⚡ How Forces Affect Motion

Exploration | Chapter 6 | NCERT

→ Ch. 4 described motion (position, velocity, acceleration) — but not its **cause**. This chapter explores what causes motion to change, via **Newton's three laws of motion**.

6.1 The Concept of Force

→ A force can: make an object **move from rest**, change its **speed/direction**, or change its **shape** (e.g. kicking a ball, striking with a bat, squeezing a lemon).

→ Force is a physical quantity needing **magnitude** + **direction** (like position, displacement, velocity, acceleration).

SI UNIT OF FORCE → newton (symbol N, lowercase 'n' in the word itself). Magnitude of force expresses its strength.

⚠ परीक्षा के लिए | If magnitude OR direction (or both) of a force changes, the EFFECT of the force also changes.

6.1.1 Measuring the Magnitude of a Force

→ A **spring balance** measures force magnitude — pulling its free end measures the force pulling on the internal spring. Weight = gravitational force = one type of force it measures.

★ Threads of Curiosity: smallest force we can feel directly ≈ millinewtons (10^{-3} N, a light touch); scientists can measure down to yoctonewtons (10^{-24} N) in specialised experiments.

6.2 Balanced and Unbalanced Forces

→ Usually **more than one force** acts on an object at once — e.g. pushing a box (applied force + friction); a ball floating on water (gravity down + buoyant force up).

BALANCED FORCES → Two (or more) forces equal in magnitude but opposite in direction — e.g. tug-of-war with equal pulling force; the object does NOT move/change motion.

NET FORCE → The overall (non-zero) force when applied forces are NOT balanced — determines the object's motion.

Case	How to find Net Force
Forces in SAME direction	Net force = sum of magnitudes; direction = same as both forces
Forces in OPPOSITE directions	Net force = difference of magnitudes; direction = along the larger force

→ **Example 6.1** (10 N & 6 N on a block): (a) same direction → net = **16 N** right. (b) opposite, 10N right vs 6N left → net = **4 N** right. (c) opposite, 6N right vs 10N left → net = **4 N** left.

⚠ **परीक्षा के लिए** | Multiple forces may act on an object, but its motion depends ONLY on the net force.

★ Ready to Go Beyond: forces at an angle to each other, or equal-opposite forces on two ends of an extended object (causing rotation, e.g. turning a tap/handlebar) — covered in higher grades.

6.3 The Force of Friction

→ Pushing a stationary object may not move it — a larger force is needed than the opposing **force of friction** between the surfaces in contact.

→ Object moves only when applied force > friction, so a net force acts in the direction of motion.

→ **Activities 6.1 & 6.2 (rubber-band coin stack + spring balance):** smoother surfaces (polished marble) → **smaller friction** → coins travel farther, velocity decreases more slowly; spring balance reading confirms smaller friction force needed to start motion.

→ Other forces on a pushed object: **weight (gravitational, down)** and **normal force (surface, up)** — these two are balanced, perpendicular to friction/applied force.

⚠ **परीक्षा के लिए** | Once moving, if you stop applying force, friction (opposing motion) brings the object to rest — you must continuously apply force to counter friction to maintain motion.

→ **Meet a Scientist: Galileo Galilei** (17th century) — argued via thought experiments that a body moving on a horizontal plane with all impediments removed would move **indefinitely** (force NOT needed to maintain constant velocity motion).

→ **Meet a Scientist: Isaac Newton** coined "inertia" (tendency to resist change in state of rest/uniform motion); framed 3 laws of motion in **1687**. Unit newton: lowercase in full word, capital 'N' as symbol.

★ Think as a Scientist: if friction were zero on a smooth surface, would a moving object's velocity ever decrease, or would it move forever? (Sets up Newton's First Law.)

6.4 Newton's First Law of Motion

NEWTON'S FIRST LAW → An object at rest remains at rest, and an object in motion continues to move with constant velocity, UNLESS a net force acts upon it.

→ If net force = 0 → object cannot start moving or change velocity → its **acceleration is zero** (also called the Law of Inertia).

⚠ परीक्षा के लिए | "At rest" = zero velocity. "Constant velocity" (if non-zero) = motion in a straight line, same direction, unchanging magnitude — NOT the same as being at rest.

→ **Example 6.2:** Applied force = friction (equal & opposite) → net force = 0 → box continues moving with **constant velocity** (Newton's 1st law).

→ **Example 6.3 (graphs, no net force):** At rest → position-time graph flat at a value, velocity-time graph flat at zero. Constant velocity → position-time graph is a rising straight line, velocity-time graph is flat at a non-zero value.

★ If friction is zero, a force IS needed to set a rest object moving — but once moving, NO further force is needed to maintain that constant velocity. A force is needed only to CHANGE velocity or stop the object.

6.5 Newton's Second Law of Motion

→ A force produces **acceleration**. What's the relationship between net force and acceleration?

→ **Activity 6.3 (cart-pulley, varying force):** doubling force (mass of cart fixed) → **acceleration increases**.

→ **Activity 6.4 (cart-pulley, varying mass):** doubling mass of cart (force fixed) → **acceleration decreases** — acceleration is inversely related to mass.

NEWTON'S SECOND LAW → When a net force acts on an object, it accelerates in the direction of the net force. Acceleration ∝ net force, and acceleration ∝ 1/mass.

FORMULA (EQ. 6.1, 6.2) →

$$a = F/m \quad \text{or} \quad F = ma$$

→ Direction of acceleration = direction of **net force**. SI units: mass in kg, acceleration in m s^{-2} ⇒ F in **kg m s^{-2} = newton (N)**.

ONE NEWTON → The force that produces an acceleration of 1 m s^{-2} on an object of mass 1 kg.

GRAVITATIONAL FORCE (WEIGHT) →

$F = mg$ (Eq. 6.3) | $g \approx 9.8$ m s^{-2} (or 10 m s^{-2} for quick estimates), nearly constant near Earth's surface

⚠ **परीक्षा के लिए** | g (acceleration due to gravity) does NOT depend on the object's mass.

★ Threads of Curiosity: doubling force/halving mass in Activities 6.3/6.4 may not give exactly double/half acceleration in practice — due to measurement errors and friction in the cart's wheels.

Applications of Newton's Second Law

→ Cricket fielder pulls hands back while catching → **increases time** for velocity to reduce to zero → reduces acceleration → reduces force on hands → less injury.

→ Car **airbags**: inflate on collision → increase time of impact → reduce acceleration & force on passenger → fewer injuries (works best with seatbelt).

→ Cracking a coconut: high velocity + very short stopping time → ground exerts a **very large force** → breaks the shell.

→ **Example 6.4** (barbell): total mass 30 kg → F = mg = 30×9.8 = **294 N** — weightlifter applies 294 N upward to hold it steady.

→ **Example 6.5** (25 kg block, friction 50 N): (i) push 50 N → balanced → **stays at rest**. (ii) push 55 N → net force 5N → a = 5/25 = 0.2 m/s² → using s=ut+½at², displacement in 2s = **0.4 m**.

→ **Example 6.6** (1500 kg car, v-t graph): 0–5s (u=0,v=10,t=5) → a=2 m/s² → F=**3000 N** (east). 5–10s: constant velocity → **F = 0**. 10–15s (u=10,v=0,t=5) → a=−2 m/s² → F=−**3000 N** (west, opposing motion).

6.6 Newton's Third Law of Motion

NEWTON'S THIRD LAW → Whenever one object exerts a force on a second object, the second object simultaneously exerts an equal and opposite force on the first.

⚠ **परीक्षा के लिए** | These paired forces act on TWO DIFFERENT objects — so they do NOT cancel/balance each other (balancing only happens when two equal-opposite forces act on the SAME object).

→ **Activities 6.5 & 6.6** (wheeled chair pushing table; two connected spring balances): confirm forces are **equal in magnitude, opposite in direction**, acting on different objects.

Everyday Example	Third-Law Pair
Walking/running	Foot pushes ground back → ground pushes foot forward (via friction)
Climbing a tree	Legs push trunk down → friction pushes person up
Rowing a canoe	Paddle pushes water back → water pushes paddle/canoe forward
Rocket launch	Engine expels gas down → gas pushes rocket up (net force up > weight → lift-off)

→ Bridging Science & Society: grooves on shoe soles / **tyre treads** increase friction with ground/road — without friction you'd slip while pushing off.

→ Chandrayaan-3's **Vikram lander** fired engine in its direction of motion to slow down for soft landing — exhaust gas pushed opposite to motion.

→ **Example 6.7** (fruit falling): Earth & fruit pull each other equally, but Earth's mass is so huge that its acceleration (a=F/m) is negligible — only the fruit's motion is noticeable.

→ **Example 6.8** (bullet-gun recoil): force 2N on both → a(gun)=2/5=**0.4 m/s²**; a(bullet)=2/0.1=**20 m/s²** — equal forces, unequal accelerations (different masses).

★ Newton's 3rd law applies to ALL force types — contact AND non-contact (magnetic, electrostatic, gravitational).

6.7 Forces Acting on a System of Objects

→ Two boxes (masses m_1, m_2) connected by a string, pulled by force F: string tension **T** is an **internal force** (acts equal & opposite on both boxes via Newton's 3rd law) — need not be considered separately.

→ Treating the two boxes + string as ONE **system**: only the **external force F** matters.

ACCELERATION OF THE SYSTEM →

$a = F / (m_1 + m_2)$ (Eq. 6.4) — system accelerates like a single object of combined mass

→ Other external forces: gravitational force ($m_1g + m_2g$) downward, balanced by normal force (N_1+N_2) from the ground.

★ Threads of Curiosity: while walking, arms/legs move in complex ways, yet overall motion can be studied by treating the body as ONE object — science simplifies by looking at the whole system.

📌 At a Glance — Quick Recap

① Friction acts opposite to an object's direction of motion.

② **1st Law:** object at rest stays at rest, object in motion stays at constant velocity, unless net force acts.

③ **2nd Law:** net force → acceleration in its direction; $a \propto F$, $a \propto 1/m$ ($F = ma$).

④ **3rd Law:** every action force has an equal & opposite reaction force, on a different object.

⑤ Connected objects can be analysed as ONE system using only external forces.