



LOGIC BLOOM · PHYSICS · CLASS 11

Newton's Laws of Motion

Inertia · momentum · free-body diagrams · friction · pseudo forces
NEET, JEE Main and JEE Advanced

Every problem in this chapter is the same three moves. Pick one body, draw every force on it, then write $F = ma$ along two directions. The hard problems only hide which body to pick.

11 Sections

13 Diagrams

Advanced Tier

Worked Problems

Fact Sheet

Contents

1	Inertia and the First Law	<i>and how to spot a frame that lies</i>
2	Momentum, the Second Law and Impulse	<i>force is the rate of change of momentum</i>
3	The Third Law and Conservation of Momentum	<i>pairs act on different bodies</i>
4	Free-Body Diagrams and Equilibrium	<i>the one skill the chapter tests</i>
5	Normal Force, Tension and Springs	<i>and why the lift scale changes</i>
6	Connected Bodies and Constraints	<i>count the string, not the forces</i>
7	Friction	<i>needed against available</i>
8	Circular Motion Dynamics	<i>which real force points inward</i>
9	Pseudo Forces	<i>JEE Advanced tier begins</i>
10	The Moving Wedge	<i>two bodies, one contact</i>
11	Advanced Worked Problems	<i>five problems, five techniques</i>
★	One-Page Fact Sheet	<i>every result for revision day</i>

How to Read This Set

Sections 1 to 8 cover the full syllabus for **NEET** and **JEE Main**. Sections 9 to 11 are the **JEE Advanced** layer. There you must build the route yourself.

THE WHOLE CHAPTER IN ONE LINE

One body. Every force on it. $F = ma$ along two directions.

Pulleys, wedges, lifts and banked roads all fall to this. Each section below adds one new kind of force or one new trick for choosing the body.



THINK IT
THROUGH

WHAT THIS CHAPTER IS WORTH

- It appears in **every NEET and JEE Main paper**, often as two questions or more.
- Its method returns in work and energy, rotation, fluids and electrostatics.
- A clean free-body diagram fixes most mistakes before any algebra starts.



TRAP ALERT

THE HABIT THAT FIXES THIS CHAPTER

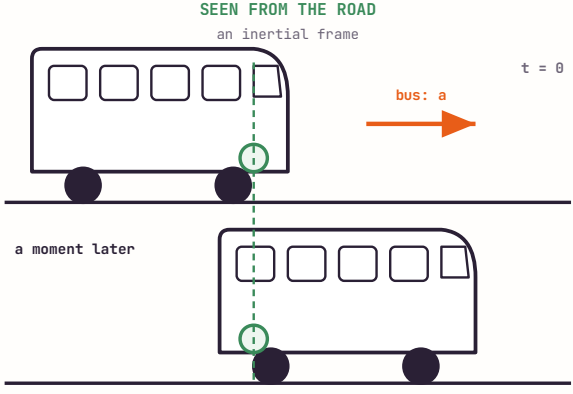
- **Never write an equation before the free-body diagram.** Draw first, then write.
- Draw forces that act **on** the chosen body only. Forces it exerts on others do not belong.
- Choose the positive direction first, then give every force a sign from it.

1 Inertia and the First Law

A body keeps its velocity unless a net force acts on it. At rest stays at rest. Moving stays moving, in a straight line at the same speed. This resistance to change is called **inertia**, and mass measures it.

THE BUS SPEEDS UP. WHAT DOES THE BALL ON ITS SMOOTH FLOOR DO?

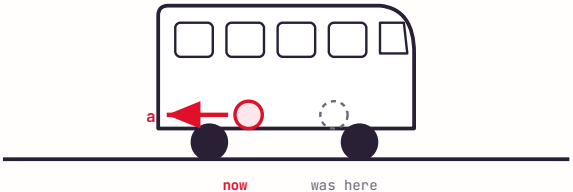
SEEN FROM THE ROAD
an inertial frame



The ball stays at the same spot on the road.
No force on it, no acceleration.

SEEN FROM INSIDE THE BUS
a non-inertial frame

The ball speeds up backward.
No force causes it: the first law fails.



now was here

Newton's laws hold only in frames that are not accelerating. The first law is the test.

The same ball, watched from the road and from inside the bus. Only one view obeys Newton's laws.

THE FIRST LAW

If $\vec{F}_{net} = 0$, then $\vec{v}$ is constant.

A frame where this holds is an **inertial frame**. The ground is one, to a very good approximation.

EVERYDAY CASE	WHAT INERTIA DOES
bus brakes suddenly	your body keeps moving forward, so you lurch ahead
bus starts suddenly	your body stays behind, so you fall back
carpet beaten with a stick	the carpet moves, the dust stays and falls out
coin on a card over a glass	flick the card away, the coin drops into the glass



MOTION DOES NOT NEED A FORCE

- **A moving body does not need a force to keep moving.** It needs a force to change its velocity.
- Things slow down on Earth because friction and air push back. Remove those and they coast forever.
- So a constant velocity always means a net force of zero.

Momentum, the Second Law and Impulse

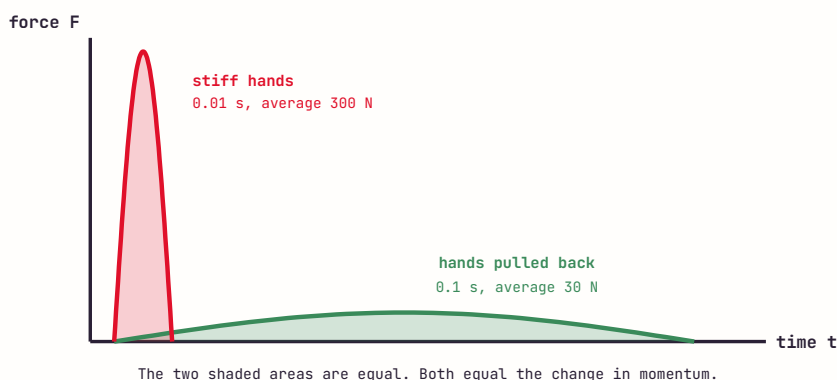
Momentum is mass times velocity, $\vec{p} = m\vec{v}$. The second law says how fast it changes.

THE SECOND LAW

$$\vec{F}_{net} = \frac{d\vec{p}}{dt}$$

For a fixed mass this becomes $\vec{F}_{net} = m\vec{a}$. Use it along x and y separately.

CATCHING A BALL: SAME CHANGE IN MOMENTUM, VERY DIFFERENT FORCE



IMPULSE = AREA

$J = \text{area under } F-t$

$J = \Delta p$

A 0.15 kg BALL AT 20 m/s

$\Delta p = 0.15 \times 20 = 3 \text{ N s}$

stopped in 0.01 s: 300 N

stopped in 0.1 s: 30 N

ten times the time, a tenth of the force

Pulling your hands back stretches the time. The same area then needs a much lower force.

IMPULSE

$$\vec{J} = \int \vec{F} dt = \Delta \vec{p}$$

For a short, sharp hit, use the average force: $F_{avg} = \frac{\Delta p}{\Delta t}$.

WORKED EXAMPLE 1

A 0.2 kg ball hits a wall at 10 m/s, at 30° to the wall. It bounces off at the same speed and angle. Contact lasts 0.02 s. Find the average force.

Only the part of velocity **across** the wall reverses. Along the wall nothing changes.

The angle is with the wall, so that part is $10 \sin 30^\circ = 5 \text{ m/s}$.

$\Delta p = 0.2 \times (5 + 5) = 2 \text{ N s}$. So $F = \frac{2}{0.02}$.

Answer: 100 N, pointing away from the wall

WORKED EXAMPLE 2

Sand drops onto a conveyor belt at 2 kg/s. The belt runs at a steady 3 m/s. What force keeps it moving, and what power does that take?

The belt's own mass is not changing speed. The new sand is, from 0 to 3 m/s.

Momentum added each second: $v \frac{dm}{dt} = 3 \times 2 = 6$ N. That is the force.

Power = $Fv = 6 \times 3 = 18$ W.

Answer: 6 N and 18 W



THINK IT
THROUGH

WHERE DID HALF THE POWER GO?

- The sand gains kinetic energy at $\frac{1}{2}v^2 \frac{dm}{dt} = 9$ W, only half of 18 W.
- The other 9 W is lost as heat. Each grain slides on the belt until it catches up.
- This split is always exactly half, whatever the speed.



TRAP ALERT

READ WHICH ANGLE YOU ARE GIVEN

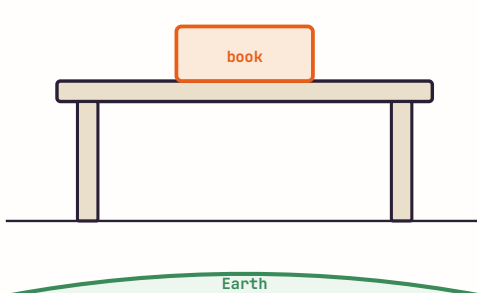
- **At 30° to the wall is not the same as 30° to the normal.** Draw it before you pick sin or cos.
- Using cos 30° here would give 173 N, which is a listed wrong option in many papers.

The Third Law and Conservation of Momentum

Forces come in pairs. If A pushes B, then B pushes A back, equally hard and in the opposite direction.

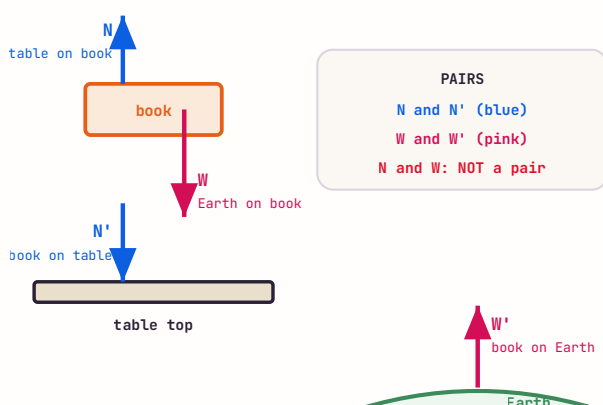
A BOOK ON A TABLE: FOUR FORCES, TWO THIRD-LAW PAIRS

THE SCENE



Earth

PULLED APART TO SEE WHO PUSHES WHOM



PAIRS

N and N' (blue)

W and W' (pink)

N and W: NOT a pair

Earth

A pair acts on two different bodies. N and W both act on the book, so they are not a pair.

Pull the bodies apart and each force lands on a different body. That is how you find the partner.

A THIRD-LAW PAIR ALWAYS	SO
acts on two different bodies	the two forces never cancel each other
is the same type of force	a normal force pairs with a normal force, gravity with gravity
acts at the same instant	there is no delay between action and reaction

CONSERVATION OF MOMENTUM

Inside a system, the pairs cancel in the total. So if no external force acts,

$$m_1 \vec{v}_1 + m_2 \vec{v}_2 + \dots = \text{constant}$$

WORKED EXAMPLE 1

A 3 kg shell at rest bursts into three equal pieces. Two fly off at right angles, each at 10 m/s. Find the velocity of the third.

The total momentum was zero, so it stays zero.

The two known pieces carry 10 kg m/s each, at right angles. Their total is $\sqrt{10^2 + 10^2} = 14.1$ kg m/s.

The third piece must cancel this. It has mass 1 kg.

Answer: 14.1 m/s, at 135° to each of the other two

WORKED EXAMPLE 2

A 5000 kg rocket ejects gas at 800 m/s relative to itself. How much gas must it burn each second to rise with an acceleration of 20 m/s² at launch?

The gas carries away momentum at $u \frac{dm}{dt}$ each second. That is the thrust.

The rocket needs thrust $-mg = ma$, so thrust = $5000 \times (10 + 20) = 150000$ N.

$$\text{So } \frac{dm}{dt} = \frac{150000}{800}.$$

Answer: 187.5 kg of gas every second



THINK IT
THROUGH

CONSERVE MOMENTUM ONE DIRECTION AT A TIME

- Momentum is a vector. Each direction obeys its own rule.
- If outside forces act only vertically, horizontal momentum is still conserved.
- Fire a cannon at an angle from a smooth floor. It recoils sideways, and the floor takes the vertical kick.
- Section 10 uses this to check a block sliding on a free wedge.



TRAP ALERT

THE PAIR THAT IS NOT A PAIR

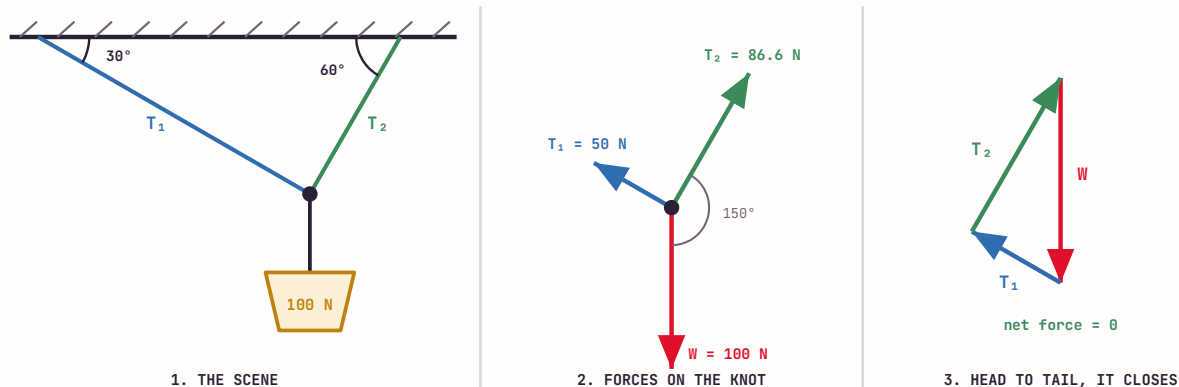
- **The normal force and the weight of a book are not a third-law pair.**
- They are equal only because the book is not accelerating. In a lift they differ.
- The weight's real partner is the book pulling the whole Earth upward.

Free-Body Diagrams and Equilibrium

A free-body diagram shows one body alone, with every force acting on it. It is the most tested skill in this chapter.

STEP	WHAT TO DO
1. choose	pick one body, or one knot, or a group moving together
2. isolate	draw it alone, away from everything it touches
3. gravity	add mg straight down
4. contacts	add one force for each thing it touches: normal, friction, tension, spring
5. axes	pick x and y , ideally along the acceleration
6. equations	write $\sum F_x = ma_x$ and $\sum F_y = ma_y$

A 100 N LAMP ON TWO STRINGS: SCENE, FREE-BODY DIAGRAM, FORCE TRIANGLE



Lami: $T_1 / \sin 150^\circ = T_2 / \sin 120^\circ = W / \sin 90^\circ$, so $T_1 = 50 \text{ N}$ and $T_2 = 86.6 \text{ N}$

The knot is the body to pick. Its three forces close into a triangle, because the net force is zero.

LAMI'S THEOREM, FOR THREE FORCES IN EQUILIBRIUM

$$\frac{F_1}{\sin \alpha} = \frac{F_2}{\sin \beta} = \frac{F_3}{\sin \gamma}$$

Each angle is the one **between the other two** forces.

WORKED EXAMPLE 1

A block of mass m rests on a smooth incline of angle θ . A horizontal push F holds it still. Find F and the normal force.

Forces: mg down, N at right angles to the slope, F horizontal.

Along the slope: $F\cos\theta = mg\sin\theta$, so $F = mg\tan\theta$.

Across the slope: $N = mg\cos\theta + F\sin\theta = \frac{mg}{\cos\theta}$.

Answer: $F = mg\tan\theta$ and $N = \frac{mg}{\cos\theta}$

WORKED EXAMPLE 2

A 4 kg block sits on a smooth 30° incline. A string runs over a pulley at the top to a hanging 1 kg block. Which way do they move, and how fast do they speed up?

Compare the two pulls first. Down the slope: $4 \times 10 \times \sin 30^\circ = 20$ N. Hanging block: 10 N.

So the 4 kg block slides down the slope. Take that as positive.

System: $a = \frac{20 - 10}{5} = 2$ m/s². Hanging block: $T - 10 = 1 \times 2$, so $T = 12$ N.

Answer: the 4 kg block slides down at 2 m/s², and $T = 12$ N



TWO SLIPS IN EVERY FREE-BODY DIAGRAM

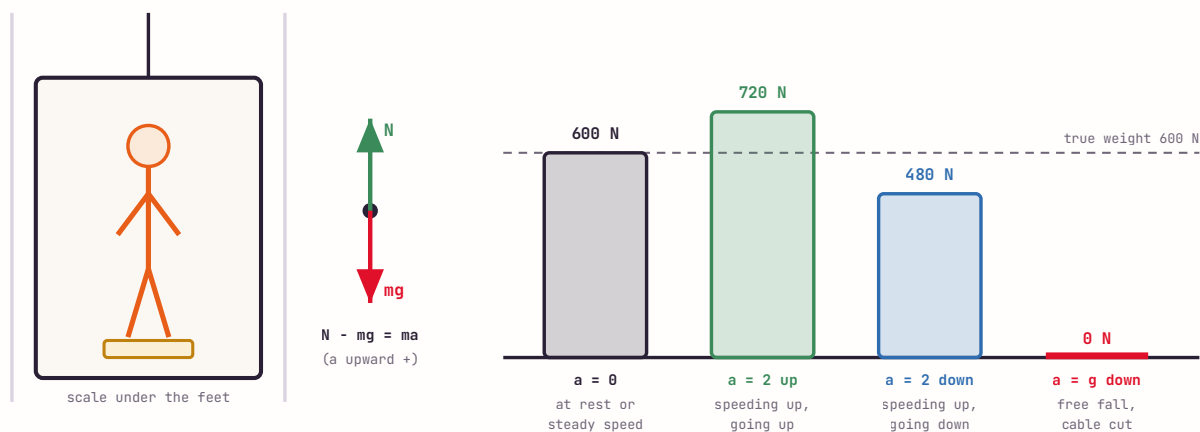
- **Adding ma as a force.** In the ground frame, ma is the result, not a force.
- **Assuming $N = mg$.** Here the push adds to N , so N is bigger than $mg \cos \theta$.

Normal Force, Tension and Springs

Only a few kinds of force appear in mechanics problems. Each has fixed rules about its direction.

FORCE	DIRECTION	RULE TO REMEMBER
weight	straight down	mg , whatever else is happening
normal	at right angles to the contact surface	only pushes; it becomes zero when contact is lost
tension	along the string, away from the body	only pulls; the same all along a light string
spring	along the spring	kx , and it cannot jump in an instant
friction	along the surface	opposes slipping, or the tendency to slip

A 60 kg PERSON ON A SCALE IN A LIFT: WHAT THE SCALE READS



The scale shows $N = m(g + a)$. Direction of acceleration matters, not direction of motion.

The scale reads the normal force, not the weight. Only the acceleration changes it.

WORKED EXAMPLE

A 400 kg lift carries a 60 kg person and speeds up going upward at 2 m/s^2 . Find the cable tension and the scale reading.

Lift and person together: $T - (460)(10) = 460 \times 2$, so $T = 460 \times 12$.

Person alone: $N - 600 = 60 \times 2$, so $N = 720 \text{ N}$.

Answer: cable 5520 N, scale 720 N



THINK IT
THROUGH

WHEN THE ROPE HAS MASS

- A light string has the same tension everywhere. A heavy rope does not.
- Pull a rope of length L along a smooth floor with force F . At distance x from your hand,
$$T = F\left(1 - \frac{x}{L}\right).$$
- Each part of the rope must pull the rest of the rope behind it.



TRAP ALERT

UP OR DOWN IS NOT THE POINT

- **Moving down does not mean the scale reads less.**
- A lift going down but slowing down accelerates upward. The scale reads more.
- Always find the direction of acceleration, then use $N = m(g + a)$.

Connected Bodies and Constraints

Blocks joined by strings share one acceleration, or a fixed ratio of accelerations. Find that link first. Then write one equation per body.

WORKED EXAMPLE 1

Blocks of 2, 3 and 5 kg sit in a row on a smooth floor, joined by light strings. A 20 N pull acts on the 5 kg block. Find each tension.

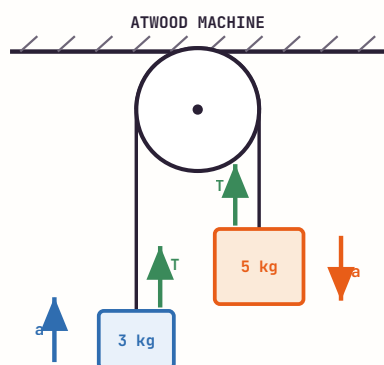
Whole system: $a = \frac{20}{10} = 2 \text{ m/s}^2$.

The string behind the 5 kg block drags $2 + 3 = 5 \text{ kg}$. So $T_1 = 5 \times 2 = 10 \text{ N}$.

The last string drags only the 2 kg block. So $T_2 = 2 \times 2 = 4 \text{ N}$.

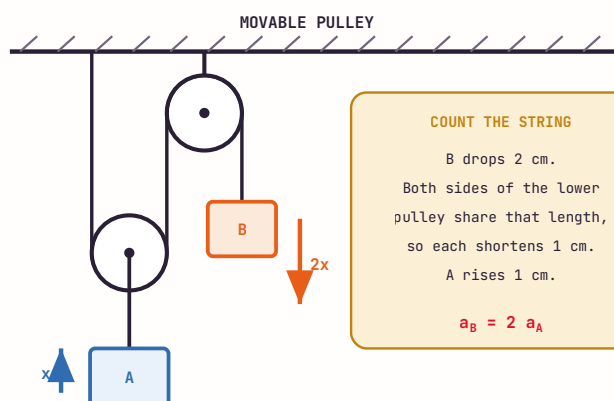
Answer: 10 N and 4 N

TWO STRING SYSTEMS: THE ATWOOD MACHINE AND A MOVABLE PULLEY



$$a = (5 - 3)g / 8 = 2.5 \text{ m/s}^2$$

$$T = 2(3)(5)g / 8 = 37.5 \text{ N}$$



COUNT THE STRING

B drops 2 cm.
Both sides of the lower pulley share that length, so each shortens 1 cm.
A rises 1 cm.

$$a_B = 2 a_A$$

Length: $2y_A + y_B = \text{constant}$
so $2a_A + a_B = 0$, and A feels $2T$

Left, both blocks share one acceleration. Right, the string length forces B to move twice as far as A.

THE CONSTRAINT METHOD

Write the total length of each string in terms of block positions.

Set it constant. Differentiate twice. The result links the accelerations.

WORKED EXAMPLE 2

In the movable pulley set-up, A and B are both 2 kg. Find the acceleration of each.

Let A rise with acceleration a . Then B falls with $2a$.

B: $20 - T = 2(2a)$. A feels the string twice: $2T - 20 = 2a$.

From the second, $T = 10 + a$. Put it in the first: $10 - a = 4a$, so $a = 2 \text{ m/s}^2$.

Answer: A rises at 2 m/s^2 , B falls at 4 m/s^2 , and $T = 12 \text{ N}$

SET-UP	CONSTRAINT
two blocks on one string over a fixed pulley	same size of acceleration
block hanging from a movable pulley	the free end moves twice as fast
block on a wedge	no motion across the slope, in the wedge frame
two blocks joined by a rigid rod	same acceleration along the rod



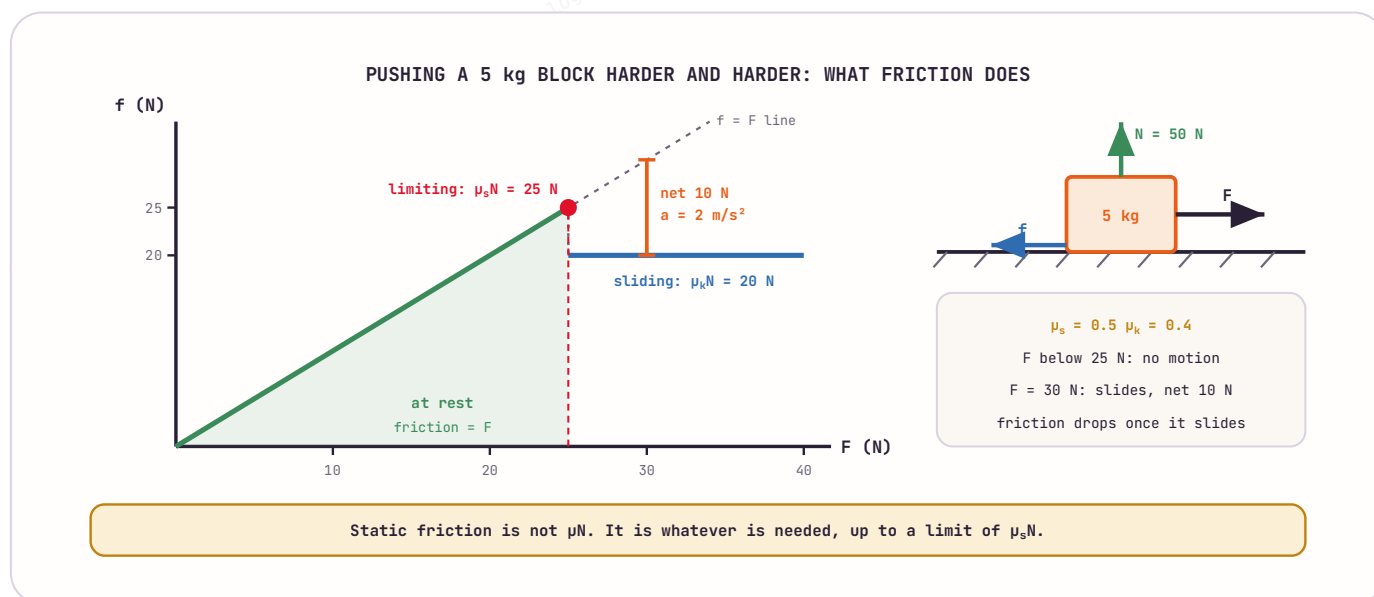
TRAP ALERT

EQUAL MASSES DO NOT MEAN BALANCE

- **Two equal masses on a movable pulley still move.** A is held by $2T$, B by only T .
- Always write the constraint first. Guessing a shared acceleration gives a wrong answer.

7 Friction

Friction acts along the surface and opposes slipping. Static friction adjusts itself, up to a limit. Kinetic friction is fixed once the surfaces slide.



Friction follows the push exactly until the peak. After that it drops to a fixed, smaller value.



▶ PLAY

STILL GUESSING THE FRICTION?

Push the block and watch friction match you.

Drag the force slider. Friction grows with your push, hits the limit, then drops as the block breaks free. logicbloom.co.in/download · Free to start.



SCAN

CASE ON AN INCLINE OF ANGLE θ	RESULT
block stays at rest	friction = $mg \sin \theta$, not μN
steepest angle it can rest at	$\tan \theta = \mu_s$, the angle of repose
sliding down	$a = g(\sin \theta - \mu_k \cos \theta)$
pushed up, sliding up	slows at $g(\sin \theta + \mu_k \cos \theta)$

THE SLIP TEST

1. Assume the surfaces do **not** slip. Find the friction needed.
2. Compare it with the most available, $\mu_s N$.
3. Needed is less? No slip, and your answer stands. More? Redo with $\mu_k N$.

WORKED EXAMPLE 1

A 2 kg block sits on a 4 kg block. Friction between them is 0.3. The floor is smooth. A force F pulls the lower block. Find the largest F with no slipping, and the accelerations when $F = 30$ N.

Only friction drives the top block. Its largest acceleration is $\mu g = 3 \text{ m/s}^2$.

Moving together at 3 m/s^2 needs $F = 6 \times 3 = 18 \text{ N}$.

At 30 N they slip. Top: 3 m/s^2 . Bottom: $\frac{30-6}{4} = 6 \text{ m/s}^2$.

Answer: 18 N; then 3 m/s^2 and 6 m/s^2

WORKED EXAMPLE 2

A 2 kg block is placed on a 37° incline with friction 0.5. Does it slide? What range of force up the slope keeps it still?

Down-slope pull: $mg \sin 37^\circ = 12 \text{ N}$. Most friction: $\mu mg \cos 37^\circ = 8 \text{ N}$. So it slides.

To hold it, friction can help either way. Smallest push: $12 - 8 = 4 \text{ N}$.

Largest push before it slides up: $12 + 8 = 20 \text{ N}$.

Answer: it slides; any push from 4 N to 20 N holds it



TRAP ALERT

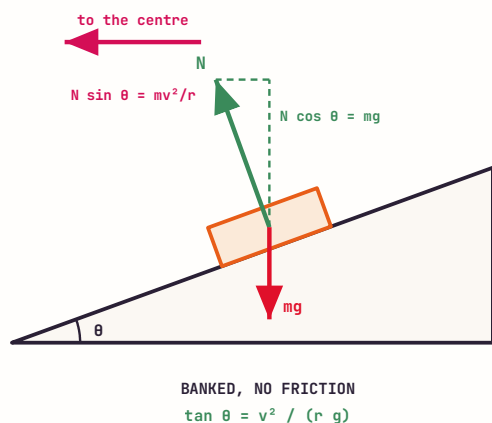
FRICTION CAN PUSH THINGS FORWARD

- **Friction opposes slipping, not motion.** On the top block it points forward.
- It is the only force that makes the top block speed up at all.

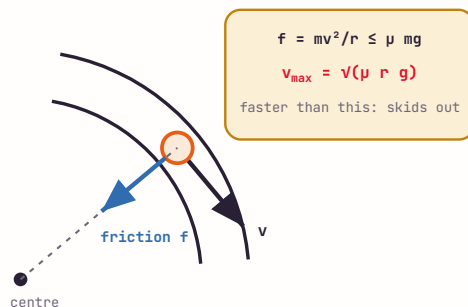
Circular Motion Dynamics

A body moving in a circle accelerates toward the centre, at $\frac{v^2}{r}$. Some real force must supply $\frac{mv^2}{r}$. Centripetal force is that job, not a new force.

TURNING A CAR: WHICH REAL FORCE POINTS TO THE CENTRE?



FLAT ROAD, SEEN FROM ABOVE



Banking tilts the normal force so part of it points inward. On a flat road, only friction can do that job.

SITUATION	WHAT SUPPLIES THE INWARD FORCE	RESULT
car on a flat curve	friction	$v_{\max} = \sqrt{\mu r g}$
banked road, no friction	part of the normal force	$\tan \theta = \frac{v^2}{r g}$
stone on a string, horizontal circle	tension	$T = \frac{mv^2}{r}$
conical pendulum	part of the tension	$\tan \theta = \frac{v^2}{r g}$

WORKED EXAMPLE 1

A curve has radius 100 m and friction 0.4. Find the top speed on a flat road. Then bank it at $\tan \theta = 0.4$ and find the new top speed.

Flat: $v = \sqrt{0.4 \times 100 \times 10} = 20$ m/s.

Banked, with friction pointing down the slope at top speed:

$$v^2 = r g \frac{\tan \theta + \mu}{1 - \mu \tan \theta} = 1000 \times \frac{0.8}{0.84} = 952.$$

Answer: 20 m/s flat; 30.9 m/s banked

WORKED EXAMPLE 2

A bob on a 1 m string moves in a horizontal circle. The string makes 60° with the vertical. Find the tension and the time for one turn.

Vertical: $T \cos 60^\circ = mg$, so $T = 2mg$.

Horizontal: $T \sin 60^\circ = m\omega^2(L \sin 60^\circ)$, so $\omega^2 = \frac{T}{mL} = 20$.

Time for one turn $= \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{20}}$.

Answer: $T = 2mg$, and one turn takes 1.40 s



THINK IT
THROUGH

THE ROTOR RIDE: FRICTION HOLDS YOU UP

- In a spinning drum you press against the wall. The normal force points to the centre and supplies $m\omega^2 r$.
- Friction on the wall then holds you up. You need $\mu m\omega^2 r \geq mg$.
- So the floor can drop away once $\omega \geq \sqrt{\frac{g}{\mu r}}$. For $r = 2$ m and friction 0.5, that is 3.16 rad/s.
- Your mass cancels. A child and an adult are both safe at the same speed.



TRAP ALERT

NEVER ADD MV^2/R TO THE DIAGRAM

- **Centripetal force is not an extra arrow.** Draw only real forces.
- Then set the inward part of their total equal to $\frac{mv^2}{r}$.

The JEE Advanced layer

Everything so far is complete for NEET and JEE Main. From here each problem needs a route you build yourself. No single formula reaches the answer.

9 Pseudo Forces

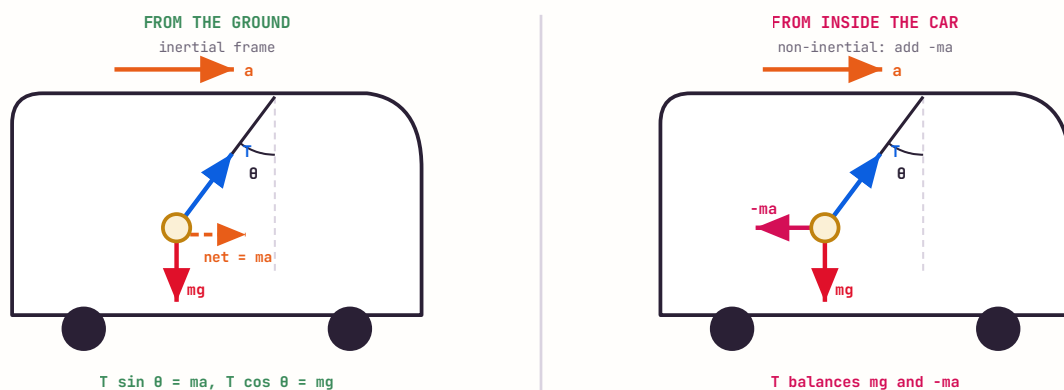
Sometimes it is easier to work inside an accelerating box, a lift, a car or a wedge. Newton's laws fail there, as the bus showed. One fix makes them work again.

THE RULE FOR AN ACCELERATING FRAME

If your frame accelerates at $\vec{a}_0$, add a force $-\vec{m}\vec{a}_0$ to every body.

Then use $\vec{F} = m\vec{a}$ as usual, with all accelerations measured in your frame.

A PENDULUM IN A CAR THAT SPEEDS UP AT 7.5 m/s^2



Both give $\tan \theta = a / g = 0.75$, so $\theta = 37^\circ$. Inside, gravity feels like $g_{\text{eff}} = 12.5 \text{ m/s}^2$.

Two views of one pendulum. The car view adds a backward pseudo force and then treats the bob as balanced.



▶ PLAY

PSEUDO FORCES STILL FEEL MADE UP?

Ride inside the car and watch the pendulum lean.

Change the car's acceleration. The bob tilts to $\tan \theta = a/g$, and the force arrows switch between the two frames. logicbloom.co.in/download · Free to start.



SCAN

WORKED EXAMPLE

An Atwood machine with 3 kg and 5 kg blocks hangs inside a lift. The lift speeds up upward at 2 m/s^2 . Find the acceleration of the blocks relative to the lift, and the tension.

In the lift frame, each block feels an extra 2m downward. So gravity behaves like $g_{\text{eff}} = 12 \text{ m/s}^2$.

Use the usual results with 12 in place of 10: $a = \frac{2 \times 12}{8} = 3 \text{ m/s}^2$.

$$T = \frac{2 \times 3 \times 5 \times 12}{8} = 45 \text{ N}.$$

Answer: 3 m/s^2 relative to the lift, and $T = 45 \text{ N}$



THINK IT
THROUGH

ROTATING FRAMES

- In a frame spinning at ω , add an outward force $m\omega^2 r$, called the centrifugal force.
- It is a pseudo force too. Use it only if you chose to work in the spinning frame.
- Problem 5 below uses it to track a bead on a spinning rod.



TRAP ALERT

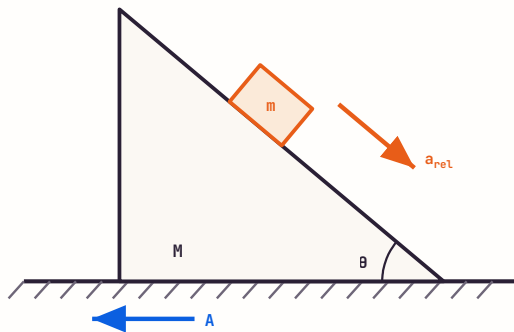
PSEUDO FORCE BELONGS TO ONE FRAME ONLY

- **Never mix frames.** Add $-ma_0$ only if every acceleration is measured from that frame.
- In the ground frame there is no pseudo force at all.

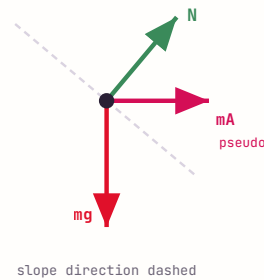
The Moving Wedge

A block slides down a smooth wedge, and the wedge is free to slide on a smooth floor. The block pushes the wedge back. So neither body has a known acceleration.

A BLOCK SLIDES DOWN A SMOOTH WEDGE THAT IS FREE TO MOVE



BLOCK, SEEN FROM THE WEDGE



ALONG THE SLOPE

$$m a_{rel} = mg \sin \theta + mA \cos \theta$$

ACROSS THE SLOPE

$$N = mg \cos \theta - mA \sin \theta$$

THE WEDGE

$$N \sin \theta = M A$$

Solve: $A = mg \sin \theta \cos \theta / (M + m \sin^2 \theta)$. With $M = m$ and $\theta = 45^\circ$, $A = g/3$.

Work in the wedge's frame. The block feels a pseudo force mA and slides straight along the slope.

WHY THE WEDGE FRAME IS THE EASY CHOICE

In that frame, the block moves only **along** the slope. So its acceleration across the slope is zero. That single fact is the constraint. It gives N directly.

WORKED EXAMPLE 1

Take $M = m$ and $\theta = 45^\circ$, all surfaces smooth. Find the wedge's acceleration and the block's acceleration relative to it.

$$A = \frac{mg \sin \theta \cos \theta}{M + m \sin^2 \theta} = \frac{g/2}{3/2} = \frac{g}{3}.$$

$$a_{rel} = g \sin \theta + A \cos \theta = \frac{g}{\sqrt{2}} \left(1 + \frac{1}{3} \right) = 9.43 \text{ m/s}^2.$$

Check: the block's ground acceleration sideways is $a_{rel} \cos 45^\circ - A = 3.33 \text{ m/s}^2$. That equals A , as momentum demands for equal masses.

Answer: $A = 3.33 \text{ m/s}^2$, and 9.43 m/s^2 along the slope

WORKED EXAMPLE 2

Now hold the block still on the wedge by pushing the wedge sideways. Take $\theta = 45^\circ$ and smooth surfaces. What acceleration must the wedge have?

In the wedge frame the block feels mg down and a pseudo force ma away from the push.

For the block to stay put, their parts along the slope must cancel: $m \cos \theta = mg \sin \theta$.

So $a = g \tan \theta = g$.

Answer: 10 m/s^2 , with the wedge speeding up toward the side its slope faces



THINK IT
THROUGH

HOW FAR DOES THE FREE WEDGE MOVE?

- The floor is smooth, so horizontal momentum stays zero the whole time.
- So the centre of mass cannot move sideways. If the block moves b sideways over the ground, the wedge moves back by $\frac{m}{M}$ times that.
- Relative to the wedge the block travels the full base length L . So the wedge moves back $\frac{mL}{M+m}$.



TRAP ALERT

THE NORMAL FORCE IS NOT $mg \cos \theta$

- **On a moving wedge, N is less than $mg \cos \theta$.** The wedge moves away from the block.
- Here $N = mg \cos \theta - m A \sin \theta$, which is smaller.
- Using $mg \cos \theta$ gives the wrong A and the wrong everything after it.

Each problem uses a different technique. None of them can be solved by recalling one formula.

PROBLEM 1 • CALCULUS

A 2 kg block rests on a floor with friction 0.5 (static and kinetic). A horizontal force $F = 5t$ newtons acts on it, with t in seconds. Find its speed at $t = 6$ s.

What it demands: noticing that motion starts late, then integrating a time-varying force from that start

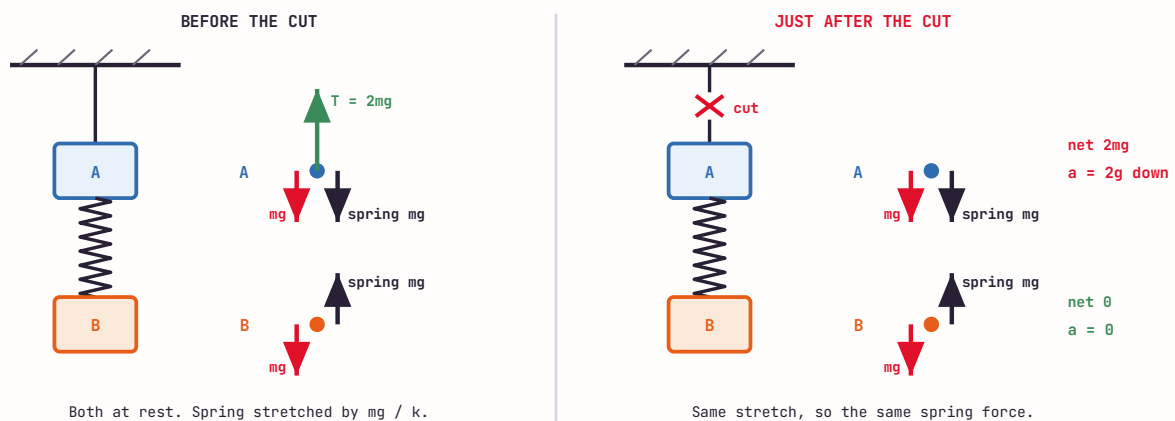
Nothing moves while $5t < \mu mg = 10$. So motion starts at $t_0 = 2$ s, not at $t = 0$.

After that: $m \frac{dv}{dt} = 5t - 10$, so $2 dv = (5t - 10) dt$.

Integrate from 2 to 6: $2v = \left[\frac{5t^2}{2} - 10t \right]_2^6 = 30 - (-10) = 40$.

Answer: 20 m/s

TWO EQUAL BLOCKS, A STRING AND A SPRING: CUT THE TOP STRING



A string can go slack at once. A spring needs time to change length, so its force carries over.

A spring's force depends on its stretch. The stretch cannot change in zero time.

PROBLEM 2 • COUNTERINTUITIVE • ONE OR MORE CORRECT

Two 2 kg blocks hang as shown: string, then A, then a spring, then B. The top string is cut. Just after the cut, which of these are correct?

What it demands: separating what can change instantly from what cannot. The obvious answer, both fall at g , is wrong

(A) A falls at g (B) A falls at $2g$ (C) B has zero acceleration (D) the spring force becomes zero

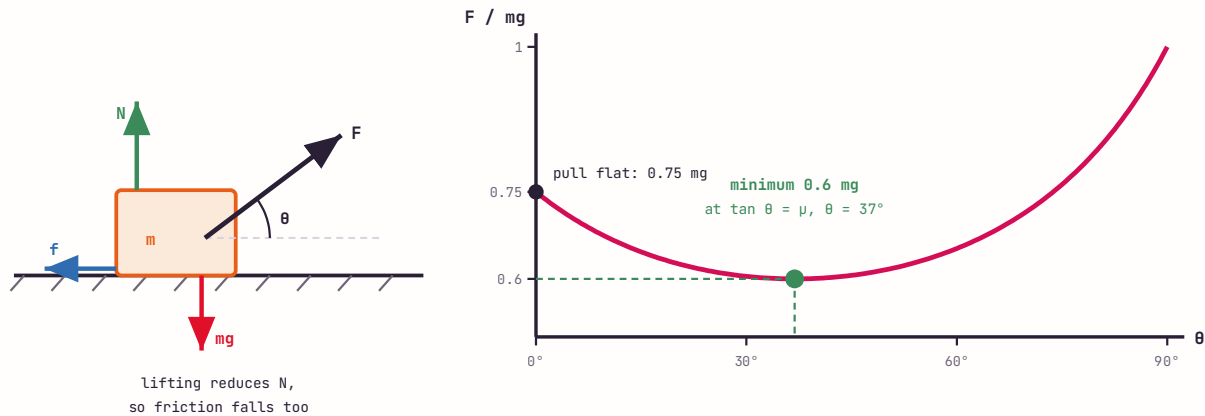
Before the cut the spring holds up B, so its force is $mg = 20$ N.

The stretch is the same an instant later. So the spring still pulls A down and B up with 20 N.

A: $20 + 20 = 40$ N down, so 20 m/s^2 , which is $2g$. B: 20 up, 20 down, so zero.

Answer: (B) and (C)

DRAGGING A BLOCK ON A ROUGH FLOOR ($\mu = 0.75$): THE BEST ANGLE TO PULL



Minimum force = $\mu mg / \sqrt{1 + \mu^2}$. Pulling a little upward beats pulling flat.

Lift the rope and the force needed falls. It bottoms out at $\tan \theta = \mu$, then rises again.

PROBLEM 3 • OPTIMISATION

A 10 kg block sits on a floor with friction 0.75. You pull with a rope at angle θ above the horizontal. What is the smallest force that can start it moving?

What it demands: setting up F as a function of angle, then finding its minimum

Vertical: $N = mg - F \sin \theta$. Horizontal, at the limit: $F \cos \theta = \mu N$.

So $F = \frac{\mu mg}{\cos \theta + \mu \sin \theta}$. The bottom is largest when $\tan \theta = \mu$.

Then the bottom equals $\sqrt{1 + \mu^2} = 1.25$. So $F_{\min} = \frac{0.75 \times 100}{1.25}$.

Answer: 60 N at $\theta = 37^\circ$, against 75 N for a flat pull

PROBLEM 4 • TWO CHAPTERS • NUMERICAL

A coin sits 0.5 m from the centre of a turntable, with friction 0.5. The table starts from rest with angular acceleration 6 rad/s^2 . When does the coin slip? Give t in seconds to two decimal places.

What it demands: circular motion and friction together; the tangential part is the step most students miss

Friction must supply two parts. Along the path: $ar = 3 \text{ m/s}^2$. Toward the centre: $\omega^2 r$.

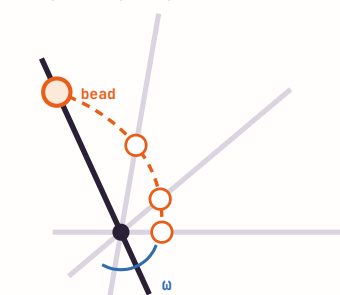
It slips when the total reaches $\mu g = 5$: $\sqrt{3^2 + (\omega^2 r)^2} = 5$, so $\omega^2 r = 4$.

So $\omega^2 = 8$ and $\omega = 2.83 \text{ rad/s}$. Since $\omega = \alpha t$, $t = \frac{2.83}{6}$.

Answer: $t = 0.47 \text{ s}$

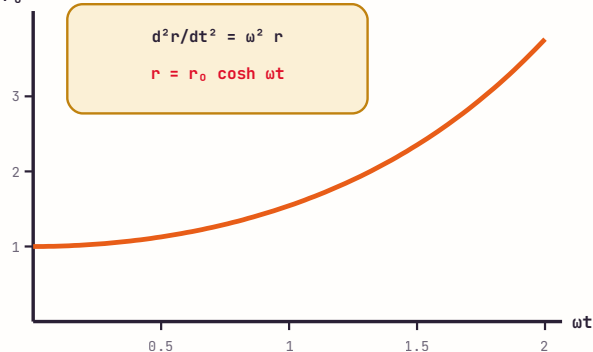
A BEAD ON A SMOOTH ROD SPINNING AT STEADY ω : IT SLIDES OUTWARD

SEEN FROM ABOVE



path traced over the floor

r / r_0



In the rod's frame only the centrifugal force acts along the rod, and it grows with r .

Seen from above the bead spirals out. Seen from the rod it simply slides outward, faster and faster.

PROBLEM 5 • ROTATING FRAME

A bead can slide on a smooth straight rod. The rod spins in a horizontal plane at 2 rad/s about one end. The bead starts at rest on the rod, 0.1 m from that end. Find its speed along the rod at 0.5 m.

What it demands: choosing the rotating frame, then turning a force that grows with r into an integral

In the rod's frame, the only force along the rod is centrifugal: $m\omega^2 r$.

So $v \frac{dv}{dr} = \omega^2 r$. Integrate from 0.1 m: $v^2 = \omega^2(r^2 - 0.01)$.

At 0.5 m: $v = 2\sqrt{0.25 - 0.01} = 2\sqrt{0.24}$.

Answer: 0.98 m/s along the rod

★ Newton's Laws of Motion • Fact Sheet

Every rule for revision day. Print this page alone.

FIRST LAW

Net force zero, velocity constant.

Holds only in inertial frames.
Mass measures inertia.

SECOND LAW

$$F = \frac{dp}{dt}, \text{ or } F = ma$$

Use it along x and y separately.
Variable mass: add $v \frac{dm}{dt}$.

IMPULSE

$$J = \int F dt = \Delta p$$

Longer contact time,
smaller average force.

THIRD LAW

Pairs act on different bodies.

Same type of force.
N and mg are not a pair.

MOMENTUM

No external force:

total momentum is constant.
Works for bursts and recoil.

FREE-BODY DIAGRAM

One body, all forces on it.

No ma arrow in ground frame.
Lami: $\frac{F}{\sin \alpha}$ is equal for all three.

LIFT

$$N = m(g + a), \text{ a upward +}$$

Direction of a matters,
not direction of motion.

CONSTRAINTS

Write the string length.

Differentiate twice.
Movable pulley: $a_B = 2a_A$.

FRICTION

Static: up to $\mu_s N$.

Kinetic: exactly $\mu_k N$.

Repose: $\tan \theta = \mu_s$.

CIRCLES

Inward net force $\frac{mv^2}{r}$.

Flat: $v_{max} = \sqrt{\mu r g}$

Banked: $\tan \theta = \frac{v^2}{rg}$

PSEUDO FORCE

Frame accelerating at a_0 :

add $-ma_0$ to every body.

Rotating: add $m\omega^2 r$ outward.

INSTANT CHANGES

A string can go slack at once.

A spring force cannot jump.
Best pull angle: $\tan \theta = \mu$.



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★ FORCES STILL FEEL LIKE GUESSWORK?

Play it. Then practice it.

Open Newton's Laws of Motion in the Logic Bloom app. Draw free-body diagrams that check themselves. Ride inside an accelerating car. Push a block until friction gives way. Free to start.

SCAN → PLAY · READ · PRACTICE