A-LEVEL MATHS (EDEXCEL 9MA0) · MECHANICS YEAR 2 · CHAPTER 4: MOMENTS · A* EXAM PRACTICE

Hints online, answers free with an account:
mathswariz.uk/worksheets/a-level-mechanics-year-2-chapter-4-a-star/

# Moments: A* questions

78 marks

Date


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## X A* exam questions

A to A*

Extended Edexcel-style questions. Show every step. The hints are at the end of the sheet. Use one at a time.

**X1** The unit vectors $\mathbf{i}$ and $\mathbf{j}$ are perpendicular and lie in the plane of the forces, with $\mathbf{i}$ to the right and $\mathbf{j}$ up. Distances are in metres and forces in newtons. Three forces act on a rigid body: $\mathbf{F}_1 = (3\mathbf{i} + 2\mathbf{j})$ at the point with position vector $\mathbf{i}$, $\mathbf{F}_2 = (-\mathbf{i} + 4\mathbf{j})$ at the point with position vector $2\mathbf{i} + 3\mathbf{j}$, and $\mathbf{F}_3 = (2\mathbf{i} - \mathbf{j})$ at the point with position vector $-\mathbf{i} + 2\mathbf{j}$, all relative to the origin $O$.

**(a)** Find the resultant moment of the three forces about $O$, stating its sense. [3 marks]

Answer .....

**(b)** The point $P$ has position vector $x\mathbf{i} + y\mathbf{j}$. Show that the resultant moment of the three forces about $P$ is $(10 - 5x + 4y)\ \mathrm{N\ m}$ anticlockwise. [3 marks]

Answer .....



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**(c)** Find the equation of the line of points about which the resultant moment is zero. Explain why this line has the same gradient as the resultant force. [3 marks]

**(d)** A fourth force $\mathbf{G}$ is added so that the four forces are in equilibrium. Find $\mathbf{G}$ and the point where its line of action meets the $x$-axis. [3 marks]

Answer .....

**Total for X1: 12 marks**


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**X2** A non-uniform rod $AB$ has length $4a$ and weight $W$. Its centre of mass is $G$, where $AG = a$. The rod hangs in equilibrium in a horizontal position, held by two light strings attached at $A$ and $B$. The string at $A$ makes an angle $\alpha$ with the vertical and the string at $B$ makes an angle $\beta$ with the vertical, with the strings on opposite sides of the vertical lines through $A$ and $B$, as shown. The strings and the rod lie in one vertical plane.

**(a)** Show that $\tan\beta = 3\tan\alpha$. [6 marks]





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**(b)** Given that $\alpha = 30^\circ$, find $\beta$ and the tension in each string, giving the tensions as exact multiples of $W$. [4 marks]

Answer .....

**(c)** A particle of weight $W$ is now attached to the rod at the point $P$. The rod still hangs horizontally with the string at $A$ at $30^\circ$ to the vertical, and the string at $B$ is now at $45^\circ$ to the vertical. Show that $AP = (4\sqrt{3} - 5)a$. [6 marks]

**Total for X2: 16 marks**


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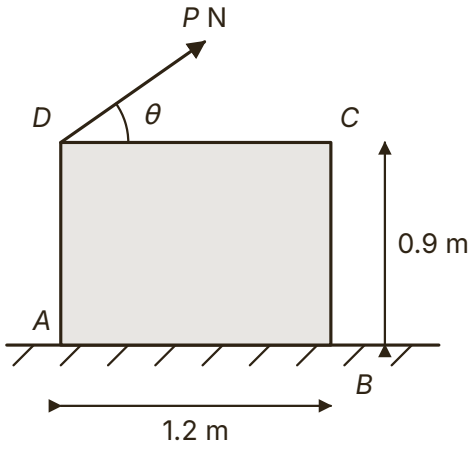
**X3** A crate is modelled as a uniform rectangular lamina $ABCD$ with $AB = 1.2\ \text{m}$ and $BC = 0.9\ \text{m}$, and weight $400\ \text{N}$. It stands in a vertical plane with $AB$ on rough horizontal ground, as shown. A rope is attached at $D$ and pulls with a force of $P\ \text{N}$ at an angle $\theta$ above the horizontal, towards the side of $B$, where $0° \leq \theta \leq 90°$. The crate does not slide. Find the least value of $P$ that makes the crate start to tip about $B$, and the value of $\theta$ at which it acts. The rope can pull with a force of at most $200\ \text{N}$. Find the range of values of $\theta$ for which the crate can be tipped about $B$. [10 marks]




Answer Least $P = \ldots$ at $\theta = \ldots$ ; range $\ldots$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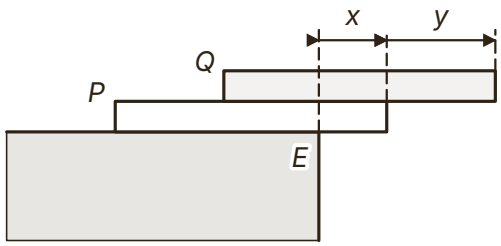
**X4** Two identical uniform planks $P$ and $Q$ each have length $2a$ and weight $W$. Plank $P$ lies on a horizontal table, at right angles to the straight edge $E$ of the table, with a length $x$ of $P$ beyond the edge. Plank $Q$ lies on top of $P$, parallel to it, with a length $y$ of $Q$ beyond the end of $P$, as shown. The planks are modelled as rods.

**(a)** Explain why the greatest possible value of $y$ is $a$. [2 marks]



not to scale

**(b)** Given that $y = a$, find the greatest possible value of $x$, and hence the greatest distance that the far end of $Q$ can reach beyond the edge $E$. [4 marks]

Answer .....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**(c)** A particle of weight $kW$, where $k > 0$, is now fixed to $Q$ at its far end. The planks are placed to make the far end of $Q$ as far beyond the edge $E$ as possible. Find this distance in terms of $a$ and $k$. [5 marks]

Answer .....

**Total for X4: 11 marks**


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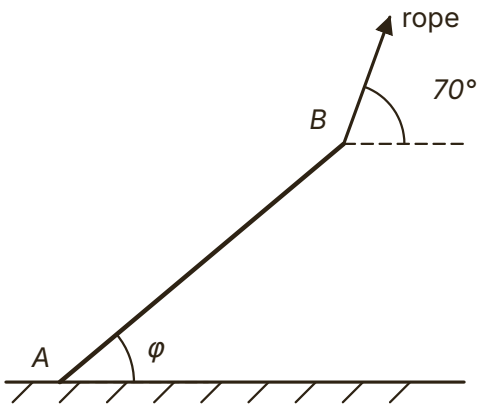
**X5** A uniform pole $AB$ has length $6\ \mathrm{m}$ and weight $W$. The end $A$ rests on rough horizontal ground. The pole is held in equilibrium at an angle $\varphi$ to the horizontal by a light rope attached at $B$. The rope makes an angle of $70^\circ$ with the horizontal, as shown, where $\varphi < 70^\circ$, and the pole and the rope lie in one vertical plane. Show that the tension in the rope is $\dfrac{W\cos\varphi}{2\sin(70^\circ-\varphi)}$, and find the greatest value of $\varphi$ for which the pole can be held in this way. [9 marks]




Answer Greatest $\varphi = \ldots$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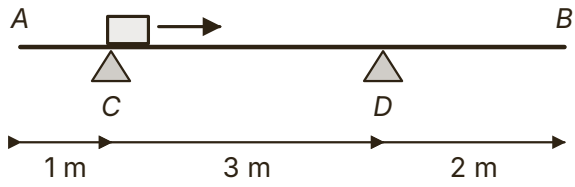
**X6** A uniform plank $AB$ has length $6\ \text{m}$ and mass $30\ \text{kg}$. It rests horizontally on supports at $C$ and $D$, where $AC = 1\ \text{m}$ and $AD = 4\ \text{m}$. A toy truck of mass $25\ \text{kg}$ is at rest on the plank at $C$. At time $t = 0$ the truck starts to move along the plank towards $B$. At time $t$ seconds its acceleration is $0.4t\ \text{m s}^{-2}$. The truck is modelled as a particle and the supports are rough enough to stop the plank sliding.

**(a)** Show that the plank is about to tip when the truck is $5.2\ \text{m}$ from $A$. [3 marks]




**(b)** Find the time at which the plank is about to tip. [4 marks]

Answer .....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**(c)** Find the speed of the truck at this time. [2 marks]

Answer .....

**(d)** The truck is in fact $0.4\ \text{m}$ long, with its centre of mass at its middle, and its front end starts at $C$. Find the time at which the plank is about to tip in this refined model. [2 marks]

Answer .....

**Total for X6: 11 marks**

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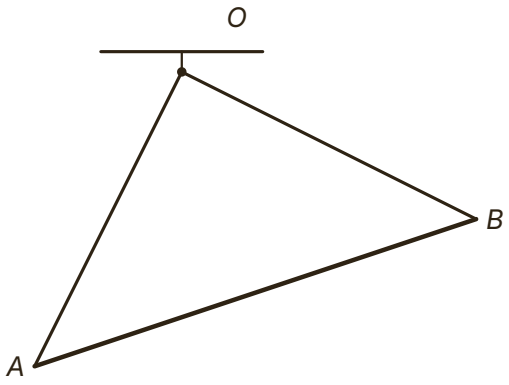
**X7** A non-uniform rod $AB$ has length $6a$ and weight $W$. Its centre of mass $G$ is such that $AG = 2a$. The ends $A$ and $B$ are attached to two light inextensible strings $OA$ and $OB$ of equal length, whose other ends are tied to a fixed point $O$. Angle $AOB = 90°$. The rod hangs in equilibrium, as shown.

**(a)** Explain why $G$ is vertically below $O$. [2 marks]





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**(b)** Show that the rod makes an angle $\arctan \frac{1}{3}$ with the horizontal. [3 marks]

**(c)** Find the tension in each string, giving your answers as exact multiples of $W$. [4 marks]

Answer .....

**Total for X7: 9 marks**


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## F How did it go?

Colour one circle on each line.

| | Not yet | Nearly | Yes |
|---|---|---|---|
| I can find the moment of a force given as a vector about any point, and the line of action of a resultant. | ○ | ○ | ○ |
| I can use moments and resolving for a rigid body held by forces at angles, and decide when a stack of planks tips. | ○ | ○ | ○ |
| I can use R sin(θ + α) and double angle formulae to find the least force or a range of angles. | ○ | ○ | ○ |
| I can decide when a body is about to tip and which reaction is zero. | ○ | ○ | ○ |


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# Hints

Use one hint at a time. Cover the ones below it with a sheet of paper.

**X1**

**Hint 1** The moment about the origin of $X\mathbf{i} + Y\mathbf{j}$ acting at $(x, y)$ is $xY - yX$, anticlockwise positive.

**Hint 2** About $P$, replace $x_k$ by $x_k - x$ and $y_k$ by $y_k - y$. The terms in $x$ and $y$ collect into the components of the resultant force.

**Hint 3** For equilibrium both the resultant force and the resultant moment must be zero. A force at $(c, 0)$ has moment $c \times (\text{its } \mathbf{j} \text{ component})$ about $O$.

**X2**

**Hint 1** Take moments about $A$ and about $B$. Only the vertical part of each tension has a moment about the other end of the rod.

**Hint 2** The horizontal parts of the two tensions must balance. Divide to compare $T\sin$ with $T\cos$.

**Hint 3** In (c) the moments about $B$ include the particle at distance $4a - p$. Rationalise the denominator at the end.

**X3**

**Hint 1** About to tip about $B$: the only ground reaction is at $B$, so take moments about $B$.

**Hint 2** Split the pull at $D$ into horizontal and vertical parts and find the distance of each from $B$.

**Hint 3** Write the combination of $\sin\theta$ and $\cos\theta$ as $R\sin(\theta + \alpha)$. Its greatest value gives the least force.

**X4**

**Hint 1** $Q$ can tip about the end of $P$. When it is about to tip, where must its centre of mass be?

**Hint 2** When $Q$ is about to tip, everything resting on $P$ presses on it at the end of $P$. Then take moments for $P$ about the table edge $E$.

**Hint 3** In (c), take moments for $Q$ about the end of $P$ first, with the particle at the far end of $Q$; then use the total force on the end of $P$.


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**X5**

**Hint 1** Take moments about $A$. The distance you need is the perpendicular distance from $A$ to the rope.

**Hint 2** Resolve vertically to find the normal reaction at $A$. What must be true of it while $A$ is on the ground?

**Hint 3** Expand $\sin(70^\circ - \varphi)$ and rearrange the inequality into one about $\tan\varphi$.

**X6**

**Hint 1** A load moving towards $B$ makes the plank tip about $D$. Which reaction is zero then?

**Hint 2** Integrate the acceleration to get the velocity and then the distance moved. The truck starts at rest.

**Hint 3** In (d), the point that must reach $5.2\ \mathrm{m}$ from $A$ is the centre of mass of the truck, not its front.

**X7**

**Hint 1** Each tension acts along its string. What is the moment of a force about a point on its line of action?

**Hint 2** Let $M$ be the midpoint of $AB$. In an isosceles right-angled triangle, $OM$ is perpendicular to $AB$ and equal to half of $AB$.

**Hint 3** The two strings are perpendicular, so the distance from $B$ to the line $OA$ is the length $OB$. Use the horizontal distance from $B$ to $G$ for the weight.


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