

Moments, levers and Gears

Mark Scheme



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1. Moments, levers, and gears are simple mechanical systems that allow us to transmit forces and multiply their turning effects.

For each of the following questions **circle** the letter of the correct answer.

- a) The figure below shows a steel beam. A crane cable provides an upward force of 200 N to keep the beam in equilibrium.

What is the weight of the steel beam?

A – is the only correct answer.	1 mark
	Total: 1 mark

- b) The figure below shows a force being applied to a lever to lift a heavy weight that a teacher is trying to lift.

Which change would the teacher need to make to lift the heavy weight with a smaller force?

D – is the only correct answer.	1 mark
	Total: 1 mark

- c) The figure below shows three uniform beams X, Y, and Z. Each beam is perfectly balanced on a pivot at its centre. Two downward forces are applied to each beam as shown.

Which of the beams will rotate anticlockwise?

B – is the only correct answer.	1 mark
	Total: 1 mark

- d) The diagram shows a simple gear train. Gear A is the driving gear, and it is turned clockwise by a motor.

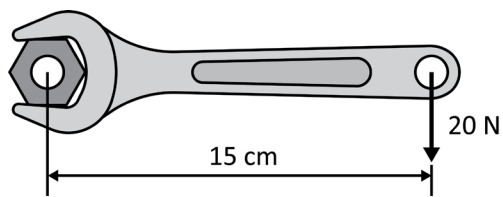
Which statement correctly describes the motion and turning effect of the larger driven gear (Gear B)?

C – is the only correct answer.	1 mark
	Total: 1 mark

(Total for Question 1 is 4 marks)

2. For each of the scenarios below calculate the moment of the force.

a) Calculate the moment of the force applied to the spanner.



Moment = force $\times$ distance

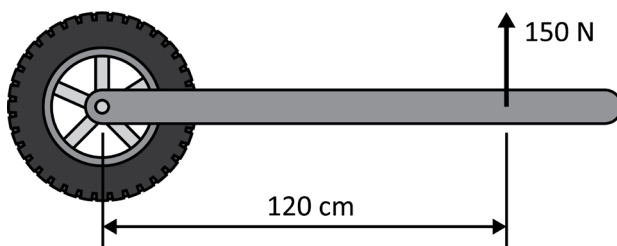
$$\text{Moment} = 20 \times 0.15$$

$$\text{Moment} = \mathbf{3}$$

Unit: **N/m**

Award 1 mark for the correct moment and 1 for the correct unit.

b) Calculate the moment of the force applied to lift the wheelbarrow.



Moment = force $\times$ distance

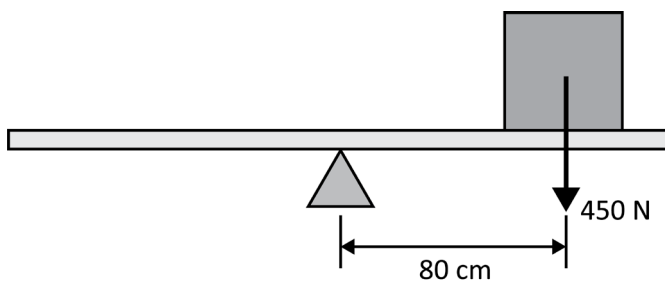
$$\text{Moment} = 150 \times 1.20$$

$$\text{Moment} = \mathbf{180}$$

Unit: **N/m**

Award 1 mark for the correct moment and 1 for the correct unit.

c) Calculate the moment caused by the box resting on the see-saw.



Moment = force $\times$ distance

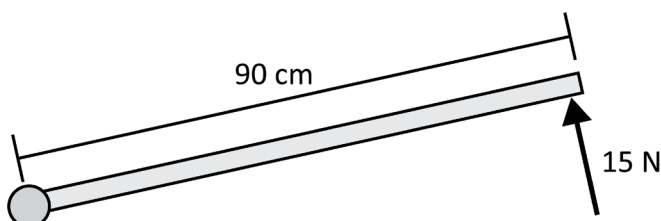
$$\text{Moment} = 450 \times 0.80$$

$$\text{Moment} = \mathbf{360}$$

Unit: **N/m**

Award 1 mark for the correct moment and 1 for the correct unit.

d) Calculate the moment of the force pushing the door open in **Diagram D**.



Moment = force $\times$ distance

$$\text{Moment} = 15 \times 0.90$$

$$\text{Moment} = \mathbf{13.5}$$

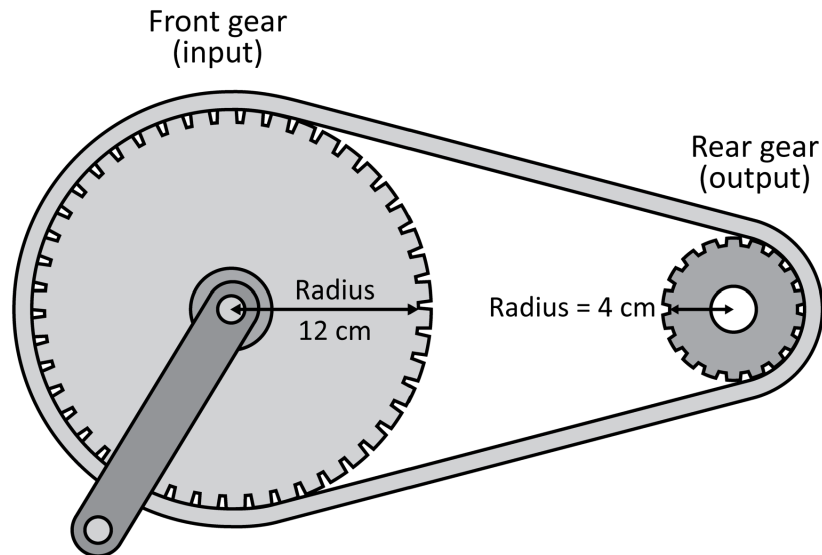
Unit: **N/m**

Award 1 mark for the correct moment and 1 for the correct unit.

(Total for Question 2 is 8 marks)

3. A cyclist is pedalling a bicycle.

The diagram shows the gear system connecting the pedals to the rear wheel.



- a) The cyclist applies a downward force to the pedal. This creates an input moment of 45 Nm on the front gear. The radius of the front gear is 12 cm.

Calculate the force pulling on the bicycle chain.

Moment = force $\times$ distance	1 mark
$45 = F \times 0.12$	1 mark
$F = 45 \div 0.12$ Force = 375 N	1 mark
	Total: 3 marks

- b) The force from the chain pulls on the rear gear, which has a radius of 4 cm.

Calculate the output moment (turning effect) on the rear gear.

$M = 375 \times 0.04$	1 mark
Moment = 15 (Nm)	1 mark
	Total: 2 marks

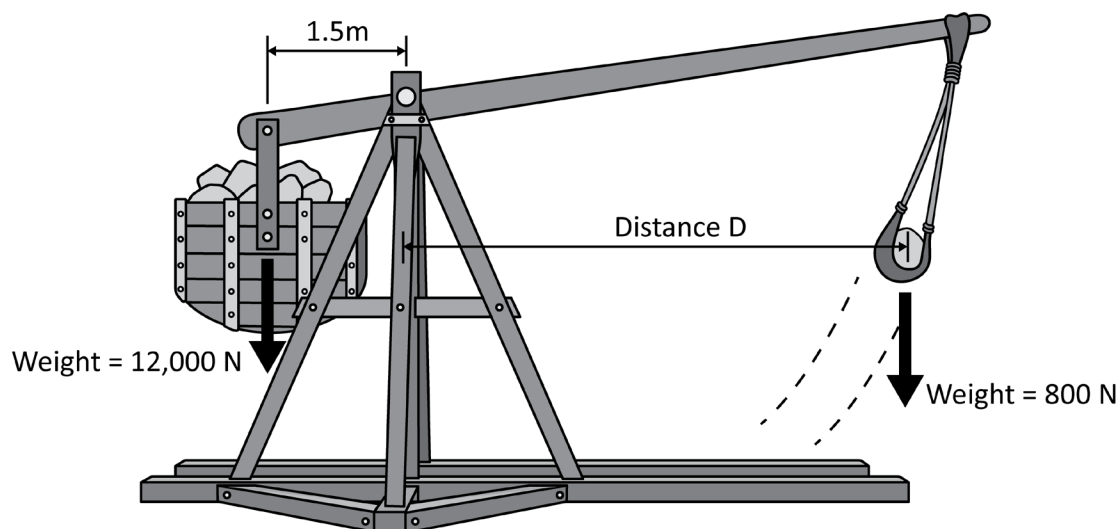
- c) The cyclist turns the front gear at a steady speed of **1.5 rotations per second**.

Calculate how many times the rear gear will rotate in exactly 10 seconds.

Gear ratio = $12 \div 4$	
Gear ratio = 3	1 mark
Rear speed = 1.5×3	
Rear speed = 4.5 rotations per second.	1 mark
Total = 4.5×10	
Total = 45	1 mark
	Total: 3 marks

(Total for Question 3 is 8 marks)

4. In the medieval period very large catapults called trebuchets were used to hurl very heavy stones at walls and other fortifications. The figure below shows a trebuchet and a large stone.



- a) State the equation that links moment, force and distance.

Moment = force $\times$ distance	1 mark
Accept any correct version of this formula.	
	Total: 1 mark

- b) Calculate the anticlockwise moment produced by the counterweight.

Moment = force $\times$ distance	
Moment = 12 000 $\times$ 1.5	1 mark
Moment = 18 000	1 mark
F = 45 $\div$ 0.12	
Unit = N/m	1 mark
	Total: 3 marks

- c) Calculate the distance between the pivot and the stone.

anticlockwise moment = clockwise moment	
18 000 = 800 $\times$ distance	1 mark
Distance = 18000 $\div$ 800	1 mark
Distance = 22.5 m	1 mark
	Total: 3 marks

- d) For the next launch, the team wants to hurl a much heavier stone.
They decide to slide the heavy counterweight further to the left, away from the pivot.

Explain why moving the counterweight further from the pivot allows the trebuchet to lift a heavier stone.

Increasing the distance (from the pivot) increases the total (anticlockwise) moment / turning effect.	1 mark
This larger moment is able to balance/overcome the larger clockwise moment created by the heavier stone.	1 mark
	Total: 2 marks

- e) The trebuchet is triggered, and the wooden arm swings upwards.

As the arm swings past an angle of 45° , the heavy counterweight is still hanging straight down with a force of 12,000 N. However, the anticlockwise moment it produces is now **less** than it was.

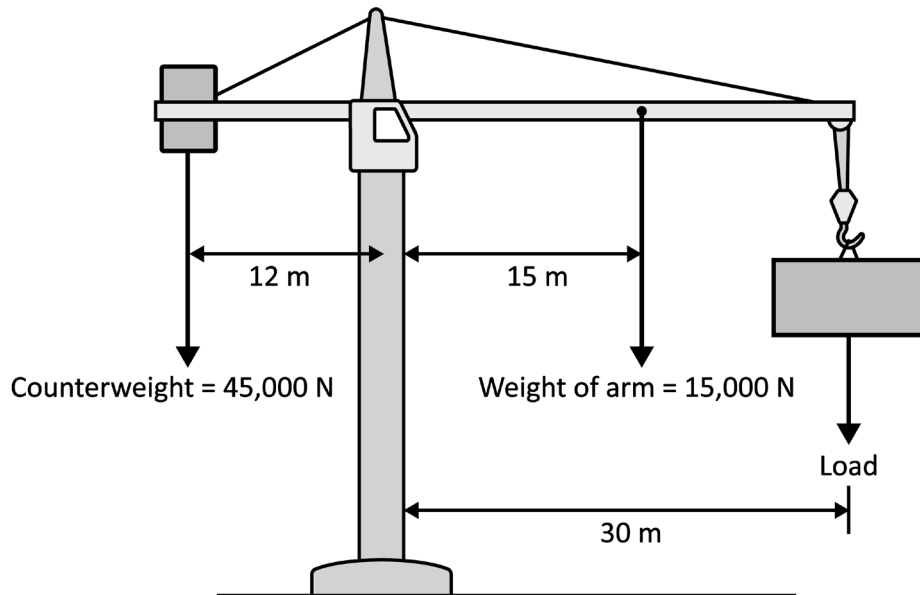
Explain why the moment produced by the counterweight decreases as the arm swings upwards.

The perpendicular distance from the pivot to the line of action of the force has decreased. Allow 1 mark for identifying that the perpendicular or horizontal distance has decreased.	1 mark
Because $\text{Moment} = \text{force} \times \text{distance}$, a smaller distance results in a smaller turning effect / moment. Allow 1 mark for linking this decrease in distance to a decrease in the overall moment. Do not accept "the force decreases" as the weight of the box is constant.	1 mark
	Total: 2 marks

(Total for Question 4 is 11 marks)

5. A large tower crane is lifting a shipping container on a construction site.

The crane operator must ensure the crane is perfectly balanced before lifting the load.



The crane's horizontal arm is balanced on a central pivot.

Calculate the maximum weight of the load the crane can lift.

You must show all of your working.

Step 1: Calculate the total anticlockwise moment. Anticlockwise moment = $F \times d$ Anticlockwise moment = $45,000 \times 12$ Anticlockwise moment = 540,000 Nm	1 mark
Step 2: Calculate the known clockwise moment of the arm. Clockwise moment = $15,000 \times 15$ Clockwise moment = 225,000 Nm	1 mark
Step 3: State the equilibrium rule that the total anticlockwise = total clockwise. Therefore, total clockwise must = 540,000 Nm	1 mark
Step 4: Find the missing clockwise moment which is the load. Load Moment = total clockwise – arm moment Load Moment = $540,000 - 225,000$ Load Moment = 315,000 Nm	1 mark
Step 5: Calculate the weight (force) of the load. Load weight = Moment $\div$ distance Load weight = $315,000 \div 30$ Load weight = 10,500 N	1 mark
	1 mark
	Total: 6 marks

(Total for Question 5 is 6 marks)

6. A worker uses a metal crowbar as a lever to try and lift a heavy crate.

a) State what is meant by the term moment of a force.

The <u>turning effect of a force</u>	1 mark
<u>About a pivot.</u>	1 mark
	Total: 2 marks

b) Calculate the anticlockwise moment produced by the worker.

Moment = force $\times$ distance	
Moment = 600×1.2	1 mark
Moment = 720	1 mark
Unit = N/m	1 mark
	Total: 3 marks

c) Determine whether the worker is able to lift the crate using the lever.

You must show calculations to justify your answer.

Moment = force $\times$ distance	
Moment = 3200×0.2	1 mark
Moment = 640	1 mark
Comparison conclusion: The anticlockwise moment (720 Nm) is greater than the clockwise moment (640 Nm).	1 mark
Therefore: Yes, the worker is able to lift the crate.	
	Total: 3 marks

d) The worker is unable to increase the downward force they apply to the crowbar.

Suggest **one** change the worker could make to the arrangement in the figure above to successfully lift the crate.

A suggestion to include one of the following:	
- Move the pivot closer to the crate. - Use a longer crowbar (to increase the distance from the pivot to the worker).	
	Total: 1 mark

(Total for Question 6 is 9 marks)

7. A motor is connected to an industrial gearbox. The gearbox contains two gears, **P** and **Q**.

Gear P is the input gear and has **15 teeth**.

Gear Q is the output gear, has **60 teeth**, and a radius of 40 cm.

- a) State the direction of rotation of Gear Q.

Anticlockwise.	1 mark
	Total: 1 mark

- b) Explain **how** the gear system shown in the diagram acts as a force multiplier.

An explanation to include the following:	
The output gear (Q) has more teeth / a larger radius than the input gear (P).	1 mark
Allow 1 mark for identifying the size/teeth difference.	
This means a larger turning effect / moment is transmitted to Gear Q (but it turns at a slower speed).	1 mark
Allow 1 mark for stating this increases the turning effect/moment.	
	Total: 2 marks

- c) The motor applies an input moment of 120 Nm to turn Gear P.
Calculate the moment produced by Gear Q.

Moment = force $\times$ distance	
Moment = 120×4	1 mark
Moment = 480 N/m	1 mark
	Total: 2 marks

- d) Calculate the force exerted by the teeth of Gear Q.

Force = Moment $\div$ distance	1 mark
Force = $480 \div 0.40$	1 mark
Force = 1200 N/m	1 mark
	Total: 3 marks

(Total for Question 7 is 8 marks)