System of Particles and Rotational Motion

Standard difficulty · 20 questions · 40 marks · Time: 36 minutes

Name: _____ Date: _____ Score: ____ / 40

Show your working for Sections B and C. Answers are on the last page — try every question first!

Section A — Choose the correct answer — 8 × 1 = 8 marks

1. Masses of 2 kg and 6 kg are 9 m apart. The centre of mass is at what distance from the 2 kg mass?
(a) 4.5 m **(b)** 2.25 m **(c)** 7.75 m **(d)** 6.75 m

2. A force of 37 N acts at 1.9 m from the axis, at 0° to the line joining the axis to the point. The torque is:
(a) 70.3 N m **(b)** 140.6 N m **(c)** 0 N m **(d)** 19.47 N m

3. The moment of inertia of a uniform disc about its axis, of mass 4 kg and radius 1 m, is:
(a) 3 kg m^2 **(b)** 1 kg m^2 **(c)** 4 kg m^2 **(d)** 2 kg m^2

4. A wheel with moment of inertia 4.4 kg m^2 spins at 33 rad/s. Its angular momentum is:
(a) 290.4 kg m^2/s **(b)** 2,395.8 kg m^2/s
(c) 145.2 kg m^2/s **(d)** 0.13 kg m^2/s

5. The rotational analogue of mass is:
(a) moment of inertia **(b)** angular velocity
(c) torque **(d)** angular momentum

6. A flywheel of moment of inertia 2.5 kg m^2 rotates at 25 rad/s. Its rotational kinetic energy is:
(a) 62.5 J **(b)** 1,562.5 J **(c)** 31.25 J **(d)** 781.25 J

7. A spinning body changes its moment of inertia from 4 kg m^2 to 18 kg m^2 with no external torque. If it was spinning at 19 rad/s, it now spins at:
(a) 4.22 rad/s **(b)** 8.44 rad/s **(c)** 85.5 rad/s **(d)** 19 rad/s

8. Assertion (A): A ring and a disc, each of mass 3 kg and radius 1 m, have moments of inertia about their axes of 3 and 1.5 kg m^2 respectively.
Reason (R): Moment of inertia depends only on the mass, not on how it is spread.
(a) Both A and R are true, and R is the correct explanation of A.
(b) Both A and R are true, but R is not the correct explanation of A.
(c) A is true, but R is false.
(d) A is false, but R is true.

Section B — Short answer — 8 × 2 = 16 marks

9. Masses of 1 kg at (1, 1), 4 kg at (2, −3), 4 kg at (5, 4) (in metres). Find the centre of mass.

10. A wheel starts at 15 rad/s and has a constant angular acceleration of 2 rad/s^2. Find its angular velocity after 8 s and the angle turned through.

11. A torque of 26 N m acts on a wheel of moment of inertia 3.3 kg m^2 starting from rest. Find the angular acceleration and the angular velocity after 9 s.

12. A hollow sphere of mass 9 kg rolls without slipping at 5 m/s. Find its translational, rotational and total kinetic energy.

13. A thin rod of mass 7 kg and length 1.9 m has $I = ML^2/12$ about its centre. Use the parallel axis theorem to find its moment of inertia about one end.

14. On a see-saw, a child of mass 40 kg sits 2.1 m from the pivot. Where must a child of mass 43 kg sit on the other side to balance it?

15. A fan of moment of inertia 1.9 kg m^2 rotates at 30 revolutions per minute. Find its angular speed in rad/s, and its rotational kinetic energy (leave π in the answer).

16. A skater spinning at 4 rad/s with moment of inertia 5 kg m^2 pulls in the arms, reducing the moment of inertia to 1/2 of its value. Find the new angular speed and the ratio of the new kinetic energy to the old.

Section C — Word problems — 4 × 4 = 16 marks

17. A flywheel of moment of inertia 3.4 kg m^2, starting from rest, is acted on by a constant torque of 8 N m for 8 s. Find (a) the angular acceleration, (b) the final angular speed, (c) the angle turned through, (d) the work done by the torque, (e) the final kinetic energy.

18. A hollow sphere starts from rest at the top of an incline 5.33 m high and rolls down without slipping. Find its speed at the bottom, and explain why it is less than the speed of a block sliding down a smooth incline of the same height. (Take g = 10 m/s^2.)

19. A uniform beam 9 m long weighing 90 N rests on supports at its two ends. A load of 20 N is placed 7.5 m from the left end. Find the reactions at the two supports.

20. A disc of moment of inertia 8 kg m^2 spins at 27 rad/s. A second disc (9 kg m^2), not rotating, is dropped onto it on the same axis, and they rotate together. Find (a) the common angular speed, (b) the kinetic energy before and after, (c) the loss of energy.

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Answer key

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Q	Answer	Working
1	**(d) 6.75 m**	$x = m_2d/(m_1 + m_2)$
2	**(c) 0 N m**	$\tau = rF \sin\theta$
3	**(d) 2 kg m²**	$I = \frac{1}{2}MR^2$
4	**(c) 145.2 kg m²/s**	$L = I\omega$
5	**(a) moment of inertia**	—
6	**(d) 781.25 J**	$K = \frac{1}{2}I\omega^2$
7	**(a) 4.22 rad/s**	$I_1\omega_1 = I_2\omega_2$
8	**(c) A is true, but R is false.**	A is true: ring $MR^2 = 3$; disc $\frac{1}{2}MR^2 = 1.5$. R is false.
9	**(29/9, 5/9) m**	$x = \Sigma mx/\Sigma m$, $y = \Sigma my/\Sigma m$, $\Sigma m = 9$
10	**31 rad/s; 184 rad**	$\omega = \omega_0 + \alpha t$; $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$
11	**7.88 rad/s²; 70.91 rad/s**	$\tau = I\alpha$; $\omega = \alpha t$
12	**112.5 J, 75 J, 187.5 J**	rotational KE = $\frac{1}{2}mv^2 \times k^2/R^2$ with $k^2/R^2 = 2/3$
13	**8.42 kg m² (= ML²/3)**	$I = I_cm + M(L/2)^2 = 2.11 + 6.3175$
14	**1.95 m from the pivot**	moments balance: $m_1d_1 = m_2d_2$
15	**1π rad/s; 0.95π² J**	$\omega = 2\pi N/60$; $K = \frac{1}{2}I\omega^2$
16	**8 rad/s; 2 : 1 (the kinetic energy increases 2 times)**	$I_1\omega_1 = I_2\omega_2$; $K = L^2/2I$
17	**(a) 2.35 rad/s²; (b) 18.82 rad/s; (c) 75.29 rad; (d) 602.35 J; (e) 602.35 J (equal to the work done)**	$W = \tau\theta = \frac{1}{2}I\omega^2$
18	**8 m/s ($v^2 = 2gh \div (1 + k^2/R^2) = 106.67 \div 5/3$). A sliding block would reach 10.33 m/s; the rolling body puts part of its energy into rotation.**	$mgh = \frac{1}{2}mv^2(1 + k^2/R^2)$, $k^2/R^2 = 2/3$
19	**Left 48.33 N; right 61.67 N**	moments about the left end: R_right × 9 = 90 × 4.5 + 20 × 7.5
20	**(a) 12.71 rad/s; (b) 2,916 J and 1,372.24 J; (c) 1,543.76 J**	angular momentum is conserved: $I_1\omega_1 = (I_1 + I_2)\omega$

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