LOGIC BLOOM · PHYSICS · MECHANICS

Friction & Block Systems

Laws of Motion · **Built to JEE Advanced depth** · NEET sections marked

The chapter where nearly every mechanics problem secretly begins. Friction as a self-adjusting force, the one test that settles every stacked-block question, and the non-inertial tricks that turn hard problems into two lines. Fourteen worked questions, none of them one-liners.

7 Sections | 11 Diagrams | 14 Worked Questions | NEET Marked | Fact Sheet

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Contents

0 How to Read This Set

This is built to **JEE Advanced** depth. Every section carries a badge saying who needs it, so a NEET aspirant can take the green sections and skip the rest without wondering what was missed.

IN NEET AND JEE	Core material. Friction laws, the rough incline, basic stacked blocks, pulleys with friction.
JEE MAIN AND ADVANCED	Slipping systems, relative acceleration, and multi-body constraint problems.
JEE ADVANCED MAINLY	Non-inertial frames, wedges, optimisation of the pull angle, the overhanging chain.

THINK IT THROUGH

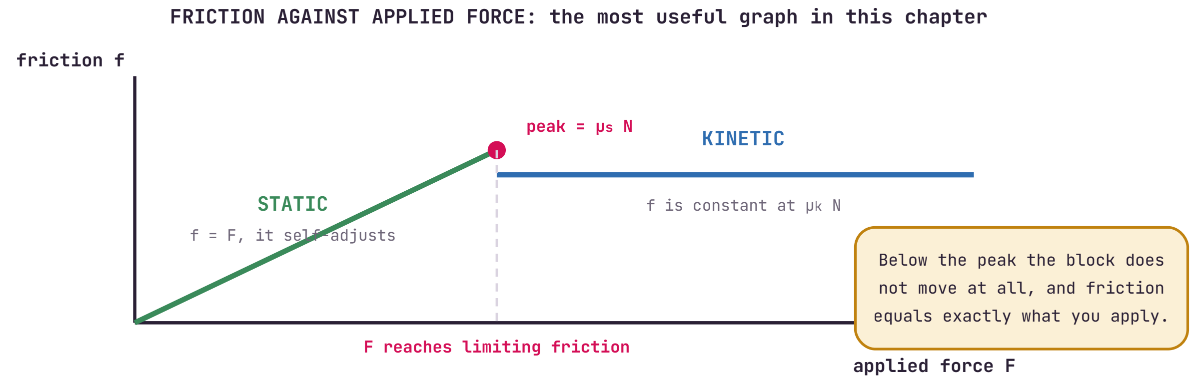
ONE IDEA RUNS THROUGH THE WHOLE CHAPTER

Static friction is not a number you look up. It is **whatever it needs to be**, up to a ceiling of $\mu_s N$. Almost every mistake in this chapter comes from using the ceiling when the problem wanted the actual value, or the reverse. Hold that one distinction and most of what follows is bookkeeping.

1 What Friction Actually Is

IN NEET AND JEE

Friction is the surface force that resists relative sliding between two bodies in contact. It acts along the surface, and it comes in two regimes that behave completely differently.



Static friction climbs to match whatever you apply, up to a ceiling. Past that ceiling the block moves and friction drops slightly to a constant kinetic value.

★ THE TWO LAWS

$$f_s \le \mu_s N \qquad \text{(static, self-adjusting)}$$

$$f_k = \mu_k N \qquad \text{(kinetic, fixed)}$$

μ_s is slightly larger than μ_k, which is why a stuck object jerks into motion.

Independent of contact area	within reason, because the true microscopic contact area is what matters, and that grows with N
Independent of sliding speed	μ_k is treated as constant across ordinary speeds
Proportional to the normal force	press harder and friction rises in exact proportion
Not always opposing motion	it is what pushes you forward when you walk, and what drives a block on an accelerating plank

MYTH CHECK

MYTH

A wider block grips the floor better, because more surface is touching it.

THE SCIENCE

Friction depends on the normal force, not the apparent area. Spreading the same weight over twice the area halves the pressure, so the true microscopic contact stays about the same. A brick slides equally well on its face or on its edge.

MYTH CHECK

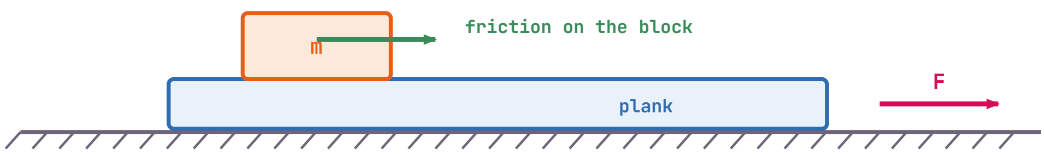
MYTH

Friction always acts to slow things down, so it always opposes the direction of motion.

THE SCIENCE

Friction opposes **relative sliding** between surfaces, not motion itself. On an accelerating plank, friction is the only forward force on the block sitting on it, so friction is precisely what makes it move.

FRICTION DOES NOT ALWAYS OPPOSE MOTION



The block has no other horizontal force on it, so friction is what accelerates it forward.

Here friction is the cause of the motion, not a brake on it.

The block has no other horizontal force acting on it. Friction is the cause of its acceleration, not a brake on it.

▶ PLAY

STRUGGLING TO PICTURE THE CEILING?

Push the block yourself and watch friction rise to meet you.

The friction game lets you dial the applied force up and see static friction track it exactly, then break at the limit. The graph stops being something to memorise. **logicbloom.co.in/download** · Free to start.

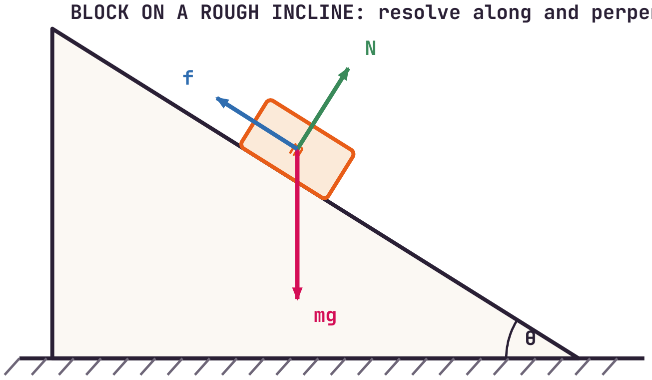
SCAN

2 The Rough Incline

IN NEET AND JEE

Tilt the surface and gravity splits into two parts: one pressing the block into the plane, one dragging it along. Everything follows from that split.

BLOCK ON A ROUGH INCLINE: resolve along and perpendicular to the surface



At rest: f = mg sinθ, and f ≤ μN

Sliding down: a = g(sinθ - μcosθ)

Pushed up: a = g(sinθ + μcosθ)

ANGLE OF REPOSE

tan θ = μ gives the steepest angle at which the block still holds.

Resolve weight along and perpendicular to the surface. The perpendicular part sets N, and therefore sets the friction ceiling.

▶ PLAY

INCLINE FORCES NOT RESOLVING CLEANLY?

Tilt the slope and watch the block let go.

Drag the angle past the repose point and see exactly where friction runs out. Then drill the sliding-and-time questions in Brain Gym while the picture is fresh. **logicbloom.co.in/download** · Free to start.

SCAN

★ THE THREE CASES

$$N = mg\cos\theta, \qquad \text{driving force} = mg\sin\theta$$

$$a_{down} = g(\sin\theta - \mu\cos\theta), \qquad a_{up} = g(\sin\theta + \mu\cos\theta)$$

THINK IT THROUGH

ANGLE OF REPOSE

Increase the tilt until the block just begins to slide. At that angle mg sinθ has grown to equal $\mu_s$mg cosθ, so **tan θ_{repose} = μ_s**. Below it the block sits still and friction is only as large as it needs to be. This angle is also called the angle of friction.

TRAP ALERT

⚠ THE MASS CANCELS, AND THAT SURPRISES PEOPLE

Every term in the incline equations carries m, so the acceleration does not depend on the mass at all. A heavy block and a light block of the same material slide down together. Questions that offer you two different masses are usually checking whether you know this.

3 Stacked Blocks

IN NEET AND JEE

Two blocks, one on top of the other. Do they move as one lump, or does the top one get left behind? There is exactly one procedure, and it never changes.

THE ONLY ALGORITHM YOU NEED FOR STACKED BLOCKS

STEP 1
Assume they move together.
a = F / (total mass)

→

STEP 2
Find the friction REQUIRED
on the upper block: f = ma

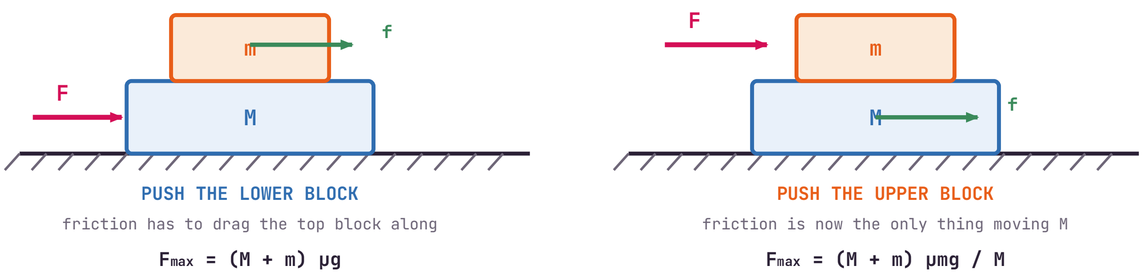
→

STEP 3
Compare it with μN.
Bigger? They slip.

If the required friction fits inside μN, both blocks share one acceleration and you are finished.
If it does not, they separate: the upper block gets a = μg on its own and the lower one takes whatever is left.
Never assume slipping without running the test, and never assume together without checking the limit.

Run this test before writing anything else. It converts a confusing two-body problem into a single yes-or-no question.

THE SAME STACK, TWO COMPLETELY DIFFERENT ANSWERS



The same stack gives two different answers depending on which block you push, because friction has a different job in each case.

★ **MAXIMUM FORCE FOR THEM TO MOVE TOGETHER**

$$\text{Push the lower block:}\quad F_{max} = (M+m)\,\mu g$$

$$\text{Push the upper block:}\quad F_{max} = \frac{(M+m)\,\mu m g}{M}$$

THINK IT THROUGH

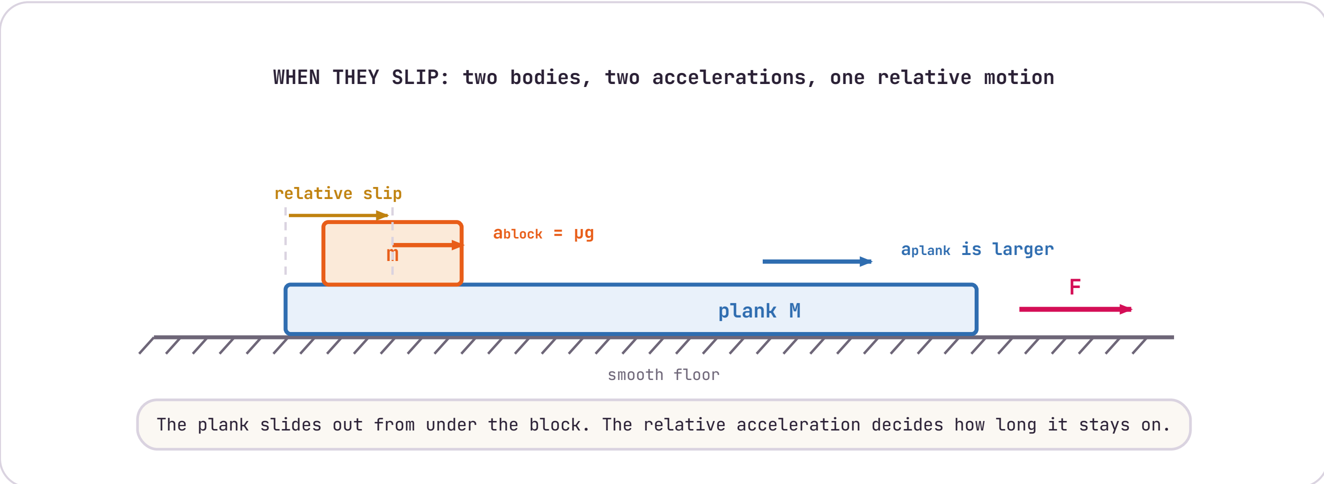
WHY THE TWO ANSWERS DIFFER

When you push the lower block, friction only has to accelerate the small mass on top. When you push the upper block, that same friction has to accelerate the whole lower block, which is usually heavier. The weaker link changes, so the limit changes.

4 When They Slip

JEE MAIN AND ADVANCED

Once the test fails, the two bodies stop sharing an acceleration. Each gets its own free-body diagram, and kinetic friction now has a fixed value.



Slipping means two accelerations. The block is driven only by kinetic friction, so its acceleration is simply μg.

★ AFTER THEY SEPARATE

$$a_{block} = \mu g \qquad a_{plank} = \frac{F - \mu m g}{M}$$

$$a_{rel} = a_{plank} - a_{block}, \qquad L = \frac{1}{2} a_{rel} t^2$$

TRAP ALERT

⚠ USE THE RELATIVE ACCELERATION, NOT EITHER ONE ALONE

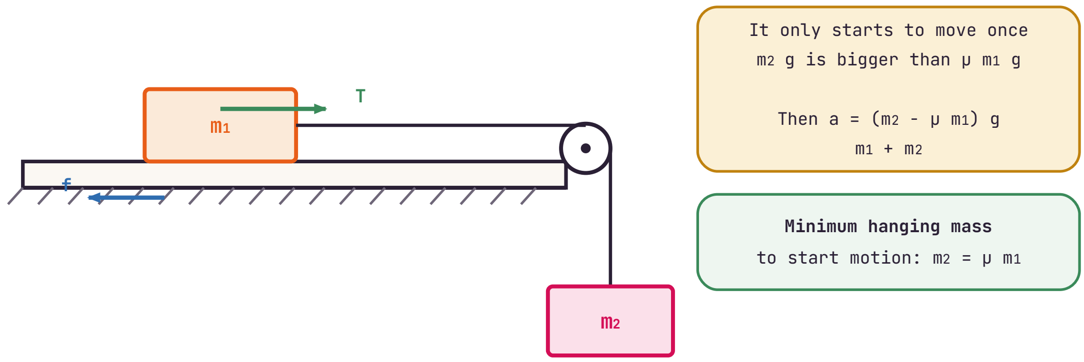
Questions asking how long the block stays on the plank, or how far it slides back, are asking about **relative** motion. Work in the ground frame, find both accelerations, subtract, and only then apply the kinematic equation to the length of the plank.

5 Strings, Pulleys and Connected Blocks

IN NEET AND JEE

An inextensible string forces the connected bodies to share the magnitude of acceleration. Add friction and you get the most common numerical in the whole chapter.

BLOCK ON A ROUGH TABLE, DRIVEN BY A HANGING MASS



The hanging weight is the driver, the table friction is the brake. Nothing moves until the first beats the second.

★ BLOCK ON A ROUGH TABLE, HANGING MASS OVER A PULLEY

$$\text{Motion starts only if} \quad m_2 g > \mu m_1 g$$

$$a = \frac{(m_2 - \mu m_1)g}{m_1 + m_2}, \qquad T = m_2(g - a)$$

THINK IT THROUGH

TENSION IS NEVER SIMPLY THE HANGING WEIGHT

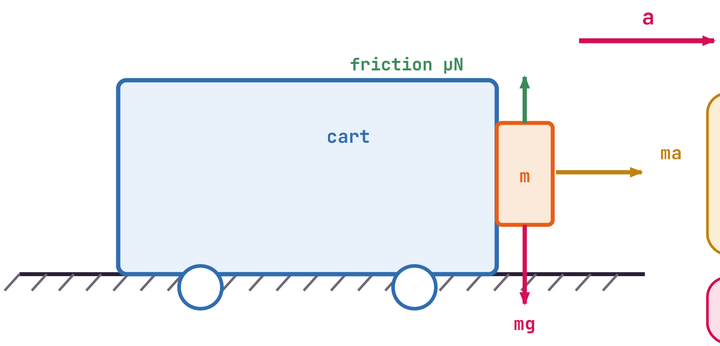
Writing T = $m_2 g$ assumes the hanging block is in equilibrium, which it is not once the system accelerates. T is always less than $m_2 g$ while the block descends, and greater than it while the block is being hauled up.

6 Non-Inertial Frames

JEE ADVANCED MAINLY

Sitting inside an accelerating vehicle, Newton's laws appear to fail. You restore them by adding one fictitious force of magnitude ma, pointing opposite to the frame's acceleration.

NON-INERTIAL FRAME: the block that friction alone holds up



In the cart's own frame the block is pressed against the wall by ma, so N = ma.

It holds while μma ≥ mg

Minimum acceleration: a = g/μ

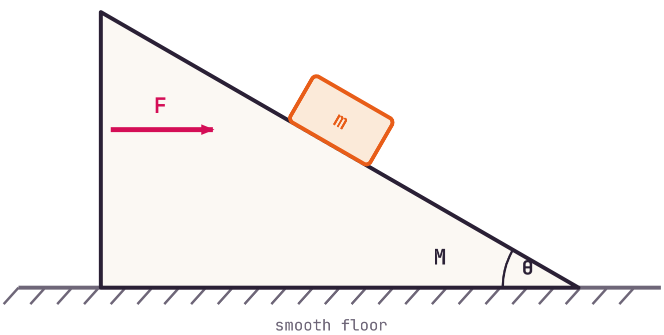
In the cart frame the block is pinned to the wall by the pseudo-force. That pseudo-force is what supplies the normal reaction, and therefore the friction.

★ BLOCK HELD AGAINST A VERTICAL FACE

$$N = ma \quad \Rightarrow \quad f_{max} = \mu ma$$

$$\text{it does not slide down while} \quad \mu ma \geq mg \quad \Rightarrow \quad a \geq \frac{g}{\mu}$$

THE WEDGE: push the whole system so nothing slides on it



For the block not to slide, the whole system must accelerate at a = g tanθ

so F = (M + m) g tanθ

Too little F and the block slides down. Too much and it rides up.

Accelerate the whole wedge at exactly g tanθ and the block rides along without sliding on it.

⚠ PSEUDO-FORCE ONLY EXISTS IN THE ACCELERATING FRAME

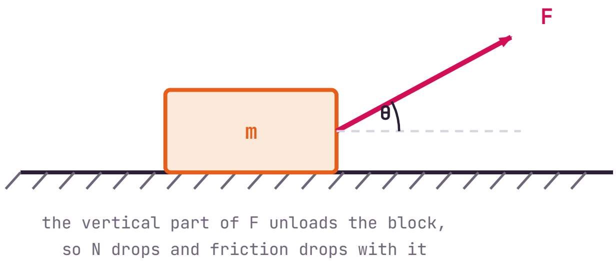
Never draw ma and then also solve in the ground frame. Pick one frame and stay in it. If you work from the ground, there is no pseudo-force at all and the horizontal component of N is what supplies the acceleration. Both routes give the same answer, and mixing them gives neither.

7 Minimum Force and Special Systems

JEE ADVANCED MAINLY

Two setups appear again and again in Advanced papers, and both reward knowing the result rather than deriving it under time pressure.

PULLING AT AN ANGLE BEATS PUSHING FLAT



F = μmg / (cosθ + μ sinθ)

Smallest when tanθ = μ,
giving F_{min} = μmg / √(1 + μ²)

The best pull angle is exactly the angle of friction. Pushing flat along the floor is never the cheapest way to move it.

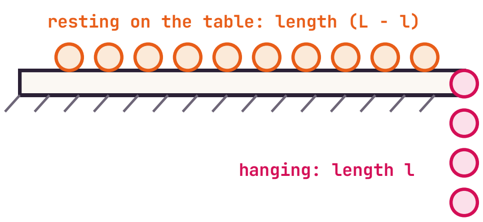
Pulling at an angle lightens the block, which lowers N and lowers friction with it. There is an optimal angle, and it is not zero.

★ CHEAPEST WAY TO DRAG A BLOCK

$$F = \frac{\mu m g}{\cos\theta + \mu \sin\theta}$$

$$\text{minimum at } \tan\theta = \mu, \quad \text{giving} \quad F_{min} = \frac{\mu m g}{\sqrt{1+\mu^2}}$$

THE OVERHANGING CHAIN: how much may dangle before it slides



It just begins to slide when the hanging weight equals the limiting friction on the part still resting on the table.

Maximum hanging fraction
l / L = μ / (1 + μ)

The hanging part pulls, the resting part grips. Equate them and the length cancels out, leaving a pure ratio.

8 Important Questions

Fourteen questions, tagged by exam. Every one needs at least two chained steps or turns on a decision you have to make correctly before any formula helps. Try each before reading the working.

Q1 Below the limit, then above it

NEET

A 5 kg block rests on a floor with $\mu_s = 0.5$ and $\mu_k = 0.4$ (g = 10). Find the friction force and the acceleration when the applied horizontal force is (a) 20 N, then (b) 30 N.

CORE Compare the applied force with the ceiling $\mu_s N$ before deciding which law applies.

WORKING

$$\mu_s N = 0.5(5)(10) = 25\text{ N}$$

$$\text{(a) } 20 < 25 \Rightarrow \text{static: } f = \mathbf{20}\text{ N},\ a = \mathbf{0}$$

$$\text{(b) } 30 > 25 \Rightarrow \text{kinetic: } f = 0.4(50) = 20\text{ N},\ a = \frac{30-20}{5} = \mathbf{2}\ \text{m/s}^{\mathbf{2}}$$

TRAP In case (a) friction is 20 N, not 25 N. The ceiling tells you whether it moves, not what the friction equals. Notice both cases give f = 20 N for completely different reasons.

Q2 Rough incline, n times the time

JEE MAIN

A block slides down a rough 45° incline and takes n times as long as it would on a smooth incline of the same angle and length. Find μ.

CORE Same distance from rest, so $s = \frac{1}{2}at^2$ gives $t \propto 1/\sqrt{a}$.

WORKING

$$a_{smooth} = g\sin 45^\circ, \qquad a_{rough} = g(\sin 45^\circ - \mu\cos 45^\circ)$$

$$n = \frac{t_{rough}}{t_{smooth}} = \sqrt{\frac{a_{smooth}}{a_{rough}}} \Rightarrow n^2 = \frac{1}{1-\mu}$$

$$\mu = \mathbf{1} - \frac{\mathbf{1}}{\mathbf{n^2}}$$

TRAP Time ratio is the inverse square root of the acceleration ratio, not the ratio itself. Squaring in the wrong direction gives $\mu = 1 - n^2$, which is negative for any $n > 1$ and should be an instant warning.

Q3 Up takes less time than down

JEE MAIN

A block is projected up a rough incline of angle 45° with μ = 0.5. It rises, stops, and slides back. Find the ratio of the time of ascent to the time of descent.

CORE Friction reverses when the motion reverses, so the two accelerations differ. The distance is the same both ways.

WORKING

$$a_{up} = g(\sin\theta + \mu\cos\theta), \qquad a_{down} = g(\sin\theta - \mu\cos\theta)$$

$$\text{same } s: \ \frac{t_{up}}{t_{down}} = \sqrt{\frac{a_{down}}{a_{up}}} = \sqrt{\frac{\sin 45^\circ - 0.5\cos 45^\circ}{\sin 45^\circ + 0.5\cos 45^\circ}}$$

$$= \sqrt{\frac{0.5}{1.5}} = \frac{1}{\sqrt{3}} \Rightarrow \mathbf{t_{up} : t_{down} = 1 : \sqrt{3}}$$

TRAP Going up, gravity and friction both retard the block, so it decelerates hard and the trip is quick. Coming down they fight each other. Ascent is always the faster leg on a rough incline.

Q4 The cheapest way to drag a crate

JEE ADVANCED

A 10 kg crate sits on a floor with μ = 0.5 (g = 10). Find the minimum force needed to just move it, and the angle at which that force should be applied.

CORE A force at angle θ above the horizontal reduces N to $mg - F\sin\theta$, so friction falls as θ rises. Set up F(θ) and minimise.

WORKING

$$F\cos\theta = \mu(mg - F\sin\theta) \Rightarrow F = \frac{\mu mg}{\cos\theta + \mu\sin\theta}$$

$$\text{minimum when } \tan\theta = \mu = 0.5 \Rightarrow \theta = \mathbf{26.6^\circ}$$

$$F_{min} = \frac{\mu mg}{\sqrt{1+\mu^2}} = \frac{50}{\sqrt{1.25}} = \mathbf{44.7}\ \text{N}$$

TRAP Pushing horizontally would need the full 50 N. Note the sign: **pulling upward** at 26.6° helps, while pushing downward at the same angle increases N and makes it harder.

Q5 Same stack, push it two ways

JEE ADVANCED

A 2 kg block rests on a 4 kg block on a frictionless floor, with μ = 0.4 between the blocks (g = 10). Find the maximum horizontal force for the two to move together when it is applied to (a) the lower block, then (b) the upper block.

CORE Friction between the blocks is the weak link. Find the largest acceleration it can supply to whichever block it has to drive.

WORKING

$$f_{max} = \mu mg = 0.4(2)(10) = 8 \text{ N}$$

$$\text{(a) friction drives the 2 kg: } a_{max} = \tfrac{8}{2} = 4 \Rightarrow F = 6(4) = \mathbf{24} \text{ N}$$

$$\text{(b) friction drives the 4 kg: } a_{max} = \tfrac{8}{4} = 2 \Rightarrow F = 6(2) = \mathbf{12} \text{ N}$$

TRAP Half the answer, from the identical stack. Always ask which block friction has to accelerate, not merely how large friction can be. Pushing the lighter block on top is the weaker arrangement.

Q6 The plank slides out

JEE ADVANCED

A 1 kg block sits at one end of a 2 m long, 4 kg plank on a frictionless floor, with μ = 0.2 between block and plank (g = 10). A force of 15 N is applied to the plank. Show that they slip, and find how long the block stays on the plank.

CORE Run the move-together test first, then treat them as two separate bodies and work with the relative acceleration.

WORKING

$$\text{together: } a = \tfrac{15}{5} = 3 \Rightarrow \text{needs } f = 1(3) = 3 \text{ N, but } f_{max} = 0.2(1)(10) = 2 \text{ N}$$

$$\text{so they slip: } a_{block} = \mu g = 2, \qquad a_{plank} = \frac{15-2}{4} = 3.25 \text{ m/s}^2$$

$$a_{rel} = 1.25 \Rightarrow 2 = \tfrac{1}{2}(1.25)t^2 \Rightarrow t = \mathbf{1.79} \text{ s}$$

TRAP The plank length is a **relative** displacement, so it goes with the relative acceleration, never with either body's own acceleration. Using 3.25 here gives 1.11 s and is wrong.

Q7 How much must hang before anything moves

NEET

A 4 kg block on a rough table (μ = 0.5) is connected by a light string over a frictionless pulley to a hanging mass (g = 10). Find the minimum hanging mass that starts the motion, and the acceleration and tension when the hanging mass is 4 kg.

CORE Motion begins when the hanging weight exceeds limiting friction. After that, treat the pair as one system with a common acceleration.

WORKING

$$m_2 g > \mu m_1 g \Rightarrow m_2 > 0.5(4) = \mathbf{2}\ \text{kg}$$

$$a = \frac{(4 - 0.5 \times 4)(10)}{4 + 4} = \frac{20}{8} = \mathbf{2.5}\ \text{m/s}^2$$

$$T = m_2(g - a) = 4(10 - 2.5) = \mathbf{30}\ \text{N}$$

TRAP T is 30 N, not 40 N. The hanging block is accelerating downward, so the string cannot be supporting its full weight. A tension equal to $m_2 g$ would mean zero acceleration.

Q8 Friction above and below

JEE ADVANCED

A 4 kg block A rests on a 6 kg block B which rests on the ground. μ between A and B is 0.4, and between B and the ground is 0.2 (g = 10). A horizontal force F is applied to B. Find the range of F for which both blocks move together.

CORE Two separate conditions: F must beat the ground friction to move anything, and the acceleration must stay within what friction can give block A.

WORKING

$$\text{ground friction} = 0.2(10)(10) = 20\ \text{N} \Rightarrow F > \mathbf{20}\ \text{N}$$

$$\text{A can be dragged at most at } a = \mu g = 0.4(10) = 4\ \text{m/s}^2$$

$$F - 20 = (10)(4) \Rightarrow F_{max} = \mathbf{60}\ \text{N} \Rightarrow 20\ \text{N} < F \leq 60\ \text{N}$$

TRAP The normal force on the ground is the weight of **both** blocks, so the ground friction uses 10 kg, not 6 kg. Using only B's mass gives 12 N and shifts the whole range.

Q9 Pinned to the wall of a cart

JEE ADVANCED

A block is pressed against the smooth-looking vertical front face of a cart, with μ = 0.4 between block and cart (g = 10). Find the minimum acceleration of the cart for the block not to slide down.

CORE Work in the cart's frame. The pseudo-force presses the block into the wall and so it is the pseudo-force that creates N.

WORKING

$$N = ma \Rightarrow f_{max} = \mu N = \mu ma$$

$$\text{no sliding: } \mu ma \geq mg \Rightarrow a \geq \frac{g}{\mu} = \frac{10}{0.4} = \mathbf{25}\ \text{m/s}^2$$

TRAP The mass cancels, so the answer is the same for a matchbox and a brick. Also note that N here has nothing to do with weight, which is the step most people cannot see without drawing the frame.

Q10 Push the wedge so nothing slides

JEE ADVANCED

A 2 kg block rests on the smooth 30° face of an 8 kg wedge, which itself sits on a smooth floor (g = 10). Find the horizontal force applied to the wedge that keeps the block from sliding on it.

CORE If the block does not slide, the block and wedge share one acceleration. For the block, only N and gravity act, so N must supply both the vertical balance and the horizontal acceleration.

WORKING

$$N\cos\theta = mg, \qquad N\sin\theta = ma \Rightarrow a = g\tan\theta$$

$$a = 10\tan 30^\circ = 5.77\ \text{m/s}^2$$

$$F = (M+m)a = 10(5.77) = \mathbf{57.7}\ \text{N}$$

TRAP F accelerates the whole system, so it uses the combined 10 kg, while the condition a = g tanθ comes from the block alone. Mixing the two masses is the standard slip here.

Q11 How much chain may hang

JEE ADVANCED

A uniform chain of length 2 m rests on a rough table with μ = 0.25. Find the maximum length that can hang over the edge before the chain starts to slide.

CORE Let l hang. The hanging weight pulls, and only the part still on the table contributes to friction, so both the weight and the normal force scale with length.

WORKING

$$\left(\frac{ml}{L}\right)g = \mu\left(\frac{m(L-l)}{L}\right)g \Rightarrow l = \mu(L-l)$$

$$\frac{l}{L} = \frac{\mu}{1+\mu} = \frac{0.25}{1.25} = 0.2 \Rightarrow l = \mathbf{0.4}\ \text{m}$$

TRAP Only the chain still on the table presses on it, so the friction uses mass (L − l)/L, not the whole chain. Using the full mass gives l/L = μ and a wrong 0.5 m.

Q12 Two blocks, two coefficients, one string

JEE ADVANCED

Blocks A (1 kg, μ = 0.5) and B (2 kg, μ = 0.25) are joined by a light string and slide down a 37° incline, with A behind B (sin 37° = 0.6, cos 37° = 0.8, g = 10). Find their common acceleration and the tension in the string.

CORE Check first whether the string is even taut: compare the accelerations each block would have alone. Then treat them as one system, and use a single block to extract T.

WORKING

$$\text{alone: } a_A = g(0.6 - 0.5\times 0.8) = 2, \quad a_B = g(0.6 - 0.25\times 0.8) = 4$$

$$B \text{ would outrun } A \Rightarrow \text{string is taut}$$

$$a = g\left[\sin\theta - \frac{(\mu_A m_A + \mu_B m_B)\cos\theta}{m_A + m_B}\right] = \mathbf{3.33}\ \text{m/s}^2$$

$$\text{for A: } m_A a = m_A g\sin\theta - \mu_A m_A g\cos\theta + T \Rightarrow T = \mathbf{1.33}\ \text{N}$$

TRAP If A were in front instead, the string would go slack and each block would slide at its own rate with T = 0. The order of the blocks changes the answer, so never assume the string is taut.

Q13 Which way does friction point

NEET

A 2 kg block rests on a plank. The plank is pulled so that the block and plank move together with an acceleration of 3 m/s^2. Find the magnitude and direction of the friction on the block.

CORE The block has no other horizontal force on it, so friction must be the entire net force producing its acceleration.

WORKING

$$f = ma = 2(3) = \mathbf{6}\text{ N, forward}$$

$$\text{(this must also satisfy } f \le \mu_s mg \text{ for them to stay together)}$$

TRAP Friction here points in the direction of motion, because it is the cause of the block's acceleration. Writing f = μmg would be wrong twice over: it is static friction, and it is nowhere near its ceiling.

Q14 Assertion and reason on a stationary block

JEE ADVANCED

A 2 kg block rests without sliding on a rough incline of 20° with μ = 0.6 (g = 10). **Assertion:** the friction on the block is μmg cos θ. **Reason:** friction always equals μN. Judge both statements.

CORE The block is in equilibrium, so friction must balance the component of weight along the incline. Compare that with the ceiling.

WORKING

$$\text{required } f = mg\sin\theta = 20\sin 20^\circ = 6.84\text{ N}$$

$$\text{ceiling } \mu N = 0.6(20)\cos 20^\circ = 11.28\text{ N} > 6.84\text{ N}$$

$$\text{Assertion false, Reason false}$$

TRAP μN is the maximum static friction, never the actual value for a block at rest. Since tan 20° = 0.36 is below μ = 0.6, the block sits comfortably inside the limit and friction is only 6.84 N.

★ Friction & Block Systems · Fact Sheet

Every result for revision day. Print this page alone.

THE TWO LAWS

$f_s \le \mu_s N$, self-adjusting

$f_k = \mu_k N$, constant
μ_s is slightly bigger than μ_k.

ROUGH INCLINE

$N = mg\cos\theta$

$a_{down} = g(\sin\theta - \mu\cos\theta)$
$a_{up} = g(\sin\theta + \mu\cos\theta)$.

ANGLE OF REPOSE

$\tan\theta_r = \mu_s$

Below it the block holds.
Mass cancels everywhere.

STACKED BLOCKS

Assume together, find a.

Required f = ma on the top.
Compare with μN. Bigger? Slip.

MAX FORCE TOGETHER

Push lower: $F = (M+m)\mu g$

Push upper: $F = (M+m)\mu mg/M$
Ask which block f must drive.

AFTER THEY SLIP

$a_{block} = \mu g$

$a_{plank} = (F - \mu mg)/M$
Use a_{rel} for the plank length.

PULLEY ON A TABLE

Starts if $m_2 g > \mu m_1 g$

$a = (m_2 - \mu m_1)g/(m_1+m_2)$
$T = m_2(g - a)$.

NON-INERTIAL

Add ma opposite to the frame.

Block on a cart face: N = ma
Holds while $a \ge g/\mu$.

WEDGE

Block does not slide when

$a = g\tan\theta$
so $F = (M+m)g\tan\theta$.

CHEAPEST PULL

$F = \mu mg/(\cos\theta + \mu\sin\theta)$

Best at $\tan\theta = \mu$
$F_{min} = \mu mg/\sqrt{1+\mu^2}$.

HANGING CHAIN

$l/L = \mu/(1+\mu)$

Only the part on the table contributes friction.

TIME UP VS DOWN

$t_{up}/t_{down} = \sqrt{a_{down}/a_{up}}$

Going up is always quicker on a rough incline.

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