ALL SAINTS' COLLEGE

Ewing Avenue, Bull Creek, Western Australia

12 Physics ATAR Motion & Forces Test 2 March 2017

Time allowed: 50 minutes
Total marks available: 50
Show calculation answers to 3 significant figures

Student Name: ___________________________

1. In June 2017 the European Space Agency will launch the satellite Sentinel-5P. It will go into a low earth Sun Synchronous Orbit (SSO) at an altitude of 824 km. It will be used to monitor air pollution. Determine the gravitational field strength of the Earth at this altitude.

(3)

g = ? M = 5.97×10^{24} kg r = $6.37 \times 10^{6} + 824\,000 = 7.194 \times 10^{6}$ m ✓

$$g = \frac{GM}{r^2}$$

$$g = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{{7.194 \text{ x } 10^{6}}^{2}} \checkmark$$

g = 7.69 N kg^{-1} ✓

2. Use equations on your data sheet that provide a conceptual basis to derive the following equation. You must explain how the concepts are linked. You may **not** start with the equation for Kepler's 3rd Law:

(3)

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

For a satellite in circular motion around a host mass the centripetal force is provided by gravity and is the only force acting on the satellite.

$$F = \frac{m_1 v^2}{r} = \frac{G m_1 m_2}{r^2}$$ ✓ (Let m_2 = host mass M)

$$\frac{v^2}{r} = \frac{GM}{r^2} \qquad by\ substitution\ of\ v = \frac{2\pi r}{T} \checkmark$$

$$\frac{4\pi^2 r^2}{rT^2} = \frac{GM}{r^2}$$ Shows correct derivation ✓

3. Titan is one of 62 moons in orbit around the planet Saturn. Saturn has a mass of 5.68 x 10^{26} kg and a diameter of 116 464 km. The orbital radius of Titan is 1 221 870 km. The gravitational force of attraction between Titan and Saturn is 3.42 x 10^{21} N. From this information calculate the mass of Titan.

(3)

$$F = \frac{Gm_1m_2}{r^2}$$

r =1 221 870 000 ✓

$$3.42 \times 10^{21} = \frac{6.67 \times 10^{-11} \times 5.68 \times 10^{26} \times m\ (Titan)}{1221870000^2}$$ ✓

m = 1.34 x 10^{23} kg ✓

4. A satellite of mass 5 400 kg is in a circular orbit and moving with a speed of 2.20 km s^{-1} around the Earth's surface. Calculate the altitude of the satellite.

(3)

$\frac{v^2}{r} = \frac{GM}{r^2}$ by derivation $v = \sqrt{\frac{GM}{r}}$ and $r = \frac{GM}{v^2}$

v = 2200 m s^{-1} ✓

$$r = \frac{GM}{v^2}$$

$$r = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{2200^2} = 82\ 272\ 520$$ ✓

Altitude = r - r_{earth} = 82 272 520 - 6.37 x 10^6 m = 7.59 x 10^7 m ✓

5. Artificial satellites orbiting the Earth are used for many applications including communication, navigation, remote-sensing and research.

a) Describe the **difference** between a Polar Orbit and an Equatorial Orbit and give **one advantage** of a Polar Orbit. You may sketch in the area below to aid your explanation.

(2)

Equatorial orbits are around the Equator with COM Earth at centre of orbit vs Polar Orbit which orbit over N and S pole?✓
Advantage Polar – can track over all of surface of Earth as Earth rotates beneath it. ✓ (or other valid)

b) Give three specific features of a sun-synchronous orbit (SSO) that distinguish it from other orbit types.

(3)

Circular Polar Orbit (must be linked) ✓
Inclination and recession is set so that the plane of the orbit is always facing the Sun at the same angle (as the Earth goes through its yearly orbit around the Sun✓
When the SSO Satellite passes the Equator from one of the poles it will always does this at the same local (solar) time.✓
Any 3 good points

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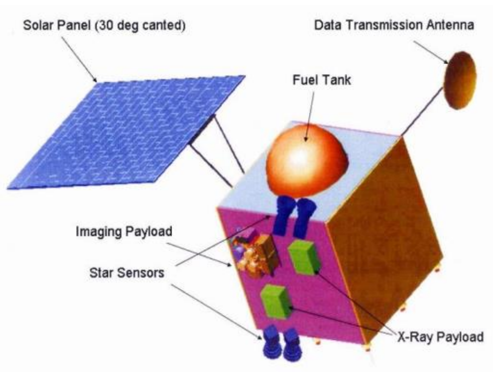
6. In 2008 the Indian Space agency successfully put the satellite Chandraayen-1 into a circular orbit around the moon. In 2009 all contact with the satellite was lost. In June 2016 NASA were able to locate the satellite again (they found it in exactly the same place where it was left in the first place!). The Chandraayen-1 satellite is a cube of side length 1.70 m with a mass of 675 kg and it is orbiting at 200 km above the lunar surface.



a) Determine the orbital period of Chandraayen-1 from this data.

(4)

R = 1.74 x 10^6 + 200 000 m = 1.94 x 10^6 ✓

M = 7.35 x 10^{22} kg ✓ T = ?

$$T^2 = \frac{4\pi^2}{GM} r^3$$

$$T^2 = \frac{4\pi^2 \times (1.94 \times 10^6)^{\ 3}}{G \times 7.35 \times 10^{22}}$$ ✓

T= 7.67 x10^3 s

$$T^2 = 58796537.78, \quad T = 7667.89\ \text{s}$$ ✓

b) Calculate the centripetal acceleration of Chandraayen-1 relative to the Moon.

(3)

$v = \frac{2\pi r}{T} = \frac{2\pi \times 1.94 \times 10^6}{7667.89}$ = 1589.665 m s^{-1} ✓ into

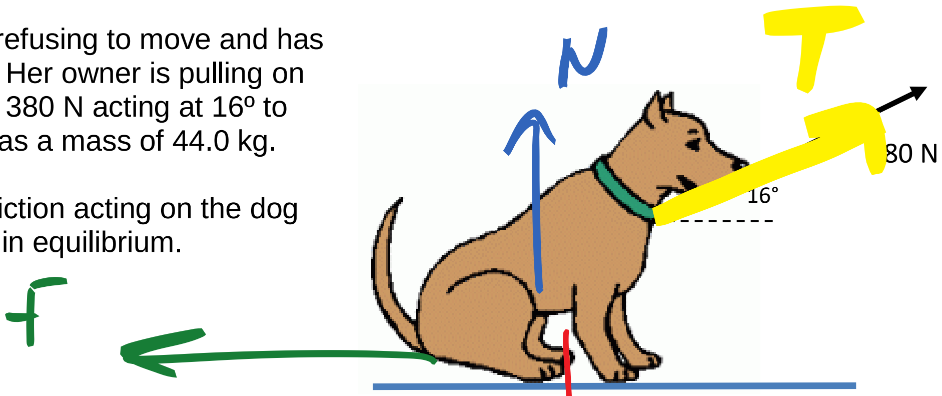
$$a = \frac{v^2}{r} = \frac{1589.665^2}{1.94 \times 10^6}$$ ✓

$$a = 1.30\ m\ s^{-2}$$ ✓

Or by using $g = \frac{GM}{r^2}$ and substituting units of m/s^2 for N/kg

Or by deriving $a = \frac{4\pi^2 r}{T^2}$

7. The dog in the picture is refusing to move and has become completely rigid. Her owner is pulling on the lead with a tension of 380 N acting at 16º to the horizontal. The dog has a mass of 44.0 kg.



a. Calculate the force of friction acting on the dog from the floor to keep it in equilibrium.

Horizontal force of friction matches horizontal component of tension

F = 380 x cos 16✓ = 365 N left ✓

(2)

b. Calculate the total normal reaction force acting from the ground onto the dog

(2)

F (up) = F (down)

$N + F_{vertical} = W$

$N = W - F_{vertical}$ = 44 x 9.8 - 380 x sin 16 ✓= 326 N up ✓

8. The photograph shows a Jar Opener that can be used by people who have a weak grip. This could be because of old age, a disability or an injury.

The right hand shown is gripping the Jar Opener. The left hand is holding a jar with a lid that is difficult to open.

Explain the physics principles that allow this device to be effective for a person with a weak grip

(2)

$T = r F \sin \theta$

The device extends the lever arm r compared to applying force at the lid. ✓ Therefore the force required F is reduced to apply the same given torque at the lid ✓

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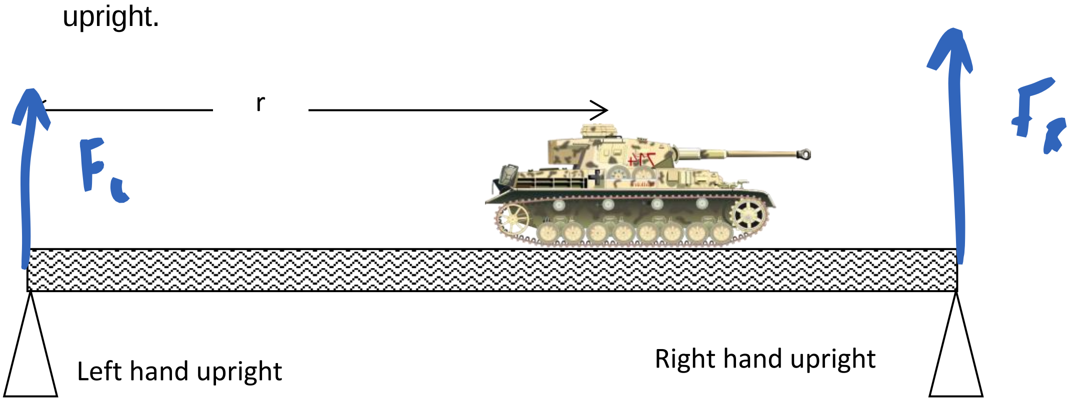
9. A 16 000 kg tank is crossing a 23.0 m long bridge supported at either end by vertical uprights. The bridge has a mass of 24 000 kg. The right hand upright is being compression with a force of 230 kN.

a. Calculate the distance r, that the centre of mass of the tank is placed from the left hand upright.

(3)



$T = r F \sin\theta$ Σacwm = Σcwm

Consider moments about point LH upright

Σcwm = Σacwm

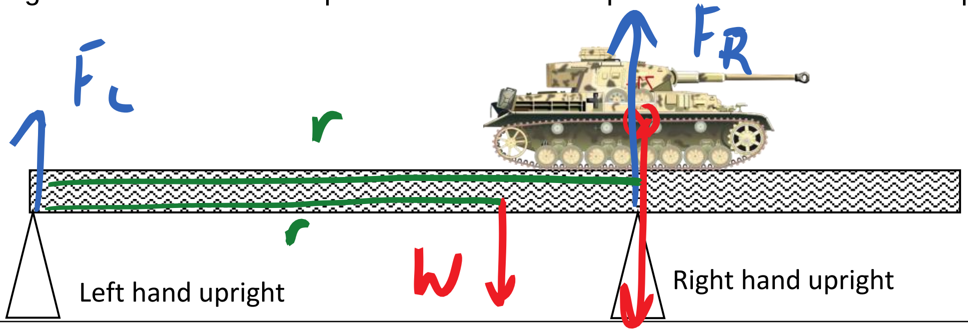
$r \times W_{tank} \times \sin 90 + r_{COM\ bridge} \times W_{bridge} \times \sin 90 = (r_{RH} \times F_{up} \times \sin 90)$

$(r \times 16\,000 \times 9.8) + 11.5 \times 24\,000 \times 9.8$ ✓= $23 \times 230\,000$✓

$r = 16.5$ m ✓

b. The right hand upright is moved to the position shown. Describe any changes (in terms of magnitude and direction) to the forces acting through both the left hand and right hand uprights. Provide a brief explanation for each response. No calculation is required.

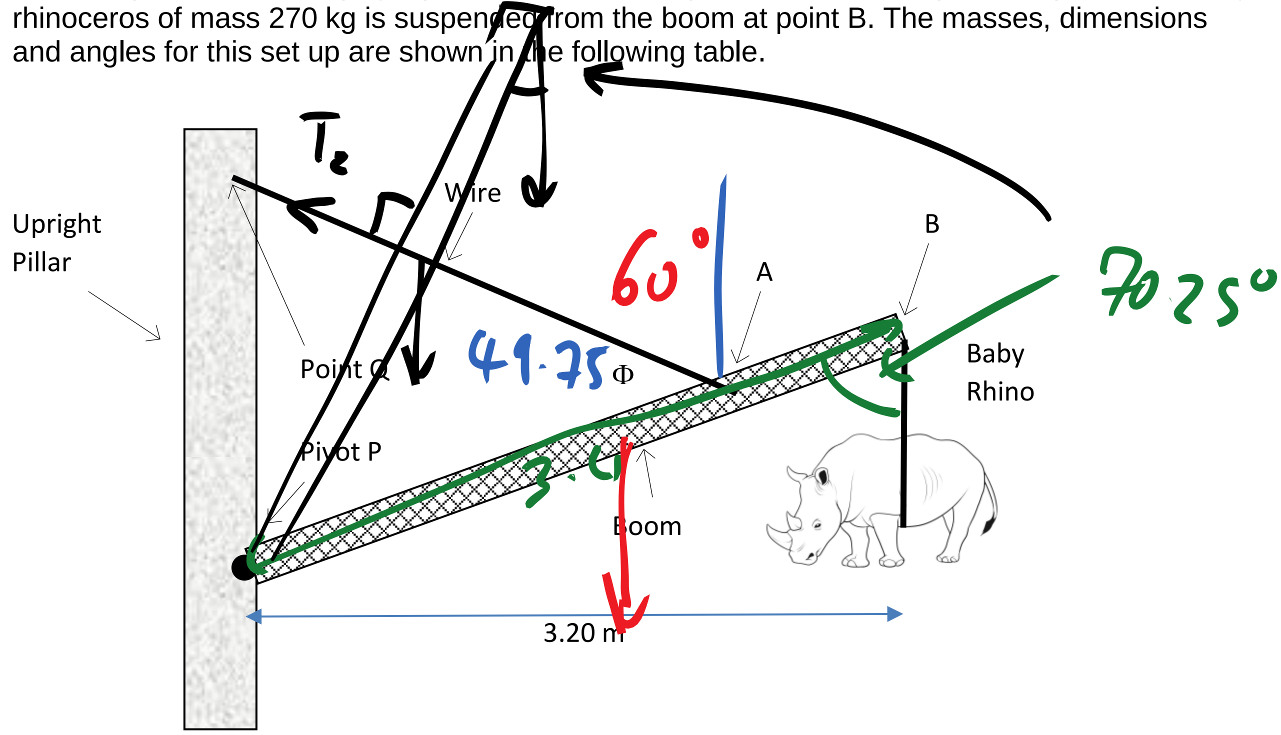
(3)



Consider moments from the left upright. The lever arm to COM of bridge and the tank are the same. Therefore CW moments are the same. The ACW moment needs to maintain rotational equilibrium but the Lever arm to RH upright has decreased, so force from RH upright has to increase. ✓ ✓

ΣF (up) = ΣF (down)
Weight forces down have stayed constant. Force from RH upright has increased. So to compensate, force up from LH upright is reduced. ✓
Acceptable alternative reasoning also allowed

10. Consider the forces acting on the boom of a crane. The wire that lifts the crane connects between point Q on the upright pillar to the boom at point A. The boom pivots at point P. A baby rhinoceros of mass 270 kg is suspended from the boom at point B. The masses, dimensions and angles for this set up are shown in the following table.



Mass of boom	120 kg
Mass of Baby Rhino	270 kg
Angle Φ	49.75°
Length of boom PB	3.40 m
Horizontal length from P to centre of mass of the Rhino	3.20 m
Length PA	2.60 m
Tension	?
Reaction force at P	?

a) Calculate the **tension** in the wire between Q and A.

(4)

$T = r\,F \sin\theta$ $\quad \Sigma acwm = \Sigma cwm$

Consider moments about point P acting on the boom

$\Sigma acwm = \Sigma cwm$

$2.6 \times F_{tension} \times \sin 49.75$ ✓ $= (1.6 \times 120 \times 9.8 \times \sin 90)$ ✓

$+ (3.20 \times 270 \times 9.8 \times \sin 90)$ ✓

$F_{tension} = 5215\text{ N} = 5.22 \times 10^3\text{ N}$ ✓

This demonstrates the $r.\sin\theta = r(\text{perpendicular})$

E.g. $3.4 \times \sin 70.25 = 3.2$

Therefore: CW moment for rhino can be calculated in 2 ways

$3.4 \times (270 \times 9.8)\ \sin 70.25 = 3.2 \times (270 \times 9.8) \times \sin 90$

FINAL QUESTION ON BACK PAGE

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b) Calculate the magnitude and direction of the reaction force acting on the boom at the pivot P. If you could not solve for part a) or are unsure of your answer then use a tension value of 5215 N.

(5)

Sum of weights = (120 + 270) x 9.8 = 3822 N $F_{tension}$ = 5215 N

Angle θ between Rhino rope and boom = $\sin^{-1}(3.2/3.4)$ = 70.25

Therefore angle between W and T = 180 – (49.75 +70.25) = 60° ✓

With reference to vector diagram ΣF on boom = 0

By cosine rule

$R^2 = W^2 + T^2 - 2WT \cos 70$

$R^2 = 3822^2 + 5215^2 - (2 * 3822 * 5215 * \cos 60)$ ✓

R = 4676.77 N = 4.68×10^3 N ✓

By sine rule

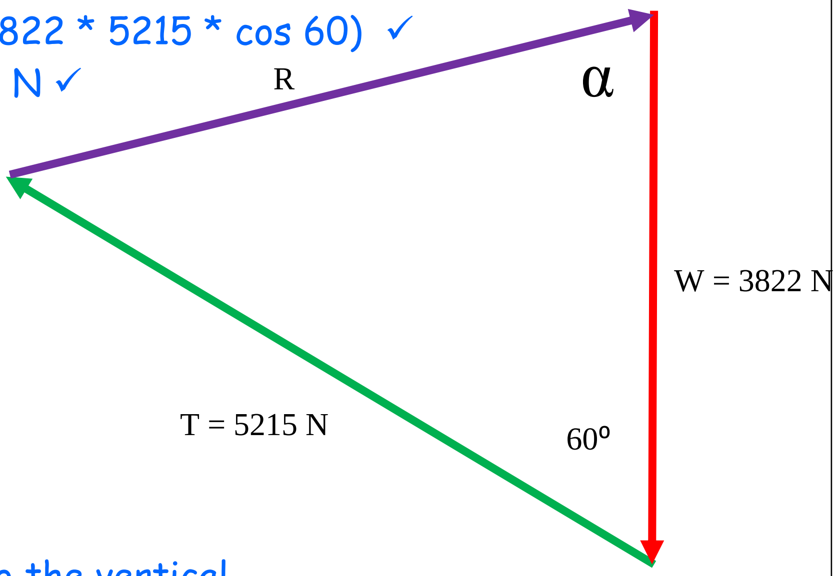
$$\frac{R}{\sin 60} = \frac{T}{\sin \alpha}$$

$$\sin \alpha = \frac{T \sin 60}{R}$$

$$\sin \alpha = \frac{5215 \sin 60}{4676.77}$$ ✓

α = 74.9° ✓

R = 4.68×10^3 N at 74.9° to the vertical



The boom is raised by shortening the length of wire between the upright pillar and location A. When this happens angle Φ can change to become 90°

i. What happens to the magnitude of the tension T in this case? *(circle a response below)*

(1)

increases [✓ decreases] stays the same not enough information given

ii. Explain **why** this occurs.

(2)

Decreases ✓
the CW torques are reduced because angle between weights and their lever arms from pivots decreases✓, torque from tension required for equilibrium is therefore less, so tension required is less (also angle 90 means ACW torque is most effective) ✓

iii. **Explain** the likely change to the *direction* of the reaction force R as angle Φ becomes 90°

(2)

There is less tension and less of a component acting left, therefore the component of the reaction force acting right is decreased, the reaction force will be more upright. ✓ ✓ Can compare vector diagrams before & after.