Class 11 Physics · Chapter 6: Systems of Particles and Rotational Motion

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. For the unit vectors of a right-handed system, $\hat{k} \times \hat{i}$ equals [1]

(a) $-\hat{j}$ (b) the null vector

(c) $\hat{k}$ (d) $\hat{j}$

Answer: (d) In cyclic order $\hat{i} \times \hat{j} = \hat{k}$, $\hat{j} \times \hat{k} = \hat{i}$, $\hat{k} \times \hat{i} = \hat{j}$. $-\hat{j}$ is $\hat{i} \times \hat{k}$, the reversed order; the null vector is $a \times a$.

2. A shell fired from a gun on level ground would have landed 240 m away. At the highest point it explodes into two fragments of equal mass, which reach the ground at the same instant. One fragment lands 180 m from the gun, on the line of fire. Neglecting air resistance, the other lands at a distance from the gun of [1]

(a) 300 m (b) 240 m

(c) 60 m (d) 420 m

Answer: (a) The explosion forces are internal, so the centre of mass follows the original parabola and lands at 240 m. Both fragments land together, so $240 = (180 + x)/2$ and $x = 300$ m.

3. A nucleus at rest breaks into two fragments whose masses are in the ratio 2 : 3. External forces are negligible. The ratio of the kinetic energy of the lighter fragment to that of the heavier fragment is [1]

(a) 2/3 (b) 3/2

(c) 9/4 (d) 1

Answer: (b) Total momentum stays zero, so the fragments have equal and opposite momenta p. $K = p^2/2m$, so $K_1/K_2 = m_2/m_1 = 3/2$. The answer 1 assumes equal energies; 9/4 squares the mass ratio.

4. The centre of gravity of a body coincides with its centre of mass when [1]

(a) the body is symmetric about an axis (b) the acceleration due to gravity is the same at every point of the body

(c) the body is at rest (d) the body is perfectly rigid

Answer: (b) With g the same for all particles it comes out of the sum $\Sigma r_i \times m_i g = 0$, giving $\Sigma m_i r_i = 0$ about the CG, which is the condition for the centre of mass. Symmetry, rest or rigidity is not what makes the two points coincide.

5. Two small balls P and Q are joined by a light rod 60 cm long. The centre of mass of the pair is 15 cm from P. The ratio of the mass of P to the mass of Q is [1]

(a) 1/3 (b) 3

(c) 4 (d) 1/4

Answer: (b) The centre of mass is nearer the heavier ball, and $m_P \times 15 = m_Q \times 45$, so $m_P/m_Q = 45/15 = 3$. The answer 1/3 puts the centre of mass nearer the lighter ball.

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6. Distinguish between the centre of mass and the centre of gravity of a body. Would the two points coincide for a tower so tall that g at its top is noticeably smaller than at its base? Give a reason. [2]

The centre of mass depends only on how the mass is distributed ($R = \Sigma m_i r_i / M$); the centre of gravity is the point about which the total gravitational torque is zero. They coincide only when g is the same at every point. For the very tall tower g is smaller at the top, so the upper parts weigh relatively less and the centre of gravity lies below the centre of mass.

- CM from mass distribution only; CG is where the gravitational torque is zero (1)
- not coincident: g varies, CG lies lower (1)

7. A 1.5 kW motor drives a grinding wheel of radius 0.10 m at a steady 300 rad s^{-1}. Find the torque the motor supplies, and the tangential force this corresponds to at the rim of the wheel. [2]

$P = \tau\omega$, so $\tau = P/\omega = 1500/300 = 5.0$ N m. At the rim $\tau = rF_\perp$, so $F = \tau/r = 5.0/0.10 = 50$ N.

- $\tau = P/\omega = 5.0$ N m (1)
- $F = \tau/r = 50$ N (1)

8. A driver turns a steering wheel with both hands, pushing up on one side of the rim and pulling down on the other with forces of equal size. Name this pair of forces and explain why the wheel turns but does not move sideways. [2]

The two forces are equal in magnitude, opposite in direction and have different lines of action: they form a couple. Their vector sum is zero, so there is no translation; their moments about the axle add in the same sense, so the net torque is non-zero and the wheel rotates.

- names a couple: equal, opposite forces with different lines of action (1)
- zero net force so no translation; non-zero torque so rotation (1)

9. State the two conditions for the mechanical equilibrium of a rigid body. How many independent scalar conditions remain when all the forces lie in one plane? Give one example of a body in translational equilibrium but not in rotational equilibrium. [3]

(1) The vector sum of the external forces is zero, $\Sigma F_i = 0$; (2) the vector sum of the external torques is zero, $\Sigma \tau_i = 0$. For coplanar forces (say in the x-y plane) only three remain: $\Sigma F_x = 0$, $\Sigma F_y = 0$ and $\Sigma \tau_z = 0$.

Example: a light rod acted on at its two ends by equal and opposite forces perpendicular to it (a couple) has zero net force but turns.

- both conditions, $\Sigma F = 0$ and $\Sigma \tau = 0$ (1)
- three for coplanar forces (1)
- a valid example such as a couple on a rod (1)

10. Find a unit vector perpendicular to both $a = \hat{i} + \hat{j}$ and $b = \hat{j} + \hat{k}$. Verify by a scalar product that your answer is perpendicular to a. [3]

$a \times b = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 1 & 1 & 0 \\ 0 & 1 & 1 \end{vmatrix} = (1\cdot1 - 0\cdot1)\hat{i} - (1\cdot1 - 0\cdot0)\hat{j} + (1\cdot1 - 1\cdot0)\hat{k} = \hat{i} - \hat{j} + \hat{k}$, which is perpendicular to both. Its magnitude is $\sqrt{3} \approx 1.73$, so $\hat{n} = (\hat{i} - \hat{j} + \hat{k})/\sqrt{3}$ (or its negative). Check: $(\hat{i} - \hat{j} + \hat{k})\cdot(\hat{i} + \hat{j}) = 1 - 1 + 0 = 0$.

- $a \times b = \hat{i} - \hat{j} + \hat{k}$ (1)
- divides by $\sqrt{3}$ to get the unit vector (either sign) (1)
- scalar product with a is zero (1)

11. Three small balls, each of mass 1.0 kg, are fixed to a light rod at the 0 m, 0.5 m and 1.0 m marks. Find the moment of inertia of the system about an axis perpendicular to the rod through (i) the end ball and (ii) the middle ball. Find its rotational kinetic energy at 4.0 rad s^{-1} in each case. [3]

$I = \Sigma m_i r_i^2$. (i) About the end: $1.0(0)^2 + 1.0(0.5)^2 + 1.0(1.0)^2 = 1.25$ kg m^2; $K = (1/2)I\omega^2 = 0.5 \times 1.25 \times 16 = 10$ J. (ii) About the middle: $1.0(0.5)^2 + 0 + 1.0(0.5)^2 = 0.5$ kg m^2; $K = 0.5 \times 0.5 \times 16 = 4.0$ J. The same body has a different I for a different axis.

- $I = 1.25$ kg m^2 about the end (1)
- $I = 0.5$ kg m^2 about the middle (1)
- K = 10 J and 4.0 J (1)