MEGA LECTURE

AQA, Edexcel, OCR

A Level

A Level Physics

Mechanics: Equilibrium And Moments (Answers)

Name:

M M E

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Total Marks: /30

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1. Leo, an 80 Kg climber, is attached to a cliff by two 1.5 m lengths of rope. To stabilise him, these are attached to the rock such that Leo and the two pieces of rope lie in a vertical plane. One piece of rope is on Leo's left and one is on his right; both are at an angle θ to the horizontal.

Total for Question 1: 8

(a) Draw a free-body diagram for the climber. Mark on your diagram the tension in the ropes (T), the climber's weight (W) and the angle between each rope and the horizontal (θ). [1]

> **Solution:** A 'Y' shape, with the single 'leg' representing the climber's weight (mg) and each 'arm' representing the tension (T) in a rope. The angles between the horizontal and the 'arms' are both θ.

For each of the following values of θ, calculate the tension that the rope must be able to withstand if Joe is not to fall.

(b) $\theta = 90$ [1]

> **Solution:** 392 N

(c) $\theta = 60$ [1]

> **Solution:** 453 N

(d) $\theta = 30$ [1]

> **Solution:** 785 N

(e) By calculating several more intermediate points, plot a graph showing the variation of the tension in a single rope (T) with the angle (θ), for values of θ from 0-90°. [3]

> **Solution:** Asymptotic to infinity at low values of θ. Decreasing to $W/2$ at 90°.

(f) Leo thinks that it would be sensible to avoid exerting a force greater than his own weight onto each strand of rope. Using your graph, approximately what value of θ should he not exceed? [1]

> **Solution:** Leo should avoid angles of θ greater than *exactly* $30°$.

2. Mirja is pulling her 50 kg dinghy up a smooth, sloped beach with the help of her father, Niila. Mirja pulls on her rope with a force of F_m N at an angle θ_m away from the line of greatest slope whilst Niila pulls on his with a force of F_n N at an angle θ_n on the other side of the line. The slope of the beach is $10°$.

Total for Question 2: 9

(a) Draw free-body diagrams for the dinghy from each of the following directions:

i. In a vertical plane showing the boat's weight (W), the normal reaction (R) and the combined tug of both people (F). [1]

> **Solution:** 3 arrows: one upslope labelled F, one downwards labelled W and one perpendicular to the slope labelled R. No friction force as the slope is smooth.

ii. In the plane of the slope, showing the component of the weight acting downslope (W_{slope}), and the pulls from Niila and Mirja (F_n and F_m, respectively). [1]

> **Solution:** 3 arrows: one downslope labelled W_{slope}, and two in approximately NW and NE directions labelled F_n and F_m (either way around).

(b) For $\theta_m = 20$ and $\theta_n = 10$, express W_{slope} in terms of F_n and F_m when the boat is stationary. [2]

> **Solution:** $W_{slope} = F_n cos10 + F_m cos20$

(c) Calculate the minimum force Mirja and Niila must each exert to make upward progress. To do this [5]
you will need to balance forces in two perpendicular directions in the plane of the slope.

Solution: $F_m = 29.6$ N

$F_n = 58.3$ N

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3. A mill-wheel is turned using two donkeys, Marguerite and Daisy. The donkeys push on either end of a beam that goes through the mill-wheel, as shown below. Each can push with a force of 1000 N.

Total for Question 3: 4
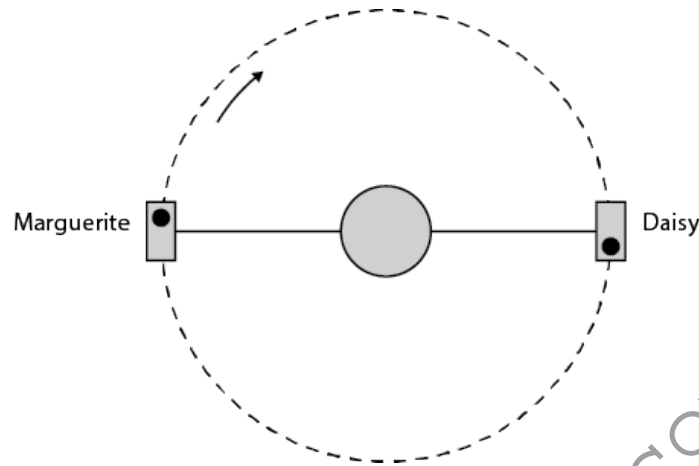
(a) State the two requirements for a body to be in total equilibrium. [2]

> **Solution:** Zero net moment *and* zero resultant force.

(b) From rest, the wheel requires a torque of 20000 Nm to overcome the static friction. What must be the minimum radius of the circle traced out by Marguerite and Daisy in order for them to be able to grind the corn? [2]

> **Solution:** 10 m

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4. Olivia is using a 90° crowbar to extract a large nail from a piece of wood, as is shown schematically below. The nail is embedded such that a vertically resolved force of x N, or more, is required to remove it.

Total for Question 4: 4
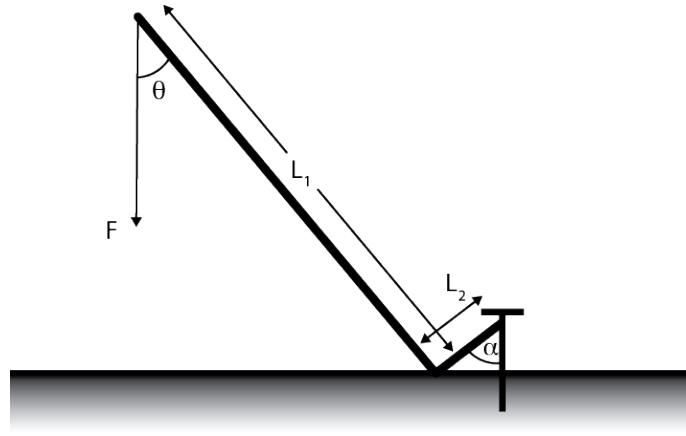
(a) By considering the moments abut the pivot point, express x in terms of the force applied (F), the lengths of the crowbar arms (L_1 and L_2) and the angles (θ and α). [3]

Solution: $x < \frac{FL_1 \sin\theta}{L_2 \sin\alpha}$

(b) To reduce the effort required, should Olivia try to minimise the angle θ or not? If not, what should she do? [1]

Solution: No - she should pull at 90°.

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5. A child is stood on a ladder placed against the smooth wall of the house.

Total for Question 5: 5

(a) Draw a free-body diagram for the ladder. [3]

> **Solution:** 5 forces should be marked on:
> W - the weight of the ladder, acting downwards.
> R_w - wall's reaction force, acting away from wall
> R_f - floor's reaction force, acting upwards
> F - frictional force on the ladder's base, acting towards the wall
> R_c - child's contact force, acting downwards
> (NB: the child's weight is not drawn because it is a free-body diagram *for the ladder*. R_c is of equal magnitude and direction though.)

(b) Could this equilibrium persist if the floor were to lose its rough surface? If not, why not? Explain in the context of the balance/imbalance of the forces. [2]

> **Solution:** No.
> The reaction of the wall is balanced by the friction; without it the system would be destabilised.