A.4 Rigid body mechanics

Practice Worksheet — name: ________________________ date: _____________

FORMULAS FOR THIS TOPIC

TORQUE $\tau = Fr\sin\theta$ ROTATIONAL SECOND LAW $\tau = I\alpha$ MOMENT OF INERTIA (POINT MASSES) $I = \Sigma mr^2$

ROTATIONAL KINEMATICS $\omega_f = \omega_i + \alpha t$ ANGULAR DISPLACEMENT $\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$

ANGULAR VELOCITY–DISPLACEMENT $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$ ANGULAR MOMENTUM $L = I\omega$

ANGULAR IMPULSE $\Delta L = \tau\Delta t$ ROTATIONAL KINETIC ENERGY $E_k = \frac{1}{2}I\omega^2 = \frac{L^2}{2I}$

SECTION A — MULTIPLE CHOICE

A1. An ice skater spinning with arms outstretched pulls her arms in. Which row is correct?

- (A) Angular momentum increases; kinetic energy constant
- (B) Angular momentum constant; kinetic energy increases
- (C) Both angular momentum and kinetic energy constant
- (D) Angular momentum constant; kinetic energy decreases

A2. Two children of equal mass sit on a seesaw, one at 2.0 m and one at 1.5 m from the pivot. For balance, an extra downward force must act on the shorter side. If each child weighs 400 N, what extra torque is needed?

- (A) 100 N m
- (B) 200 N m
- (C) 400 N m
- (D) 800 N m

A3. A solid sphere and a hollow sphere of equal mass and radius roll from rest down the same incline. Which reaches the bottom first?

- (A) The solid sphere
- (B) The hollow sphere
- (C) They arrive together
- (D) It depends on the angle of the incline

SECTION B — SHORT ANSWER

B1. A flywheel of moment of inertia $0.80\ \mathrm{kg\ m^2}$ accelerates uniformly from rest to $300\ \mathrm{rad\ s^{-1}}$ in 12 s. Calculate the torque applied and the number of revolutions completed. [4 marks]

B2. Explain why a tightrope walker carries a long pole. [3 marks]

B3. State the rotational analogue of each quantity: force, mass, linear momentum, and Newton's second law. [2 marks]

ANSWER KEY

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Section A

A1: Angular momentum constant; kinetic energy increases — No external torque acts, so $L = I\omega$ is conserved: I falls, ω rises. But $E_k = L^2/2I$, so a smaller I at fixed L means more kinetic energy — supplied by the work her muscles do pulling the arms inward.

A2: 200 N m — Torques about the pivot: $400 \times 2.0 = 800$ N m versus $400 \times 1.5 = 600$ N m. The deficit that must be supplied on the shorter side is 200 N m.

A3: The solid sphere — The hollow sphere has more mass far from the axis, hence a larger moment of inertia, so a bigger share of its potential energy becomes rotational rather than translational kinetic energy. Less translational speed means it arrives later — independent of mass, radius or angle.

Section B

B1: $\alpha = 300/12 = 25$ rad s^{-2}, so $\tau = I\alpha = 0.80 \times 25 = 20$ N m. Angular displacement: $\Delta\theta = \frac{1}{2}\alpha t^2 = \frac{1}{2}(25)(144) = 1800$ rad, which is $1800/2\pi \approx 286$ revolutions.

B2: The pole is massive and extends far from the rotation axis, greatly increasing the walker's moment of inertia about the wire. For a given unbalancing torque, $\alpha = \tau/I$ is much smaller, so the walker tips more slowly and has time to correct. Bending the pole ends downward lowers the centre of mass too.

B3: Force → torque τ; mass → moment of inertia I; linear momentum $p = mv$ → angular momentum $L = I\omega$; $F = ma \rightarrow \tau = I\alpha$ (or $F = \Delta p/\Delta t \rightarrow \tau = \Delta L/\Delta t$).