

CUET · PHYSICS · CLASS XI · CODE 322

Laws of Motion

CUET unit: Laws of Motion

By UniDrill · NCERT-grounded study material

WWW.UNIDRILL.IN

UniDrill

Snapshot

- The Aristotelian view that a sustained external force is needed for uniform motion is wrong; mechanics rests instead on Galileo's law of inertia and Newton's three laws.
- It introduces momentum $\mathbf{p} = m\mathbf{v}$, the second law $\mathbf{F} = d\mathbf{p}/dt = m\mathbf{a}$, and the impulse-momentum theorem $\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$, with worked examples on bullets, catches and collisions.
- The third law is sharpened — action and reaction are simultaneous, equal-and-opposite, and act on **different** bodies — and is then combined with the second law to derive conservation of linear momentum for an isolated system.
- Equilibrium of a particle under concurrent forces, common forces (gravity, normal, tension, spring $\mathbf{F} = -k\mathbf{x}$, static friction with μ_s , kinetic friction with μ_k , $\mu_k < \mu_s$, rolling friction), and the dynamics of circular motion (centripetal force mv^2/R ; banked roads with and without friction) complete the topic.
- CUET regularly tests definitions, the $F = ma$ relation, friction inequalities and the banked-road formula through small numerical and statement-based items.

Detailed Notes

2.1 Core concepts

- The Aristotelian law — "an external force is required to keep a body in motion" — is flawed; a moving toy car comes to rest only because friction from the floor opposes its motion, not because force is intrinsically required for uniform motion (NCERT §4.2, p. 50).
- Galileo's inclined-plane experiments showed that a ball released on one plane climbs almost to its original height on the other; in the idealised frictionless case, when the second plane is made horizontal, the ball would travel an infinite distance with constant velocity (NCERT §4.3, p. 50).
- The **law of inertia**: the state of rest and the state of uniform linear motion are equivalent — in both there is no net external force on the body; inertia is the body's resistance to change of its state of rest or uniform motion (NCERT §4.3, p. 51).
- **Newton's first law**: "Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise";

- equivalently, if the net external force on a body is zero its acceleration is zero, and acceleration is non-zero only when a net external force acts (NCERT §4.4, p. 51).
- Examples of inertia: a passenger in a bus is thrown backward when the bus suddenly starts (body tends to remain at rest while feet accelerate with bus) and thrown forward when the bus suddenly stops (body tends to continue moving while feet stop with floor due to friction) (NCERT §4.4, p. 52).
 - **Momentum** is defined as $\mathbf{p} = \mathbf{m} \mathbf{v}$; it is a vector, and the larger the mass or speed, the greater the opposing force needed to stop the body in a given time (NCERT §4.5, p. 53, Eq. 4.1).
 - Observations leading to the second law: the same force acting for the same time on bodies of different masses produces the same change in momentum; force is required even to change only the direction of momentum (e.g., a stone whirled in a horizontal circle) (NCERT §4.5, p. 53–54).
 - **Newton's second law:** "The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts"; $\mathbf{F} = \mathbf{dp}/\mathbf{dt}$, and for constant mass $\mathbf{F} = \mathbf{m} \mathbf{a}$ with $k = 1$ in SI units, giving 1 newton = 1 kg m s⁻² (NCERT §4.5, p. 54, Eqs. 4.2–4.5).
 - Important features of the second law: $F = 0 \Rightarrow a = 0$ (consistent with first law); it is a vector equation (three component equations); applicable to a particle, a rigid body or a system of particles (with F as net external force and a as acceleration of centre of mass); and it is a local law — a here-and-now is set by F here-and-now, not by past history (NCERT §4.5, p. 54–55).
 - **Impulse = Force × time duration = change in momentum**; this is useful when a large force acts for a very short time (impulsive force) — Newtonian mechanics treats impulsive forces no differently from ordinary forces except that they are large and brief (NCERT §4.5, p. 55, Eq. 4.7).
 - **Newton's third law:** "To every action there is always an equal and opposite reaction"; equivalently, force on body A by B is equal and opposite to force on B by A ($F_{AB} = -F_{BA}$). Action and reaction are simultaneous (no cause-effect), and they act on **different** bodies, so they never cancel for one body (NCERT §4.6, p. 56–57, Eq. 4.8).
 - **Conservation of linear momentum:** the total momentum of an isolated system of interacting particles is conserved — derived from the second and third laws; in a gun-bullet system fired from rest, $p_b + p_g = 0$, giving recoil; in collisions (elastic or inelastic), $p'_A + p'_B = p_A + p_B$ (NCERT §4.7, p. 57–58, Eq. 4.9).
 - **Equilibrium of a particle** means zero net external force; two-force equilibrium needs $F_1 = -F_2$; three concurrent forces in equilibrium add vectorially to zero and can be represented as sides of a closed triangle; for n forces, sides of a closed polygon (NCERT §4.8, p. 58, Eqs. 4.10–4.12).
 - **Common forces in mechanics** — gravity (action at a distance, pervasive); contact forces decomposed into normal reaction (perpendicular to surfaces) and friction

(parallel to surfaces); tension in an inextensible massless string (constant throughout); spring force $\mathbf{F} = -k \mathbf{x}$ with k as the force constant and the minus sign indicating restoring direction (NCERT §4.9, p. 59).

- **Static friction f_s** opposes impending motion and is self-adjusting up to a maximum $(f_s)_{\max} = \mu_s N$; the law is $f_s \leq \mu_s N$, with μ_s the coefficient of static friction (depends only on the nature of surfaces, not on area of contact) (NCERT §4.9.1, p. 60, Eqs. 4.13–4.14).
- **Kinetic (sliding) friction $f_k = \mu_k N$** ; it opposes actual relative motion, is independent of area of contact and nearly independent of velocity; experimentally $\mu_k < \mu_s$ (NCERT §4.9.1, p. 60, Eq. 4.15).
- **Rolling friction** is much smaller (by 2–3 orders of magnitude) than sliding/static friction; arises from momentary deformation giving a finite contact area; reduced further by ball bearings or a thin air cushion (NCERT §4.9.1, p. 62).
- **Circular motion — centripetal force:** a body moving in a circle of radius R with uniform speed v has acceleration v^2/R directed towards the centre, so $f_c = mv^2/R$; centripetal force is not a new kind of force, but the name for whichever real force (tension, gravity, friction, etc.) supplies this inward acceleration (NCERT §4.10, p. 63, Eq. 4.16).
- **Car on a level road:** friction alone provides centripetal force, so $v^2 \leq \mu_s R g$, giving $v_{\max} = \sqrt{\mu_s R g}$ — independent of the mass of the car (NCERT §4.10, p. 63, Eq. 4.18).
- **Car on a banked road:** balancing forces gives $v_{\max}^2 = R g (\mu_s + \tan \theta)/(1 - \mu_s \tan \theta)$; when $\mu_s = 0$ the optimum (no-friction-needed) speed is $v_o = \sqrt{R g \tan \theta}$, i.e., $\tan \theta = v^2/(R g)$ — at this speed the tyres experience no wear from sideways friction (NCERT §4.10, p. 64, Eqs. 4.21–4.22).
- Strategy for problem solving: draw an assembly diagram, choose a system, draw a free-body diagram including all external forces on the system (not forces on the environment), and apply the laws of motion; use the third law when crossing between subsystems (NCERT §4.11, p. 64–66).

2.2 Definitions to memorise

Term	Definition	Page
Inertia	Property of a body by virtue of which it resists change to its state of rest or uniform motion in a straight line	51
Newton's first law	If the net external force on a body is zero, its acceleration is zero; otherwise it continues at rest or in uniform motion in a straight line	51
Momentum (p)	Product of mass and velocity, $p = m v$; a vector quantity	53
Newton's second law	Rate of change of momentum is proportional to the applied force and in its direction; $F = dp/dt = m a$ for constant mass	54

Term	Definition	Page
Newton (unit of force)	Force that produces an acceleration of 1 m s^{-2} in a mass of 1 kg ; $1 \text{ N} = 1 \text{ kg m s}^{-2}$	54
Impulse	Product of force and the (short) time for which it acts; equals change in momentum ($J = F \Delta t = \Delta p$)	55
Newton's third law	Forces always occur in pairs; force on A by B is equal and opposite to force on B by A ($F_{AB} = -F_{BA}$)	56–57
Law of conservation of momentum	Total momentum of an isolated system of interacting particles is conserved	58
Equilibrium of a particle	Situation when the net external force on the particle is zero (zero acceleration; rest or uniform motion)	58
Normal reaction (N)	Component of the contact force perpendicular to the surfaces in contact	59
Tension (T)	Restoring force in a string; constant throughout an inextensible massless string	59
Spring force	Restoring force $F = -kx$ where x is the displacement from the natural length and k is the force constant	59
Static friction (f_s)	Component of contact force parallel to surfaces that opposes impending relative motion; self-adjusting with $f_s \leq \mu_s N$	60
Coefficient of static friction (μ_s)	Constant for a pair of surfaces such that $(f_s)_{\text{max}} = \mu_s N$	60
Kinetic friction (f_k)	Friction opposing actual relative motion of surfaces in contact; $f_k = \mu_k N$, with $\mu_k < \mu_s$	60
Rolling friction	Resistive force on a rolling body, arising from a small deformation-induced contact patch; much smaller than sliding friction	62
Centripetal force	The net inward radial force on a body in circular motion of speed v and radius R : $F = m v^2/R$	63
Optimum speed (banked road)	The speed $v_o = \sqrt{R g \tan \theta}$ at which no friction is needed to keep a car on a banked curve	64

2.3 Diagrams / processes to remember

- Fig. 4.1 (a) and 4.1 (b) (p. 50): Galileo's inclined-plane and double-inclined-plane experiments leading to the law of inertia.
- Fig. 4.2 (p. 52): (a) book at rest on a table — weight W balanced by normal R ; (b) car moving with uniform velocity — net force zero.
- Fig. 4.3 (p. 53): a cricketer drawing in his hands while catching a ball — larger Δt reduces the required force for the same Δp .

- Fig. 4.4 (p. 54): a stone whirled in a horizontal circle — force needed to change the **direction** of momentum even at constant speed.
- Fig. 4.5 (p. 55): a stone dropped from an accelerated train carries no horizontal force after release — the second law is a **local** relation.
- Fig. 4.6 (p. 57): two billiard balls hitting a wall, one head-on, one at 30° — used to compute impulses and the direction of force on the wall.
- Fig. 4.7 (p. 58): equilibrium of a particle under concurrent forces represented as sides of a closed triangle.
- Fig. 4.8 (p. 58): free-body diagrams for a mass suspended by a rope with a horizontal force applied at the midpoint.
- Fig. 4.10 (p. 60): static friction opposes impending motion; kinetic friction opposes actual relative motion and is usually less than $(f_s)_{\max}$.
- Fig. 4.13 (p. 62): ball bearings and air cushion as ways of reducing friction.
- Fig. 4.14 (p. 63): forces on a car on (a) a level road and (b) a banked road — used to derive v_{\max} formulas.

2.4 Common confusions / NTA trap points

- The statement "W = R for a book on a table because the two forces cancel" is **incorrect reasoning** — the correct logic is that the book is observed to be at rest, hence by the first law net force is zero, hence R must equal and oppose W. The equality has no connection with the third law (NCERT §4.4, p. 52; Points to Ponder 7, p. 68).
- Action and reaction act on **different bodies** — they can therefore never cancel each other on a single body, and "F = 0" for one body is NOT a consequence of the third law (NCERT §4.6, p. 56–57).
- $v = 0$ momentarily does NOT mean force or acceleration are zero — at the top of a vertical throw, $v = 0$ but $a = g$ downward (Points to Ponder 2, p. 68).
- Static friction is self-adjusting up to $\mu_s N$; do not set $f_s = \mu_s N$ unless the body is on the verge of slipping (Points to Ponder 6, p. 68).
- Centripetal force is not a new kind of force; always identify the underlying material force (tension, gravity, friction, normal-reaction component) that plays this role (Points to Ponder 5, p. 68).
- For a banked road, $v_{\max}^2 = R g (\mu_s + \tan \theta)/(1 - \mu_s \tan \theta)$ is the maximum (slip-up condition); $v_o = \sqrt{R g \tan \theta}$ is only the no-friction-needed **optimum**, not the maximum (NCERT §4.10, p. 64).



Practice MCQs

PYQ Alignment

Laws of Motion is one of the highest-yield chapters in CUET Physics, typically producing 1–2 questions a year across recall (statements of the three laws, definitions of friction, momentum, impulse) and short numerical items ($F = m a$, impulse = Δp , $\mu_s = \tan \theta_{\max}$, v_{\max} on banked roads). Expect statement-based and assertion-reason items on the third law's "different bodies" subtlety and on the optimum vs maximum speed on a banked road.

CUET 2023–25 — Actual PYQs from this chapter

No PYQs from this chapter appeared in CUET 2023, 2024 or 2025.



UniDrill