

Exercise walk-through

4.2

Rigid body mechanics (full A.4, HL)

International Baccalaureate · IB Diploma · Physics · HL

Supported scope

- Full A.4 Rigid body mechanics coverage (HL ONLY — the guide states there is no standard-level content in A.4), extended from the acquired first-assessment-2025 guide (SHA 4884de32bd20, guide pp. 36–37). Vector treatment of torque/angular momentum is not required; senses (clockwise/counter-clockwise) are. Rolling without slipping only for combined motion.
- State model conditions and distinguish fictional data from measurements.

Rotations · 3.1

Reasoning

For a rigid body about a fixed axis, net torque equals moment of inertia multiplied by angular acceleration. Rotational kinetic energy depends on angular speed squared. Angular momentum is conserved when net external torque is zero. Draw the pivot, force direction and perpendicular lever arm. Do not use the sloping distance from pivot to force point unless it is perpendicular to the force. For experiments, keep rotating parts guarded and loads secure.

Pulling the arms inward

- 1 Set the model** A skater has $I = 4.5 \text{ kg m}^2$ and $\omega = 2.0 \text{ rad/s}$. External torque is negligible.
- 2 Calculate** $L = I\omega = 9.0$. Halving I gives $\omega = 4.0 \text{ rad/s}$. Kinetic energy rises from 9.0 to 18 J.

Decision

Angular momentum is conserved; kinetic energy need not be. The skater supplies the extra energy through muscular work.

Exercises 2.1-2.3

2.1 A 25 N force acts 0.40 m from an axis at 60° to the lever. Calculate the torque. [2]

2.2 A 500 g mass and a 300 g mass sit 0.50 m and 0.70 m from the axis. Calculate the moment of inertia. [3]

2.3 A wheel of $I = 0.20 \text{ kg m}^2$ accelerates angularly at 4.0 rad/s^2 . Calculate the torque. [2]

Exercises 2.1·2.3

2.1 A 25 N force acts 0.40 m from an axis at 60° to the lever. Calculate the torque. [2]

$$\mathbf{2.1} \quad \tau = 25 \times 0.40 \times \sin 60^\circ = 8.7 \text{ N} \cdot \text{m}.$$

2.2 A 500 g mass and a 300 g mass sit 0.50 m and 0.70 m from the axis. Calculate the moment of inertia. [3]

$$\mathbf{2.2} \quad I = 0.500 \times 0.50^2 + 0.300 \times 0.70^2 = 0.125 + 0.147 = 0.272 \text{ kg m}^2.$$

2.3 A wheel of $I = 0.20 \text{ kg m}^2$ accelerates angularly at 4.0 rad/s^2 . Calculate the torque. [2]

$$\mathbf{2.3} \quad \tau = I\alpha = 0.20 \times 4.0 = 0.80 \text{ N} \cdot \text{m}.$$

Exercises 2.4·3.1

2.4 A disc of $I = 2.4 \text{ kg m}^2$ spins at 8.0 rad/s . Calculate its angular momentum and rotational kinetic energy. [3]

2.5 State the rolling-without-slipping relation between linear and angular speed. [1]

3.1 A beam pivots at its centre. A 120 N weight hangs 0.80 m left of the pivot and a 90 N weight 0.60 m right. Determine whether the beam is in rotational equilibrium, stating senses; if not, calculate the mass needed 0.50 m further right to balance it ($g = 9.8 \text{ m/s}^2$). [5]

Exercises 2.4·3.1

2.4 A disc of $I = 2.4 \text{ kg m}^2$ spins at 8.0 rad/s . Calculate its angular momentum and rotational kinetic energy. [3]

2.4 $L = I\omega = 2.4 \times 8.0 = 19.2 \text{ kg m}^2/\text{s}$; $E_k = \frac{1}{2} \times 2.4 \times 64 = 76.8 \approx 77 \text{ J}$. Check $L^2/2I = 368.64/4.8 = 76.8 \text{ J} \checkmark$.

2.5 State the rolling-without-slipping relation between linear and angular speed. [1]

2.5 $v = \omega r$.

3.1 A beam pivots at its centre. A 120 N weight hangs 0.80 m left of the pivot and a 90 N weight 0.60 m right. Determine whether the beam is in rotational equilibrium, stating senses; if not, calculate the mass needed 0.50 m further right to balance it ($g = 9.8 \text{ m/s}^2$). [5]

3.1 Left: $120 \times 0.80 = 96 \text{ N} \cdot \text{m}$ counter-clockwise; right: $90 \times 0.60 = 54 \text{ N} \cdot \text{m}$ clockwise; not balanced – net $42 \text{ N} \cdot \text{m}$ counter-clockwise. Balance needs $42 \text{ N} \cdot \text{m}$ clockwise at 0.50 m further right: force = $84 \text{ N} \rightarrow$ mass = $84/9.8 = 8.6 \text{ kg}$.

Exercises 3.2-3.3

3.2 A flywheel ($I = 3.0 \text{ kg m}^2$) spins at 20 rad/s and is slowed by a constant friction torque to rest in 25 s . Calculate the angular deceleration, the friction torque, and the initial angular momentum. [5]

3.3 A dancer with $I = 5.0 \text{ kg m}^2$ spins at 3.0 rad/s . She changes her shape to $I = 3.0 \text{ kg m}^2$. Calculate her new angular speed and the change in rotational kinetic energy, and state where the extra energy comes from. [5]

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3.2 $\alpha = (0 - 20)/25 = -0.80 \text{ rad/s}^2$; $\tau = I\alpha = 3.0 \times 0.80 = 2.4 \text{ N} \cdot \text{m}$ opposing the spin; $L_0 = 3.0 \times 20 = 60 \text{ kg m}^2/\text{s}$.

3.3 A dancer with $I = 5.0 \text{ kg m}^2$ spins at 3.0 rad/s . She changes her shape to $I = 3.0 \text{ kg m}^2$. Calculate her new angular speed and the change in rotational kinetic energy, and state where the extra energy comes from. [5]

3.3 No external torque: $L = 5.0 \times 3.0 = 15 \text{ kg m}^2/\text{s}$ conserved; $\omega' = 15/3.0 = 5.0 \text{ rad/s}$. E_k : from $\frac{1}{2} \times 5.0 \times 9 = 22.5 \text{ J}$ to $\frac{1}{2} \times 3.0 \times 25 = 37.5 \text{ J}$ – up 15 J ; her muscles do work pulling her mass inward.