (or by components)

R2 = T2 + W2 - 2.T.W.cos 65

R2 =(5.39×103)2+39202-2×5.39×103×3920×cos65

R = 5153.6 = 5.15 × 103 N ✓

Use sine rule to solve for angle Φ

R / sin 65 = 5390 / sin Φ ✓

sin Φ = (5390 × sin 65) / 5153.6 = 0.94788

Φ = sin-1(0.94788) = 71.4° - the angle that R makes to vertical ✓

Or identical solution by considering components

**Question 14 (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 × 104 km above the Earth’s surface.

Satellite

View of Earth from above North Pole

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

(4)

M = 5.98 🞩 1024 kg

r = altitude + rearth = 6.37 🞩 106 + 1.91 🞩 107 = 2.547 🞩 107 m ✓

v2 / r = GM / r2 (substituting v = 2πr / T)

r3 = (G.M.T2) / (4.π2)

T2 = (r3.4.π2)/ (G.M)

T2 = ((2.547 🞩 107)3.4.π2)/ (6.67 🞩 10-11 🞩 5.98 × 1024) ✓

T = 4.044 🞩 104 s ✓

T = 4.044 🞩 104­ / (60 × 60) = 11.2 hours ✓

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

(2)

No

The equation T2 = (r3.4.π2)/ (G.M) shows that the period of a satellite is fixed at a given radius of separation. The radius must increase to give a period of 24 hours. ✓ ✓

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

(1)

Towards centre of circle. ✓

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

(2)

Communications satellites to transmit telephone signals around the globe. ✓

GPS system for navigation.✓

Any 2 reasonable answers

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

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

(3)

M = 1.99 🞩 1030kg r = 1.50 🞩 1011 m ✓

v2 / r = GM / r2

v2 = GM / r

v2 = 6.67 🞩 10-11 🞩 1.99 🞩 1030 / 1.50 🞩 1011 ✓

v = 2.97 🞩 104 m s-1 ✓

Alternatively v = 2πr/T (T = 365.25 🞩 24 🞩 60 🞩 60)

1. 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)

Referring to previous equation v2 = GM / r

If mass of the sun M decreases then v also decreases. ✓

**Question 8**

Bowling ball

Pivot

Plank

Rope

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.

Let length of plank = 1.00 m = lever arm to rope

lever arm to ball = 0.750 m lever arm to plank CofM = 0.500 m

θrope = 30.0° ✓ (or other reasonable estimates)

θplank = θball = 90.0° moment = r.F.sin θ

Σacwm = Σcwm about pivot

rrope.Ftension.sin 30° = rball.Fball.sin 90° + rplank.Fplank.sin 90°

1\*Ftension\*0.5 = 0.75\*3.5\*9.8 + 0.50\*2.5\*9.8 ✓

Ftension = 75.95 ✓ = 76 N (appropriate sig figs ✓)

(4)

**Question 9**

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 TA and the tension in position B is TB. The positions are shown in the diagram below.

Position A

Position B

TA

TB

**P**

**P**

Boom

Boom

60°

90°

120°

1. When comparing the magnitude of tension in each position, circle the best response:

(1)

TA  = TB TA  > TB TA  < TB Insufficient information for a response

1. Clearly explain your choice.

(3)

Let boom length = l

Σacwm = Σcwm about pivot

Position A 0.5🞩l🞩mg🞩sin 90 = l🞩TA🞩sin 90 ✓

TA = 0.5🞩mg ✓

Position B 0.5🞩l🞩mg🞩sin 60 = l🞩TB🞩sin 120 (same method)

TB = 0.5🞩mg ✓

(Or acceptable alternative proof)

**Question 19 (13 marks)**

Venus is a planet whose orbit is between the Earth’s and the Sun. The radius of Venus is 6.05 🞩106 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.

1. Calculate the centripetal acceleration of the Magellan satellite in this orbit.

(3)

Orbital radius = 6.05 🞩 106 + 346 🞩 103 = 6.396 🞩 106 m

Orbital period = 94 🞩 60 = 5640 s

v = 2πr / T = (2π🞩 6.396 🞩 106) / 5640 = 7125.4 m/s ✓

acentripetal = v2 / r = 7125.42 / 6.396 🞩 106 ✓

acentripetal = 7.93798 = 7.94 m s-2 towards Venus ✓

(Alternatively a = 4π2r / T2 )

1. Calculate the mass of the planet Venus using the satellite data provided.

(3)

acentripetal = 7.93798 m s-2

Orbital radius = 6.05 🞩 106 + 346 🞩 103 = 6.396 🞩 106 m

Orbital period = 94 🞩 60 = 5640 s

acentripetal = v2 / r = gravitational field strength = GM / r2

7.93798 = G M / (6.396 🞩 106)2 ✓

M = (7.93798 🞩 (6.396 🞩 106)2)/(6.67 🞩 10-11) ✓

M = 4.87 🞩 1024 kg ✓

Alternatively

derive r3 = (G.M.T2 )/ 4π2

M = (r3🞩4π2) / (6.67 🞩 10-11 🞩 T2)

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

(2)

acentripetal = v2 / r = gravitational field strength = GM / r2

It can be shown that vsatellite  = √(G M / r) where M is the mass of the host planet. ✓

Therefore, the mass of the satellite has no effect on the period. ✓

1. 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)

Earth Sun distance = 1.50 🞩 1011 m

Let distance from Earth to this location = x

Then distance from Sun to this location = (1.50 🞩 1011 – x) ✓

Magnitude of gravitational field strength is equal at this location

GMsun / rsun 2= GMEarth / rEarth2 ✓ (concept)

✓

✓

x = 2.60 🞩 108 m from Earth ✓

**Question 16 (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 22º with the boom. The rope lifting the crate makes an angle of 110º with the boom.

Crate 700 kg

Boom 400 kg

Cable

A

B

C

22º

110º

1. Demonstrate by calculation that the tension in the cable is 2.95 x 104 N

(4)

ΣM = 0 Σacwm = Σcwm M = r.F.sinθ

AC = 8.00 m AB = 6.00 m θB = 22° θC = 110° ✓

Take moments from A

6🞩Ftension🞩sin 22° ✓

= 4 x 400 x 9.8 x sin 110° + 8 x 700 x 9.8 x sin 110° ✓

Ftension =

(4 x 400 x 9.8 x sin 110° + 8 x 700 x 9.8 x sin 110°)/(6 x sin22)

Ftension = 66304.711 / 2.24763956

Ftension = 29499.70 = 2.95 x 104 N ✓

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

(1)

Reaction Force

θ = 180 –(110+22) = 48°

Ftension = 29499.70 W = (700+400) x 9.8 = 10 780 N

48° ✓

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

(3)

θ = 180 –(110+22) = 48° ✓

By Cosine Rule

✓

R = 23682.58 = 2.37 🞩 104 N ✓



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

By Sine rule

✓

Φ = 67.77 or 112.23°

Must correspond to angle shown on diagram. ✓

(2)

**Question 18 (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 1025 kg, Planet Trebor has a mass of 5.44 x 1024 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).

Talus

Trebor

44 300 km

166 200 km

barycentre

New positions

1. Calculate the gravitational force of attraction between Talus and Trebor.

(3)

r = 44 300 000 + 166 200 000 = 210 500 000 m

M1 = 2.04 x 1025 kg M2 = 5.44 x 1024 Kg

1. Calculate the speed of Talus around the *barycentre.*

(3)



v = 602.2989 = 6.02 x 102 m/s

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

(2)

T = 2πr/v = 2🞩π🞩44 300 000 / 602.2989 ✓

T = 462 137.77 s = 462 137.77/(60🞩60) = 128 hours ✓

1. 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)

32 / 128 = ¼ of a revolution. ✓

Show on diagram ✓

1. 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.



m1 = mass of planet 1 (kg) m2 = mass of planet 2 (kg)

r1 = distance of planet 1 to *barycentre* (m)

r2 = distance of planet 2 to *barycentre* (m)

Common centripetal force F

substitute ✓

Common period T✓

Divide out common terms

✓

(3)

**Question 16 (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.

*Point A*

*Boom mass*

*231 kg*

*Chain*

41°

Pivot point P

64°

*Point B*

*Oil drum mass*

*144 kg*

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

(4)

Consider boom in static equilibrium, ΣM = 0

Select pivot at P and take moments

Σacwm = Σcwm Concept 

3.80xFTxsin 64  = (4.50x144x9.8xsin41) + (2.25x231x9.8xsin41) 

FT = 7507.9 / (3.80 x sin 64)

FT = 2198.23 = 2.20 x 103 N 

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

(3)

Weight = 3675 N

Tension= 2200 N

75°

Φ

Φ

Consider boom in static equilibrium, ΣF = 0

Construct vector diagram / solve by components (Concept)

θ = 180 –(41+64) = 75°

Combined weight = (231 + 144) x 9.8 = 3675 N down ✓

By Cosine Rule

✓

R = 3763 = 3.76 🞩 103 N ✓

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

(2)

By Sine rule

✓

Φ = 34.4° from vertical (or 55.6° above horizontal)

Must correspond to angle shown on diagram. ✓

A solution using components in vertical and horizontal is also possible.

**Question 18 (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.

1. Calculate the speed of Kepler-186f around its host star

(3)

Orbital radius = 0.391 x 1.50 x 1011 = 5.87 x 1010

Orbital period = 129.9 x 24 x 60 x 60 = 11 223 360 s 

v = 2πr / T = (2 x π x 5.87 x 1010) / 11 223 360 

v = 3.28 x 104 m s-1 

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

(4)

Orbital radius = 0.391 x 1.50 x 1011 = 5.87 x 1010

Orbital period = 129.9 x 24 x 60 x 60 = 11 223 360 s

v = 3.28 x 104 m s-1 

acentripetal = v2 / r = gravitational field strength = GM / r2

M = (v2 x r) / G ✓

M = ((3.28 x 104)2 x 5.87 x 1010) / (6.67 🞩 10-11) ✓

M = 9.48 🞩 1029 kg ✓

Alternatively

derive r3 = (G.M.T2 )/ 4π2

M = (r3🞩4π2) / (6.67 🞩 10-11 🞩 T2)

1. 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 how this high degree of uncertainty affects estimates for the mass of the host star.

(2)

The equations used to calculate the mass of the host star do not use the mass of the planet e.g. M = (r3🞩4π2) / (6.67 🞩 10-11 🞩 T2)

or M = (v2 x r) / G 

So this variation in mass for the planet has no effect on estimating the mass of the star 

1. 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.

Highest value of field strength when planet radius is minimum and mass is maximum. Lowest value when radius maximum and mass minimum (concept) 

g = GM/r2

r (min) = 1.11 – 0.14 = 0.97R m (max) = 3.77M

r (max) = 1.11 + 0.14 = 1.25R m (min) = 0.32M

gmaximum = G x 3.77x M / (0.97 x R)2 = 4.01g 

(gmaximum = 39.2 N kg-1if calculated)

gminimum = G x 0.32 x M / (1.25 x R)2 = 0.205g 

(gminimum = 2.00 N kg-1 if calculated)

(3)

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

(1)

151±18 parsecs

Relative uncertainty = 18/151 = 0.119 = 11.9%  (151 ±11.9%)

1. The SETI institute (Search for Extra-Terrestrial Intelligence) in California started to listen to radio emissions from Kepler-186f in April 2014. As yet, no signals attributable to intelligent life have been detected. If such a signal was detected in 2014 what would be the latest year in Earth history that the signal was transmitted from Kepler-186f?

(3)

Latest transmission = shortest distance = 151 -18 = 133 parsecs 

133 parsecs = 133 x 3.26 Light Years = 433.58 Light Years 

2014 – 433.58 = the Earth year 1580 

**Question 10**

The boom of a crane is lifting an iron ball.

* The boom has a mass of 190 kg distributed uniformly along its length of 6.00 m.
* An iron ball is suspended 4.00 m from the pivot point on the boom.
* A chain is attached 5.30 m from the pivot point and transmits a tension force of 3886 N.
* The chain makes an angle of 40° with the boom.
* The boom has been raised to 28° above the horizontal.

6.00 m

5.3 m

4.0 m

*Boom*

*Chain*

28°

40°

*Iron Ball*

Calculate that the mass of the iron ball.

(4)

Select base as pivot point and take moments such that ΣM = 0

Σcwm = Σacwm correct concept

(4x FB x sin 62) + (3 x 190 x 9.8 x sin 62) ✓ = (5.3 x 3886 x sin 40)✓

(4x FB x sin 62) = 13238.725 - 4932.1455

FB = 8306.58/(4 x sin 62) = 2351.946 🗸

m (ball) = 2351.946 /9.8 = 240 kg ✓