CLASS 11 PHYSICS — FORMULA SHEET

Chapter 6 : System of Particles and Rotational Motion (NCERT)

6.1 Centre of Mass (CoM)

Concept	Formula
CoM of two particles	$x_{cm} = (m_1x_1 + m_2x_2) \div (m_1 + m_2)$
CoM of n particles	$x_{cm} = \Sigma m_ix_i \div \Sigma m_i$ (similarly y_{cm}, z_{cm})
CoM (continuous body)	$x_{cm} = (1/M) \int x\, dm$
Velocity of CoM	$v_{cm} = \Sigma m_iv_i \div M$
Acceleration of CoM	$a_{cm} = F_{ext} \div M$
Motion of CoM	CoM moves as if total mass & external force act there
CoM of symmetric bodies	At geometric centre (sphere, ring, disc, rod)

6.2 Linear Momentum of a System

Concept	Formula
Total momentum	$P = M\, v_{cm} = \Sigma m_iv_i$
Newton's 2nd law (system)	$F_{ext} = dP/dt = M\, a_{cm}$
Conservation	If $F_{ext} = 0 \rightarrow P$ = constant, v_{cm} = constant
Internal forces	Cancel in pairs (Newton's 3rd law); don't affect CoM motion

6.3 Vector (Cross) Product & Torque

Concept	Formula
Cross product magnitude	$\|A \times B\| = AB \sin\theta$
Torque (moment of force)	$\tau = r \times F$; $\|\tau\| = rF \sin\theta = F \times$ (perpendicular distance)
Torque & angular accel	$\tau = I\, \alpha$ (rotational analogue of $F = ma$)
Angular momentum (particle)	$L = r \times p$; $\|L\| = rp \sin\theta = mvr \sin\theta$
Angular momentum (rigid body)	$L = I\, \omega$
Relation τ and L	$\tau = dL/dt$ (rotational form of Newton's 2nd law)

6.4 Equilibrium of a Rigid Body

Condition	Detail
Translational equilibrium	$\Sigma F = 0$ (net force zero)
Rotational equilibrium	$\Sigma \tau = 0$ (net torque zero)
Couple	Two equal, opposite, parallel forces → pure rotation; $\tau = F \times d$
Principle of moments (lever)	Load × load arm = Effort × effort arm
Mechanical advantage	MA = Load ÷ Effort = effort arm ÷ load arm

Condition	Detail
Centre of gravity (CG)	Point where total weight acts; coincides with CoM in uniform gravity

6.5 Moment of Inertia (I)

Concept	Formula
Moment of inertia	$I = \Sigma m_i r_i^2 = \int r^2\, dm$ (rotational analogue of mass)
Radius of gyration	$K = \sqrt{(I/M)} \rightarrow I = MK^2$
Parallel axis theorem	$I = I_{cm} + Md^2$ (d = distance between axes)
Perpendicular axis theorem	$I_z = I_x + I_y$ (planar bodies only)
Rotational KE	$KE_{rot} = ½I\omega^2$
Work done by torque	$W = \tau\theta$; Power $P = \tau\omega$

6.6 Moment of Inertia of Standard Bodies

Body (axis)	Moment of Inertia
Ring (through centre, ⊥ plane)	$I = MR^2$
Ring (diameter)	$I = ½MR^2$
Disc (through centre, ⊥ plane)	$I = ½MR^2$
Disc (diameter)	$I = ¼MR^2$
Solid sphere (diameter)	$I = (2/5)MR^2$
Hollow sphere (diameter)	$I = (2/3)MR^2$
Solid cylinder (axis)	$I = ½MR^2$
Thin rod (centre, ⊥ length)	$I = (1/12)ML^2$
Thin rod (one end, ⊥ length)	$I = (1/3)ML^2$

6.7 Rotational Kinematics & Rolling Motion

Concept	Formula
Rotational equations	$\omega = \omega_0 + \alpha t$; $\theta = \omega_0 t + ½\alpha t^2$; $\omega^2 = \omega_0^2 + 2\alpha\theta$
Linear–angular link	$v = r\omega$; $a = r\alpha$; $s = r\theta$
Conservation of L	If $\tau_{ext} = 0 \rightarrow L = I\omega =$ constant ($I_1\omega_1 = I_2\omega_2$)
Rolling condition	$v_{cm} = R\omega$ (rolling without slipping)
Total KE (rolling)	$KE = ½Mv^2 + ½I\omega^2 = ½Mv^2(1 + K^2/R^2)$
Rolling down incline (accel)	$a = g \sin\theta \div (1 + K^2/R^2)$
Velocity at bottom of incline	$v = \sqrt{[2gh \div (1 + K^2/R^2)]}$

6.8 Translational ↔ Rotational Analogues

Linear Quantity	Rotational Analogue
Mass (m)	Moment of inertia (I)
Force (F)	Torque ($\tau = I\alpha$)
Linear momentum (p = mv)	Angular momentum ($L = I\omega$)
F = ma	$\tau = I\alpha$
KE = ½mv^2	KE = ½Iω^2
Work W = Fs	Work W = $\tau\theta$
Power P = Fv	Power P = $\tau\omega$

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CoM master formula	$x_{cm} = \Sigma mx/\Sigma m$. CoM moves as if all mass & external force act there.
Torque = r × F	$\tau = rF \sin\theta$. Maximum when force is perpendicular ($\theta = 90°$).
Two theorems	Parallel: $I = I_{cm} + Md^2$. Perpendicular: $I_z = I_x + I_y$ (flat bodies only).
MI quick recall	Ring MR^2, Disc/Cylinder ½MR^2, Solid sphere ⅖MR^2, Hollow sphere ⅔MR^2.
Rod MI	Centre $(1/12)ML^2$; End $(1/3)ML^2$ — end value is 4× the centre.
Rolling KE	KE = ½$Mv^2(1 + K^2/R^2)$. Hollow bodies roll slower (bigger K^2/R^2).
Incline race	Solid sphere fastest, then disc, then ring (smallest K^2/R^2 wins).
L conservation	$I\omega$ = constant. Skater pulls arms in → I down, ω up.