5.4 Moments, levers and gears

Name: _____ Class: _____ Date: _____ **Total: 22 marks**

KEY WORDS moment

Objective

Calculate moments with $M = Fd$ (perpendicular distance), balance moments, and explain levers and gears. Physics only. Original questions for spec statement 4.5.4.

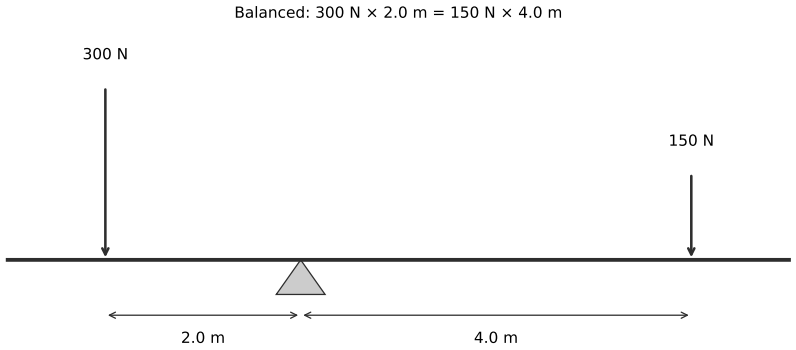
1 Key knowledge and worked examples

A force can make an object **rotate** about a pivot. The turning effect is the **moment**:

$$M = Fd$$

- M in N · m; F in N; d = **perpendicular distance from the pivot to the line of action** of the force, in m.

Balanced object: total clockwise moment = total anticlockwise moment.



$$F_1 d_1 = F_2 d_2 \text{ about the pivot.}$$

Levers and **gears** transmit the rotational effect of a force:

- a **lever**: a small force far from the pivot balances a large force close to it (the moments balance about the pivot);
- **gears**: teeth mesh so turning one gear turns another; a smaller driver gear spinning fast turns a larger gear slowly with a bigger moment (and vice versa).

Worked example. A 300 N load sits 2.0 m left of a pivot; a person pushes down 4.0 m right of it.

- Balance: clockwise = anticlockwise.

$$F_R d_R = F_L d_L$$

$$F_R = \frac{F_L d_L}{d_R} = \frac{300 \text{ N} \times 2.0 \text{ m}}{4.0 \text{ m}} = \mathbf{150} \text{ N}$$

- Half the force, twice the distance – that is the lever's trade.

2 Practice

2.1 A 40 N force acts 0.50 m from a pivot. Calculate the moment. [2]

2.2 State the balance condition for an object that does not rotate about a pivot. [1]

2.3 A child applies a tangential force of 2.0 N at the rim of gear A, of radius 0.10 m. Gear A meshes with gear B of twice the radius. Calculate the input moment and state the output moment and relative rotation rate for ideal gears. [3]

3 Exam-style questions

3.1 A see-saw balances. A 400 N child sits 1.5 m left of the pivot.

(a) Calculate the anticlockwise moment. [2]

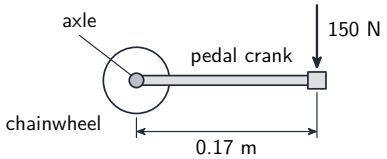
(b) A 600 N child sits right of the pivot. Calculate their distance for balance. [2]

(c) The 400 N child moves 0.5 m further from the pivot. State and explain which way the see-saw tips. [2]

3.2 A bicycle's pedal crank is 0.17 m long; the rider pushes down with 150 N perpendicular to the crank.

(a) Calculate the moment about the axle. [2]

(b) The chain transfers this turning effect to the rear wheel's gear. Explain how gears transmit rotational effects and why a lower gear helps on a hill. [3]



3.3 A uniform 6.0 m bridge of weight 3000 N rests on a support at its centre; a 1200 N car stands 1.5 m from the left end.

(a) Explain why the bridge's own weight acts at its centre. [1]

(b) Taking moments about the centre support, calculate the extra support force needed at the left end 3.0 m away. [3]

(c) State one assumption in your calculation. [1]

Solutions

2.1

$$M = Fd = 40 \times 0.50 = \mathbf{20}\ \text{N} \cdot \text{m}$$

(substitution 1, answer with unit 1)

2.2 Total clockwise moment about the pivot = total anticlockwise moment.

2.3 Moment $= 2.0 \times 0.10 = 0.20\ \text{N} \cdot \text{m}$. A gear of twice the radius turns with twice the moment at half the rate – the ideal meshed gears transmit the same tangential contact force and turn in opposite directions.

3.1 (a) $M = 400 \times 1.5 = \mathbf{600}\ \text{N} \cdot \text{m}$ anticlockwise (C1, A1). (b) Balance: $600 \times d = 600$ so $d = \mathbf{1.0}$ m (C1, A1). (c) It tips further left / down on the 400 N side: the left moment grows to $400 \times 2.0 = 800\ \text{N} \cdot \text{m}$ against $600\ \text{N} \cdot \text{m}$ right – unbalanced anticlockwise.

3.2 (a) Force perpendicular to the crank, so d = crank length.

$$M = Fd = 150 \times 0.17 = 25.5 \approx \mathbf{26}\ \text{N} \cdot \text{m}\ (2\ \text{s.f.})$$

(C1, A1) (b) The chain exerts a tangential force on the rear gear's teeth, producing a moment about its axle; a lower (larger) rear gear multiplies the moment at the wheel; more moment at lower rotation rate suits climbing, where the rider needs force rather than speed.

3.3 (a) A uniform object's weight acts at its centre of mass, the midpoint. (b) The car's moment about the centre: $1200 \times (3.0 - 1.5) = 1800\ \text{N} \cdot \text{m}$ anticlockwise (C1). The left support at 3.0 m must supply $1800\ \text{N} \cdot \text{m}$ clockwise (C1):

$$F = \frac{M}{d} = \frac{1800}{3.0} = \mathbf{600}\ \text{N}$$

(c) The car acts as a point load at its stated position / the bridge is uniform / the support is at the centre (any one, B1).