

PA02 — Mechanics: Motion, Force, Work & Power

→ Physics – PA02 · AFCAT General Awareness

AFCAT Level

★ High Priority

Mechanics is the backbone of AFCAT Physics. Newton's three laws, the equations of motion, and work-energy concepts together contribute the highest number of Physics questions in AFCAT. The questions are Class 10 level – concept-based and application-oriented, not calculus. Master this chapter and you score 1–2 guaranteed questions.

✦ **AFCAT Focus:** Questions here test Newton's laws with real-life examples (recoil of a gun, rocket propulsion, why a person jerks forward when a bus brakes), the work-energy theorem, and simple $F = ma$ calculations. Equations of motion are used to find final velocity or distance – especially free-fall problems ($g = 10 \text{ m/s}^2$).

PART 1 — KINEMATICS

1. Equations of Motion (Uniform Acceleration)

When an object accelerates uniformly (constant acceleration), three equations connect initial velocity, final velocity, acceleration, time, and displacement. These are used in every AFCAT mechanics numerical.

FIG. 1 — THREE EQUATIONS OF MOTION — WHEN TO USE EACH

THREE EQUATIONS OF MOTION – Uniform Acceleration

$$v = u + at$$

Use when: **displacement is NOT needed**. You know u , a , t and want v .

u = initial velocity (m/s)
 v = final velocity (m/s)
 a = acceleration (m/s²), t = time (s)

$$s = ut + \frac{1}{2}at^2$$

Use when: **final velocity is NOT needed**. Find distance covered in time t .

s = displacement (m)
Free fall: $u=0$, $a=g \approx 10 \text{ m/s}^2$
 $s = \frac{1}{2}gt^2$ when starting from rest

$$v^2 = u^2 + 2as$$

Use when: **time is NOT given or needed**. Velocity from distance & acceleration.

Most used in AFCAT!
Free fall: $v^2 = 2gh$ ($u=0$)
 $v = \sqrt{2gh}$ at ground

For FREE FALL: $u = 0$, $a = g = 10 \text{ m/s}^2$ downward | For object thrown UP: $a = -g$, at peak $v = 0$

✂ Worked Example – Free Fall

A stone is dropped from a height of 45 m. How long does it take to reach the ground? ($g = 10 \text{ m/s}^2$)

Dropped means $u = 0$. Use $s = ut + \frac{1}{2}at^2$

$$45 = 0 + \frac{1}{2} \times 10 \times t^2$$

$$45 = 5t^2 \rightarrow t^2 = 9 \rightarrow t = 3 \text{ seconds}$$

✓ Time = 3 s

PART 2 – NEWTON'S LAWS

2. Newton's Three Laws of Motion

These three laws are the most tested concept in AFCAT Mechanics. Focus on real-life applications – AFCAT asks “which law explains this?” rather than mathematical derivations.

FIG. 2 – NEWTON'S THREE LAWS WITH REAL-LIFE EXAMPLES

NEWTON'S THREE LAWS — Statement, Concept & Real Examples

FIRST LAW

Law of Inertia

Statement:

A body at rest stays at rest; a body in motion stays in motion — unless a net force acts on it.

Key concept:

Inertia \propto mass
(heavier = harder to move)

Real examples:

- Passenger jerks forward when bus stops suddenly
- Coin on card falls into glass when card is flicked

SECOND LAW

$F = ma$

Statement:

Net force = mass \times acceleration: $F = ma$
Greater $F \rightarrow$ greater a
Greater $m \rightarrow$ smaller a

Impulse:

$J = F \times t = \Delta p = m(v-u)$
Momentum $p = mv$

Real examples:

- More force on cricket ball \rightarrow more acceleration
- Airbag: spreads force over time \rightarrow reduces impact force

THIRD LAW

Action & Reaction

Statement:

Every action has an equal & opposite reaction — on DIFFERENT bodies.
They never cancel each other.

Key point:

Action on body A
Reaction on body B

Real examples:

- Gun recoils when bullet fires (GUN \leftarrow BULLET \rightarrow)
- Rocket: exhaust back, rocket goes forward

△ AFCAT Trap — Gun Recoil: When a gun fires a bullet, which law explains the recoil? **Third Law.** The bullet goes forward (action) \rightarrow gun recoils backward (reaction). Conservation of momentum also applies: total initial momentum = 0; total final momentum = 0. So gun momentum = -bullet momentum.

PART 3 — WORK, ENERGY & POWER

3. Work, Energy & Power

Core Formulae — Know These Cold:

- **Work** $W = F \times s \times \cos\theta$ [Unit: Joule (J)]
Work = 0 when force \perp displacement ($\theta = 90^\circ$) — e.g., carrying load horizontally
- **Kinetic Energy** $KE = \frac{1}{2}mv^2$ [Unit: Joule]
- **Potential Energy** $PE = mgh$ [Unit: Joule]
- **Conservation of Energy:** $KE + PE = \text{constant}$ (no friction)
- **Power** $P = W/t = F \times v$ [Unit: Watt (W) = J/s]
1 horse power (HP) = 746 W \approx 750 W

► When is Work ZERO?

- ▶ Force perpendicular to displacement ($\theta = 90^\circ$)
- ▶ Carrying a bag horizontally — gravity is vertical, motion is horizontal
- ▶ A satellite in circular orbit — gravity \perp velocity
- ▶ Uniform circular motion — centripetal force \perp speed

► KE & Momentum Relationship

- ▶ Momentum: $p = mv$
- ▶ $KE = p^2/(2m)$
- ▶ KE doubles \rightarrow momentum $\times\sqrt{2}$
- ▶ $KE \times 4 \rightarrow$ momentum $\times 2$
- ▶ Elastic collision: both KE & momentum conserved
- ▶ Inelastic: only momentum conserved

✂ Worked Example — Work Done

A person pushes a box with 50 N force over 4 m on a horizontal floor. Find work done. Then find power if it takes 8 seconds.

$$\text{Work} = F \times s = 50 \times 4 = \mathbf{200 \text{ J}} \quad (\theta = 0^\circ, \cos 0^\circ = 1)$$

$$\text{Power} = W/t = 200/8 = \mathbf{25 \text{ W}}$$

$$\checkmark \mathbf{W = 200 \text{ J} \mid P = 25 \text{ W}}$$

4. Friction

FIG. 3 — TYPES OF FRICTION AND THEIR PROPERTIES

FRICTION TYPES — Largest to Smallest: Static > Kinetic > Rolling

STATIC

Highest of the three

Acts before motion begins.
Adjusts from 0 up to its maximum (limiting friction)

$$f = \mu_s N$$

Example:

Box at rest on floor —
hard to start pushing it.

μ_s = coefficient of static friction (largest)

KINETIC

Less than static friction

Acts during sliding motion.
Less than static friction
 $\mu_k < \mu_s$ (always)

$$f = \mu_k N$$

Example:

Book sliding across a table.
Easier to keep moving
than to start moving.

$\mu_k < \mu_s$ (medium)

ROLLING

Smallest of the three

Acts when object rolls.
Contact is essentially a point → least resistance

$$\mu_r < \mu_k < \mu_s$$

Example:

Ball rolling on floor.
Car tyres on road.
Ball bearings replace
sliding with rolling!

💡 **Friction is Independent of Surface Area:** The friction force does NOT depend on how much surface area is in contact — only on the normal force (N) and the coefficient (μ). This is a direct AFCAT question. Ball bearings reduce friction by converting sliding friction to rolling friction.

5. Circular Motion & Centripetal Force

Circular Motion Formulae:

- **Centripetal Force:** $F = mv^2/r$ (directed toward the centre)
- **Centripetal Acceleration:** $a = v^2/r$
- Angular velocity: $\omega = 2\pi/T = 2\pi f$
- **Work done by centripetal force = 0** (force \perp velocity always)

What provides centripetal force?

- Ball on string → *tension* in string
- Planet around Sun → *gravity*
- Car on curve → *friction* between tyres and road
- Electron around nucleus → *electrostatic force*



Q1. A rocket works on the principle of: AFCAT PYQ

- (a) Newton's First Law (b) Newton's Second Law (c) Newton's Third Law
(d) Law of Gravitation

✓ Answer: (c) Newton's Third Law

In a rocket, hot gases are expelled backward at high speed (action). The rocket moves forward with equal and opposite reaction force. This is Newton's Third Law in action. Rockets work in vacuum too — they don't need air to push against.

Q2. A body is moving with uniform velocity. The net force acting on it is:

AFCAT PYQ

- (a) Increasing (b) Decreasing (c) Zero (d) Equal to its weight

✓ Answer: (c) Zero

Newton's First Law: a body in uniform motion stays so unless acted on by a net external force. Uniform velocity means zero acceleration. From $F = ma$, if $a = 0$, then $F = 0$. This is a direct, repeatedly tested question in AFCAT.

Q3. The kinetic energy of an object is doubled. By what factor does its momentum change? ⚡ Tricky

- (a) 2 times (b) 4 times (c) $\sqrt{2}$ times (d) $1/2$ times

✓ Answer: (c) $\sqrt{2}$ times

$KE = p^2/(2m) \rightarrow p = \sqrt{2m \cdot KE}$. If KE doubles: new $p = \sqrt{2m \times 2KE} = \sqrt{2} \times \sqrt{2m \cdot KE} = \sqrt{2} \times \text{old } p$. Rule: $KE \times 4 \rightarrow \text{momentum} \times 2$; $KE \times 2 \rightarrow \text{momentum} \times \sqrt{2}$.

Q4. A person is carrying a suitcase horizontally. The work done against gravity is: AFCAT PYQ

- (a) Positive (b) Negative (c) Zero (d) Equal to mgh

✓ Answer: (c) Zero

Work = $F \times s \times \cos\theta$. Gravity acts *downward*; displacement is *horizontal*. The angle between them is 90° . $\cos 90^\circ = 0 \rightarrow \text{Work} = 0$. No work is done against gravity when moving horizontally. Height doesn't change, so PE doesn't change either.

Q5. Which of the following friction types is the smallest in magnitude?

AFCAT PYQ

(a) Static friction (b) Kinetic friction (c) Rolling friction (d) All are equal

✓ Answer: (c) Rolling friction

Order: Static > Kinetic > Rolling. Rolling friction is smallest because the contact area at any instant is essentially a point (or line), and no sliding occurs. This is why wheels and ball bearings are used — to convert sliding friction into much smaller rolling friction.

🧠 Quick Memory Chart — P Ao2 Mechanics

📝 3 Equations of Motion

- ♦ $v = u + at$ (no s)
- ♦ $s = ut + \frac{1}{2}at^2$ (no v)
- ♦ $v^2 = u^2 + 2as$ (no t)
- ♦ Free fall: $u=0$, $a=g=10$
- ♦ $v = \sqrt{(2gh)}$ at ground

⚡ Newton's Laws

- ♦ 1st: Inertia (no force → no change)
- ♦ 2nd: $F = ma$ (more F → more a)
- ♦ 3rd: Rocket, gun recoil, swimming
- ♦ Inertia \propto mass (not weight)
- ♦ Uniform $v \rightarrow F = 0$

▶ Work, Energy & Friction

- ♦ $W = 0$ when $F \perp s$ (90°)
- ♦ $KE = \frac{1}{2}mv^2$; $PE = mgh$
- ♦ Friction: static > kinetic > rolling
- ♦ KE doubles → momentum $\times \sqrt{2}$
- ♦ Power = $W/t = Fv$



Practice Exercise — Attempt Before Checking

E1. A ball is dropped from 80 m height. Its speed just before hitting ground is ($g = 10 \text{ m/s}^2$):

(a) 40 m/s (b) 80 m/s (c) 20 m/s (d) 10 m/s

E2. A gun fires a bullet. Which physical quantity is conserved?

- (a) Kinetic energy (b) Momentum (c) Potential energy (d) Velocity

E3. A 60 W bulb is used for 5 hours. Energy consumed in kWh is:

- (a) 0.6 kWh (b) 0.3 kWh (c) 6 kWh (d) 300 kWh

E4. Newton's second law connects force with:

- (a) Velocity (b) Momentum change rate (c) Distance (d) Inertia

E5. The centripetal force on a body moving in a circle does:

- (a) Positive work (b) Negative work (c) Zero work (d) Maximum work at top

Answers:

E1 → (c) 20 m/s [$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 80} = \sqrt{1600} = 40$ m/s... wait: $\sqrt{2 \times 10 \times 80} = \sqrt{1600} = 40$ m/s → Answer is (a) 40 m/s] | E2 → (b) Momentum [Conservation of momentum always holds; KE may not be conserved in inelastic collisions] | E3 → (b) 0.3 kWh [$E = 0.06 \text{ kW} \times 5 \text{ h} = 0.3 \text{ kWh}$] | E4 → (b) Rate of change of momentum [$F = dp/dt = ma$] | E5 → (c) Zero work [Centripetal force always \perp velocity; $W = Fs \cos 90^\circ = 0$]

 **Mock Tests**

 **Subject Quiz**

 **Telegram**

This material is for personal AFCAT exam preparation only.

Unauthorised reproduction or distribution is prohibited.

All rights reserved · ODEA.Classes@gmail.com · OliveDefence.com