

Exercise walk-through

4.1

Turning effects of forces

A-Level Physics

4.1 Moments, couples and torque

Name: _____ Class: _____ Date: _____ **Total: 31 marks**

KEY WORDS moment • couple • torque • line of action
• perpendicular distance

Objective

Answer exam questions on the **turning effect of a force**: the **moment** of a force about a point, a **couple** and its **torque** . Syllabus 4.1, learning outcomes 2, 3 and 4.

You must be able to:

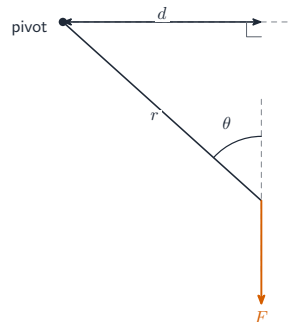
- define the moment of a force and the torque of a couple in the examiner's words
- calculate a moment from the perpendicular distance to the line of action, and add moments with their sense, clockwise or anticlockwise
- decide whether two forces form a couple, and calculate its torque

- explain what a couple does to an object: it turns it, with no resultant force

1 Key knowledge and worked examples

■ Key knowledge: moments and couples

Quantity	Definition	Equation	Unit
moment of a force about a point	the force $\times$ the perpendicular distance from the point to the line of action of the force	$M = Fd$	N m
couple	a pair of forces, equal in size and opposite in direction, whose lines of action are parallel but separated	—	—
torque of a couple	one of the forces $\times$ the perpendicular distance between their lines of action	$\tau = Fd$	N m



The moment uses the perpendicular distance d from the pivot to the line of action

- a force whose line of action passes through the point has **zero** moment about it
- give every moment its sense about the point, clockwise or anticlockwise; resultant moment = total clockwise – total anticlockwise
- **principle of moments** (2 marks): for an object in equilibrium, the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point
- a couple has **zero resultant force**: it turns the object but does not accelerate it along
- the torque uses one force and the separation of the two lines: for forces at opposite ends of a wheel's diameter, d is the **diameter**
- two equal forces in the **same** direction, or two unequal forces, are **not** a couple
- the newton metre of a moment is not the joule: a moment is a force times a perpendicular distance, not a distance moved

■ Worked example: adding moments about a pivot

A beam is pivoted at its centre. Forces act downwards on it: 40 N at 1.5 m to the left of the pivot, and 25 N at 1.0 m and 30 N at 0.50 m to the right. Ignore the weight of the beam.

1. **Anticlockwise** – moment of a force, $M = Fd$: $M_{\text{acw}} = Fd = 40 \times 1.5 = 60 \text{ N m}$.
2. **Clockwise** – add the moments of the two forces on the right: $M_{\text{cw}} = F_1d_1 + F_2d_2 = 25 \times 1.0 + 30 \times 0.50 = 40 \text{ N m}$.
3. **Resultant moment** – the difference: $M_{\text{acw}} - M_{\text{cw}} = 60 - 40 = 20 \text{ N m}$ **anticlockwise**, so the left end goes down.

■ Worked example: a couple on a steering wheel

A driver turns a steering wheel of diameter 0.36 m with two tangential forces of 15 N at opposite ends of a diameter.

1. **Couple?** – the forces are equal, opposite and parallel, with separate lines of action: yes.
2. **Torque** – torque of a couple, $\tau = Fd$, with one force and d the diameter: $\tau = Fd = 15 \times 0.36 = 5.4 \text{ N m}$.
3. **Resultant force** – the two forces are equal and opposite, so they add to zero: the wheel turns but its centre does not accelerate.

■ Worked example: a couple, or not?

Thruster A is 1.8 m left of a spacecraft's centre of gravity, pushing up with 50 N. Thruster C is 0.35 m above the centre, pushing left with 200 N.

1. About the centre, $M_A = F_A d_A = 50 \times 1.8 = 90 \text{ N m}$ clockwise.
2. $M_C = F_C d_C = 200 \times 0.35 = 70 \text{ N m}$ anticlockwise.
3. $M_{\text{net}} = M_A - M_C = 90 - 70 = 20 \text{ N m}$ clockwise.
4. This is not a couple: the forces are neither equal nor opposite/parallel, and there is a resultant force.

Exercises 2.1·2.2

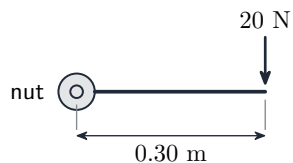
2.1 Define the **moment of a force** about a point.

[2]

moment of a force

2.2 A force of 20 N acts at right angles to a spanner, 0.30 m from the nut. Calculate its moment about the nut.

[2]



Exercises 2.1·2.2

2.1 Define the **moment of a force** about a point.

[2]

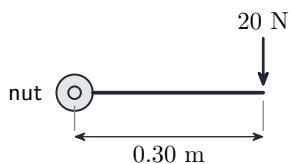
moment of a force

2.1

- the force multiplied by the **perpendicular distance**
- from the point to the **line of action** of the force

2.2 A force of 20 N acts at right angles to a spanner, 0.30 m from the nut. Calculate its moment about the nut.

[2]



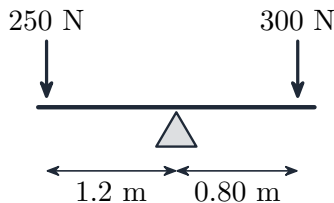
2.2

- moment of a force, $M = Fd$

$$M = Fd = 20 \text{ N} \times 0.30 \text{ m} = \mathbf{6.0 \text{ N m}}$$

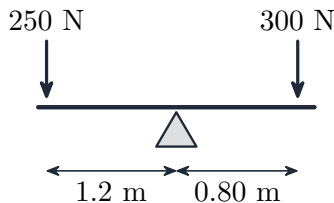
Exercise 2.3

2.3 A see-saw is pivoted at its centre. A child of weight 250 N sits 1.2 m to the left of the pivot and a child of weight 300 N sits 0.80 m to the right. Calculate the resultant moment about the pivot, and state which way the see-saw starts to turn. [3]



Exercise 2.3

2.3 A see-saw is pivoted at its centre. A child of weight 250 N sits 1.2 m to the left of the pivot and a child of weight 300 N sits 0.80 m to the right. Calculate the resultant moment about the pivot, and state which way the see-saw starts to turn. [3]



2.3

- moment of a force, $M = Fd$, on each side

$$M_{\text{acw}} = Fd = 250 \text{ N} \times 1.2 \text{ m} = 300 \text{ N m}$$

$$M_{\text{cw}} = Fd = 300 \text{ N} \times 0.80 \text{ m} = 240 \text{ N m}$$

- resultant moment = $M_{\text{acw}} - M_{\text{cw}} = 300 - 240 = \mathbf{60 \text{ N m}}$
- anticlockwise**: the left-hand side goes down

Exercise 2.4

2.4 State the **conditions** for two forces to form a couple.

[2]

couple

Exercise 2.4

2.4 State the **conditions** for two forces to form a couple.

[2]

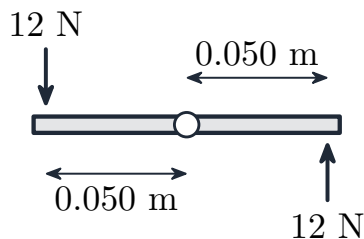
couple

2.4

- two forces **equal** in size and **opposite** in direction
- with **parallel** lines of action that are **separated** (not the same line)

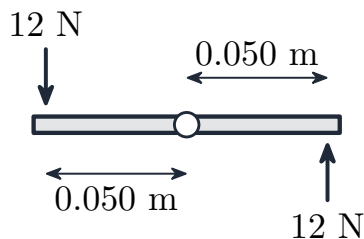
Exercise 2.5

2.5 A tap handle is turned by two forces of 12 N, in opposite directions and at right angles to the handle, applied 0.050 m on either side of its axis. Calculate the torque of the couple. [2]



Exercise 2.5

2.5 A tap handle is turned by two forces of 12 N, in opposite directions and at right angles to the handle, applied 0.050 m on either side of its axis. Calculate the torque of the couple. [2]



2.5

- torque of a couple, $\tau = Fd$, with d the separation, $d = 2r = 2 \times 0.050 = 0.10$ m

$$\tau = Fd = 12 \text{ N} \times 0.10 \text{ m} = \mathbf{1.2 \text{ N m}}$$

Exercise 3.1

3.1 Two forces of 15 N act tangentially, in opposite directions, at opposite ends of a diameter of a wheel of **radius** 0.18 m. What is the torque of the couple? [1]

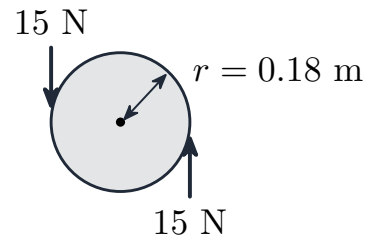
☐

A 2.7 N m

B 5.4 N m

C 11 N m

D 83 N m



Exercise 3.1

3.1 Two forces of 15 N act tangentially, in opposite directions, at opposite ends of a diameter of a wheel of **radius** 0.18 m. What is the torque of the couple? [1]

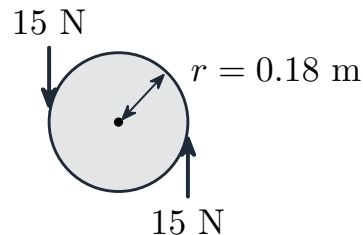


A 2.7 N m

B 5.4 N m

C 11 N m

D 83 N m



3.1 B

- torque = one force $\times$ the separation of the lines of action, which is the diameter:
 $\tau = Fd = 15 \times 0.36 = 5.4 \text{ N m}$
- **A** uses the radius; **C** uses both forces and the diameter

Exercise 3.2

3.2 Which statement about a couple acting on an object is correct?

[1]

☐

A It produces rotation only, because the resultant force is zero.

B It produces a resultant force equal to twice one of the forces.

C It accelerates the object in the direction of the larger force.

D Its torque is the sum of the two forces multiplied by the distance between them.

couple

Exercise 3.2

3.2 Which statement about a couple acting on an object is correct?

[1]

☐

A It produces rotation only, because the resultant force is zero.

B It produces a resultant force equal to twice one of the forces.

C It accelerates the object in the direction of the larger force.

D Its torque is the sum of the two forces multiplied by the distance between them.

couple

3.2 A

- the two forces of a couple are equal and opposite, so the resultant force is zero and the only effect is rotation
- **D** doubles the torque; **B** and **C** give a resultant force that a couple does not have

Exercise 3.3 (a)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(a) **Define** the torque of a couple.

[2]

Exercise 3.3 (a)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

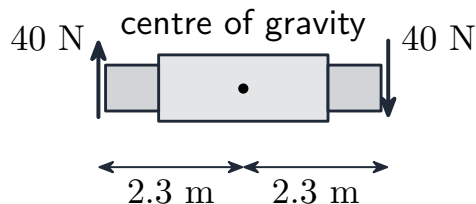
- (a) **Define** the torque of a couple. [2]
- (a) one of the forces multiplied by the perpendicular distance
- between the lines of action of the two forces

Exercise 3.3 (b)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(b) Calculate the torque of the couple on the satellite.

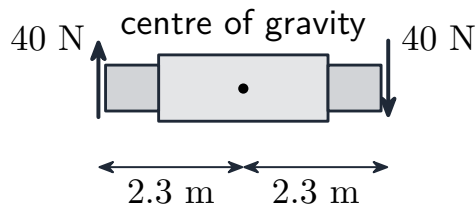
[2]



Exercise 3.3 (b)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(b) Calculate the torque of the couple on the satellite. [2]



(b) torque of a couple, $\tau = Fd$, with $d = 2r = 2 \times 2.3 = 4.6$ m

$$\tau = Fd = 40 \text{ N} \times 4.6 \text{ m} = \mathbf{184 \text{ N m}}$$

Exercise 3.3 (c)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(c) State the resultant force on the satellite, and describe its motion while the thrusters fire. [2]

Exercise 3.3 (c)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(c) State the resultant force on the satellite, and describe its motion while the thrusters fire. [2]

(c) the resultant force is **zero**

- the satellite rotates (with increasing angular speed), but its centre of gravity does not accelerate

Exercise 3.3 (d)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(d) One thruster stops. State and explain how the motion of the satellite changes. [2]

Exercise 3.3 (d)

3.3 A satellite uses two thrusters to turn. Each thruster exerts a force of 40 N on the satellite. The two forces are parallel, act in opposite directions, and each has a line of action 2.3 m from the centre of gravity of the satellite, on opposite sides.

(d) One thruster stops. State and explain how the motion of the satellite changes. [2]

(d) there is now a resultant force of 40 N

- so the satellite accelerates in the direction of that force, and it still turns because the force has a moment about the centre of gravity

Exercise 3.4 (a)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(a) State where the weight of the plank acts, and explain why.

[2]

Exercise 3.4 (a)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(a) State where the weight of the plank acts, and explain why. [2]

(a) at its **centre**, 1.5 m from each end

- the plank is **uniform**, so its centre of gravity is at its middle

Exercise 3.4 (b)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(b) Calculate the moment of the child's weight about the pivot.

[2]

Exercise 3.4 (b)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(b) Calculate the moment of the child's weight about the pivot. [2]

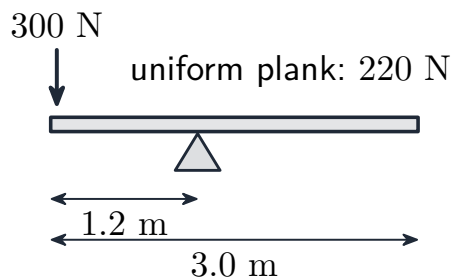
(b) moment of a force, $M = Fd$, with $d = 1.2$ m

$$M = Fd = 300 \text{ N} \times 1.2 \text{ m} = \mathbf{360} \text{ N m anticlockwise}$$

Exercise 3.4 (c)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

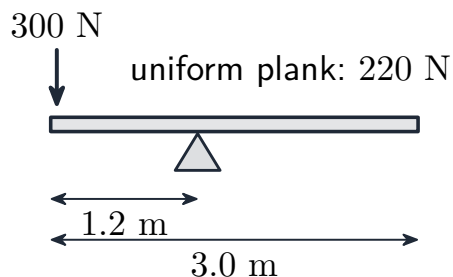
(c) Calculate the moment of the plank's weight about the pivot. [2]



Exercise 3.4 (c)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(c) Calculate the moment of the plank's weight about the pivot. [2]



(c) the weight acts at the centre, $d = 1.5 - 1.2 = 0.30$ m to the right of the pivot, and $M = F_W d$

$$M = F_W d = 220 \text{ N} \times 0.30 \text{ m} = \mathbf{66 \text{ N m clockwise}}$$

Exercise 3.4 (d)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(d) State whether the plank turns, and in which direction, explaining your answer. [2]

Exercise 3.4 (d)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(d) State whether the plank turns, and in which direction, explaining your answer. [2]

(d) it turns **anticlockwise**: the left-hand end goes down

- the anticlockwise moment, 360 N m, is greater than the clockwise moment, 66 N m

Exercise 3.4 (e)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(e) A second child stands on the right-hand end. Calculate the smallest weight this child can have if the plank is not to turn anticlockwise. [2]

Exercise 3.4 (e)

3.4 A uniform plank of weight 220 N and length 3.0 m rests on a pivot 1.2 m from its left-hand end. A child of weight 300 N stands on the left-hand end.

(e) A second child stands on the right-hand end. Calculate the smallest weight this child can have if the plank is not to turn anticlockwise. [2]

(e) the child must supply the missing clockwise moment, $M = M_{\text{acw}} - M_{\text{cw}} = 360 - 66 = 294 \text{ N m}$

- the child sits at the end, $d = 3.0 - 1.2 = 1.8 \text{ m}$ from the pivot, and $M = F_W d$

$$F_W = \frac{M}{d} = \frac{294 \text{ N m}}{1.8 \text{ m}} = \mathbf{160 \text{ N}}$$