Forces, Newton's Laws, and Free Body Diagrams

Hard Practice Set | Standards 2.1 + 2.3

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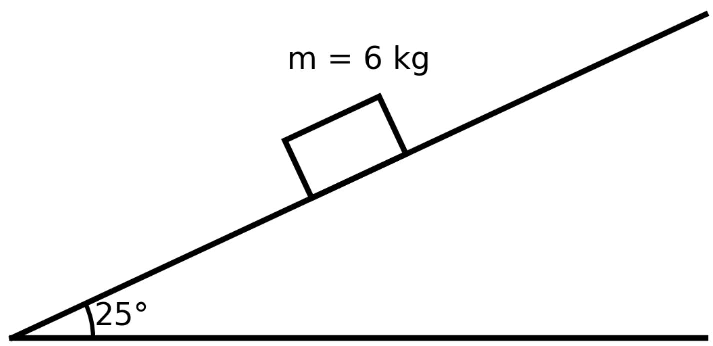
Instructions: Work each problem completely with units shown. Use $g = 9.8 \text{ m/s}^2$. Diagrams are provided where needed — draw your own FBDs in the work space. Answer key with worked solutions begins after the problems.

Tier 1 — Foundations

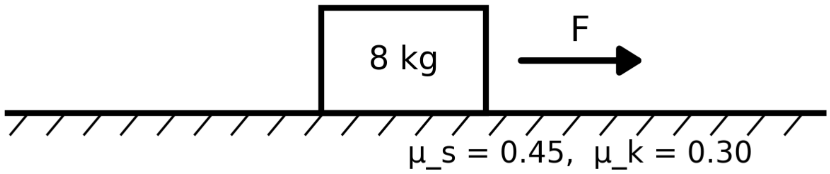
Problem 1. A 6 kg block is released from rest on the frictionless 25° incline shown. Draw a complete free body diagram for the block at the instant of release, labeling every force with its name and magnitude. State whether the net force on the block is zero, and find the block's acceleration down the slope.



Problem 2. An 8 kg object is moved between three locations. For each location, find the object's mass and its weight (force of gravity).

Location	Local g (m/s^2)	Mass (kg)	Weight (N)
Earth	9.8		
Moon	1.6		
Mars	3.7		

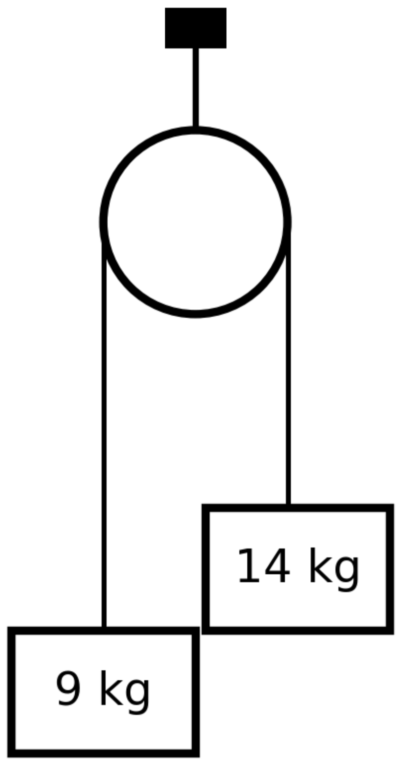
Problem 3. An 8 kg block sits on a flat surface. The coefficients of friction between block and surface are mu_s = 0.45 and mu_k = 0.30. (a) Find the minimum horizontal force F required to start the block moving. (b) Once moving, if the applied force stays at the minimum value from part (a), find the block's acceleration.



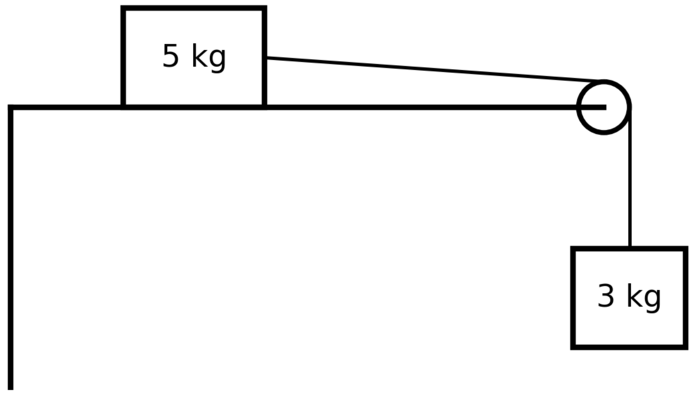
Problem 4. A 12 kg block, starting from rest, experiences a single net horizontal force of 30 N for 4 seconds on a frictionless surface. (a) Find the block's acceleration. (b) Find its final velocity. (c) Find the total distance it traveled during the 4 seconds.

Tier 2 — Standard Hard

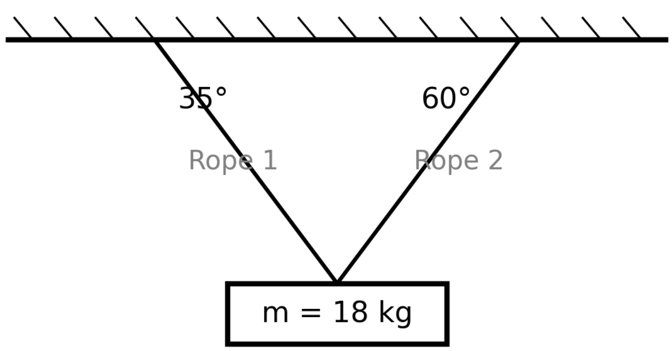
Problem 5. For the Atwood machine shown (9 kg and 14 kg masses), find: (a) the magnitude of acceleration of the system, (b) the tension in the string.



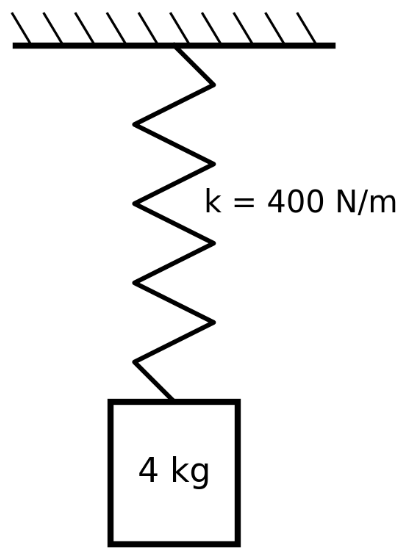
Problem 6. For the system shown (5 kg block on a frictionless table connected over an ideal pulley to a 3 kg hanging mass), find: (a) the acceleration of the system, (b) how far the 5 kg block travels along the table in 2.5 seconds, starting from rest.



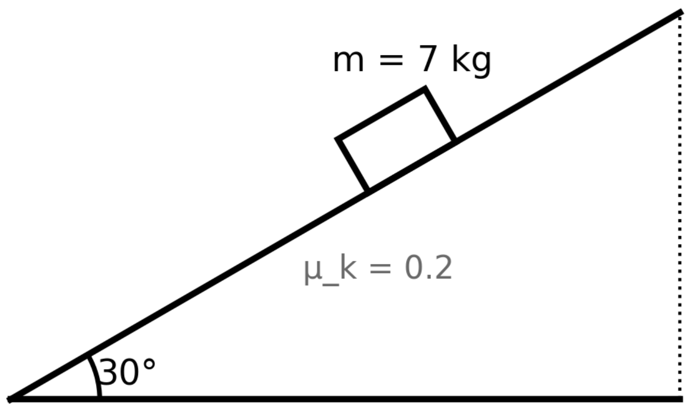
Problem 7. A motionless 18 kg sign hangs from two ropes attached to a ceiling. Rope 1 makes a 35° angle with the ceiling on the left; Rope 2 makes a 60° angle with the ceiling on the right (see diagram). Find the tension in each rope.



Problem 8. A 4 kg mass hangs from a vertical spring with spring constant k = 400 N/m, as shown. Find the distance the spring stretches from its natural length when the system is at equilibrium.

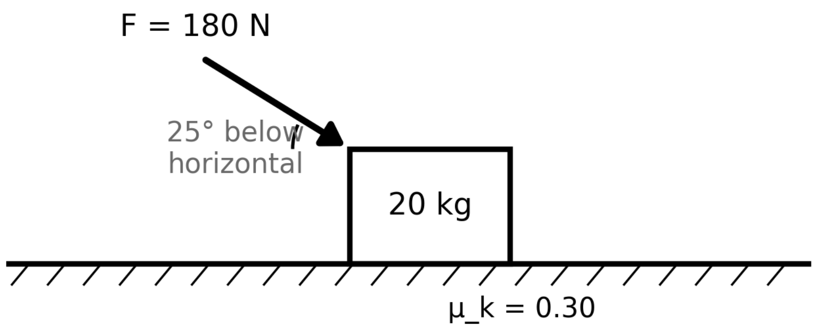


Problem 9. A 7 kg block slides down a 30° incline with coefficient of kinetic friction mu_k = 0.2 between block and surface. Find the block's acceleration down the slope, and find the normal force the incline exerts on the block.

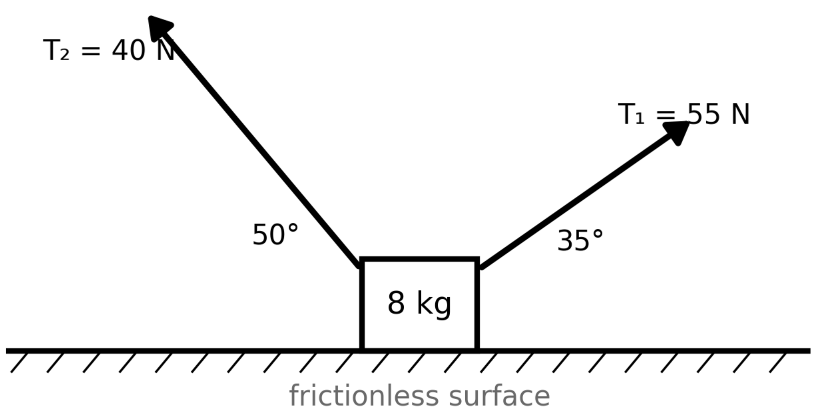


Tier 3 — Hard

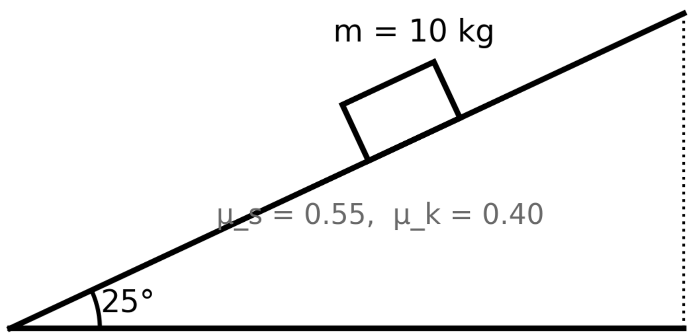
Problem 10. A 20 kg crate sits on a rough floor (mu$_k$ = 0.30). A person pushes the crate by applying a force of 180 N directed at 25° **below** horizontal (the push has a downward component, see diagram). Find: (a) the normal force on the crate from the floor, (b) the kinetic friction force, (c) the crate's acceleration.



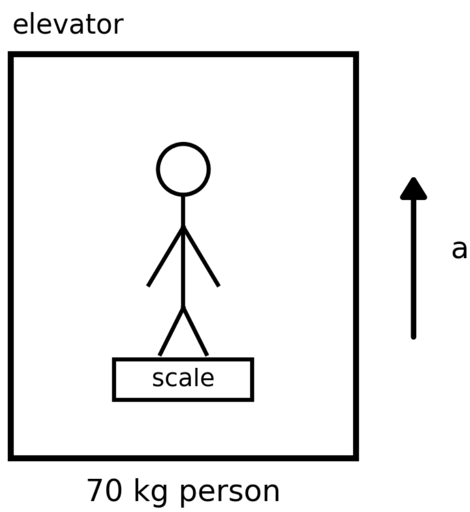
Problem 11. An 8 kg block sits on a frictionless surface and is pulled by two ropes at different angles, as shown. T_1 = 55 N at 35° above horizontal (pulling up-right), T_2 = 40 N at 50° above horizontal (pulling up-left). Find the magnitude and direction of the block's acceleration.



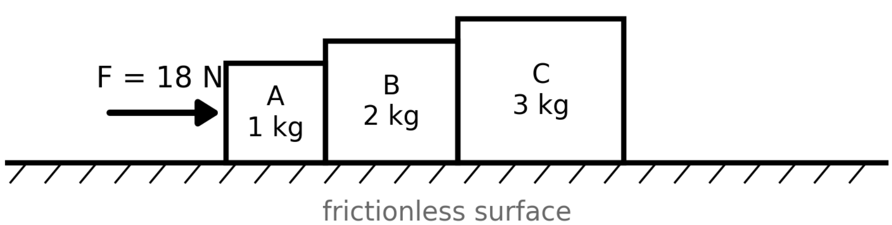
Problem 12. A 10 kg block sits at rest on a 25° incline. The coefficient of static friction is $mu_s = 0.55$, and kinetic is $mu_k = 0.40$. Determine whether the block actually starts sliding when released. If it does, find its acceleration. If it does not, find the static friction force currently acting on it.



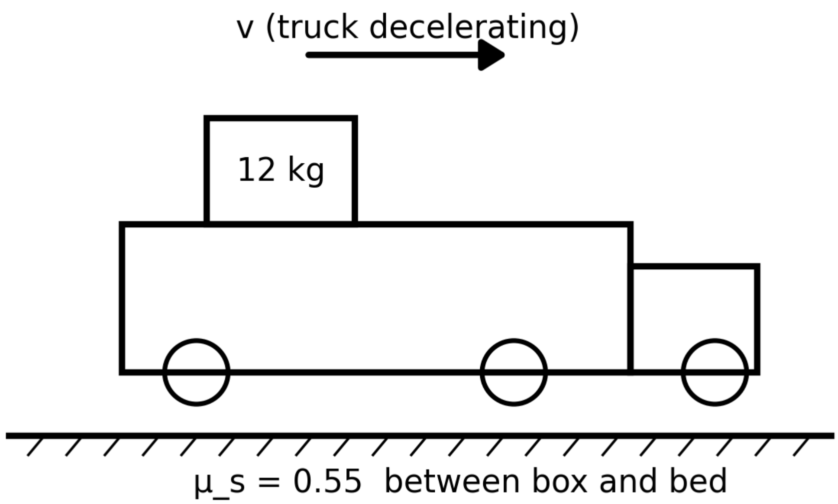
Problem 13. A 70 kg person stands on a bathroom scale inside an elevator. Find the scale's reading (in newtons) in each of the following cases: (a) the elevator accelerates upward at 2 m/s^2, (b) the elevator accelerates downward at 3 m/s^2, (c) the cable snaps and the elevator is in free fall.



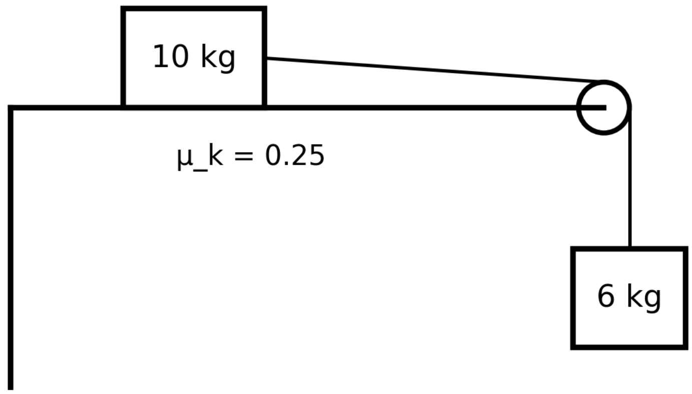
Problem 14. Three blocks (A = 1 kg, B = 2 kg, C = 3 kg) are placed in contact on a frictionless surface, as shown. A horizontal force F = 18 N is applied to block A. Find: (a) the acceleration of the system, (b) the contact force that block A exerts on block B, (c) the contact force that block B exerts on block C. (d) Verify your answer to (b) using Newton's Second Law on block A alone.



Problem 15. A 12 kg box sits on the bed of a truck. The coefficient of static friction between the box and the truck bed is mu_s = 0.55. The truck is moving forward at high speed. Find the maximum deceleration the truck can have without the box sliding forward on the bed.

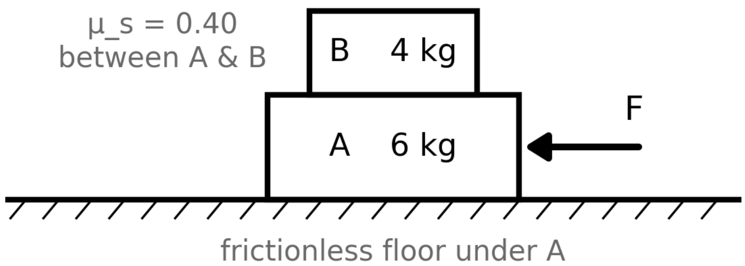


Problem 16. For the system shown (10 kg block on a rough table connected over an ideal pulley to a 6 kg hanging mass, mu_k = 0.25 between block and table), find: (a) the acceleration of the system, (b) the tension in the string, (c) the time required for the 6 kg mass to fall 1.5 m, starting from rest.

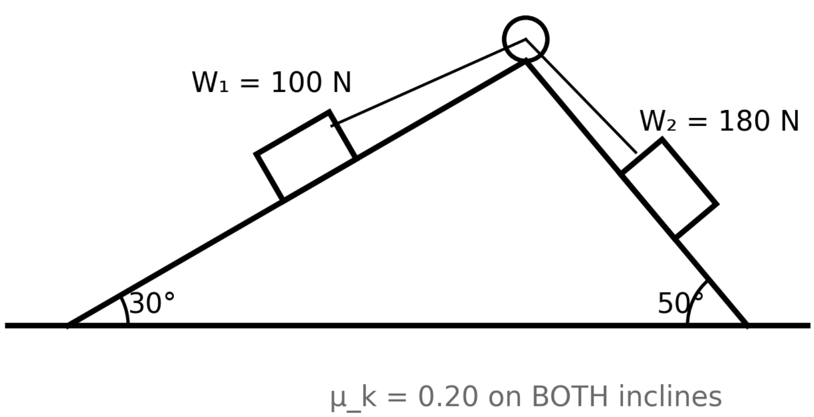

10 kg
μ_k = 0.25
6 kg

Tier 4 — Bombshells

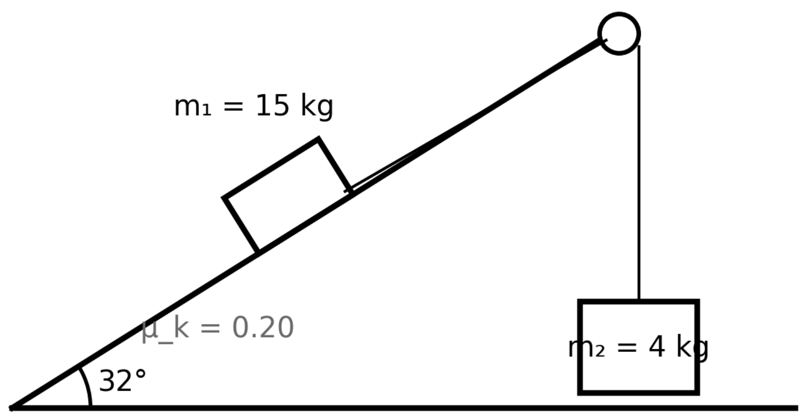
Problem 17. Block B (4 kg) sits on top of block A (6 kg), which rests on a frictionless floor. The coefficient of static friction between A and B is $mu_s = 0.40$. A horizontal force F is applied to block A. Find the maximum value of F such that block B does not slip relative to block A (i.e., both move together as one unit). State which force actually accelerates block B in this scenario.



Problem 18. Two blocks rest on two different inclines, connected over an ideal pulley at the peak between them, as shown. $W_1 = 100$ N rests on a 30° incline; $W_2 = 180$ N rests on a 50° incline. The coefficient of kinetic friction is $mu_k = 0.20$ on both inclines. (a) Determine which direction the system moves when released. (b) Find the magnitude of the system's acceleration. (c) Find the tension in the string.

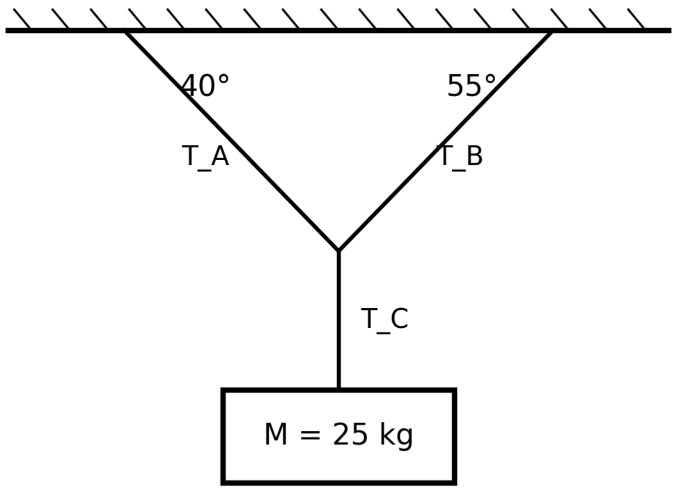


Problem 19. A 15 kg block sits on a 32° incline with kinetic friction mu_k = 0.20. It is connected by an ideal string over a pulley at the top of the incline to a 4 kg mass hanging vertically off the side, as shown. (a) Determine the direction the system moves when released. (b) Find the magnitude of acceleration. (c) Find the tension in the string. (d) Find the time required for the hanging mass to rise 1.5 m, starting from rest.

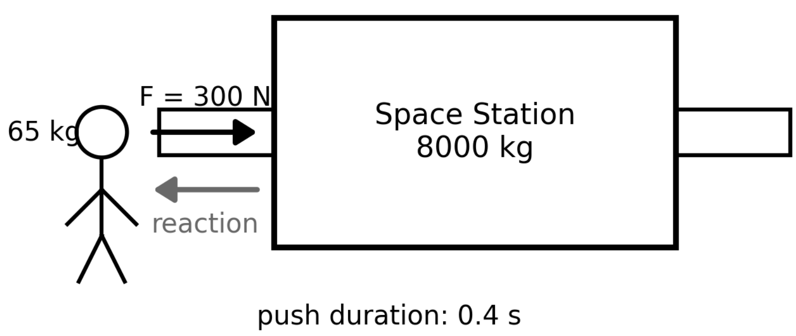


Problem 20. A 25 kg sign hangs from a junction point that is held by three cables: cable A pulls up and to the left at 40° from the ceiling (horizontal), cable B pulls up and to the right at 55° from the ceiling, and cable C hangs vertically down to the sign itself (see diagram). The system is in static equilibrium. Find the tension

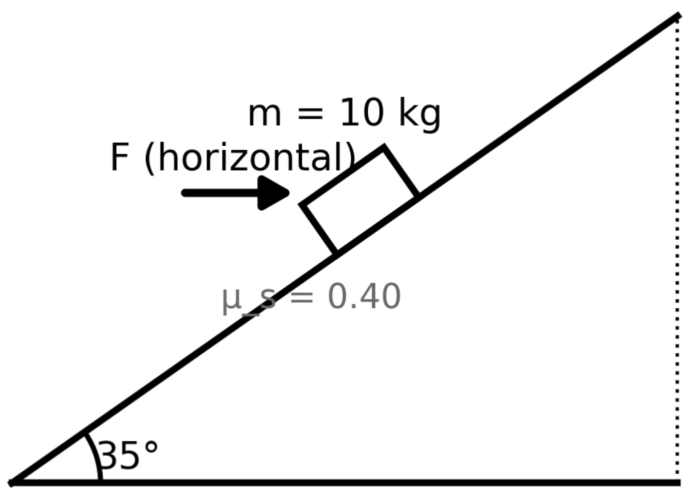
in each of the three cables (T_A, T_B, T_C).



Problem 21. A 65 kg astronaut and an 8000 kg space station are initially at rest relative to each other in deep space. The astronaut pushes off the station, exerting a force of 300 N on it for 0.4 seconds. (a) State the force the station exerts on the astronaut during the push (magnitude and direction) and identify which of Newton's laws makes this true. (b) Find the astronaut's velocity immediately after the push. (c) Find the station's velocity immediately after the push. (d) Compare the two velocities — explain in one sentence why the astronaut moves so much faster than the station, even though equal forces acted on each.



Problem 22. A 10 kg block sits on a 35° incline. The coefficient of static friction between block and incline is mu_s = 0.40. A horizontal force F is applied to the block (parallel to the ground, directed into the incline as shown), pushing the block toward the slope. (a) Find the MINIMUM value of F such that the block does not slide DOWN the incline. (b) Find the MAXIMUM value of F such that the block does not slide UP the incline. (c) State the range of F for which the block remains stationary.



Answer Key — Full Worked Solutions

All values use $g = 9.8\ m/s^2$.

Problem 1.

Forces on the block at the instant of release:

- Weight: $F_g = mg = (6)(9.8) =$ **58.8 N** straight down
- Normal force: $N = mg\cos(25°) = (6)(9.8)(0.9063) =$ **53.3 N** perpendicular to surface

Net force is NOT zero — the down-slope component of gravity is unopposed (no friction).

Net force down the slope = $mg\sin(25°) = (6)(9.8)(0.4226) = 24.85$ N

Acceleration = $mg\sin(25°) / m = g\sin(25°) = (9.8)(0.4226) =$ **4.14 m/s^2 down the slope**

Common error: *Forgetting that the normal force on an incline is mg cos(theta), NOT mg. Also: assuming that because the surface 'holds the block up,' the net force must be zero — but there is no friction to counter the down-slope gravity here.*

Problem 2.

Mass is the same at every location (it is the amount of matter in the object): **m = 8 kg** everywhere.

Weight = $F_g = mg$, which changes with local g.

- Earth (g = 9.8): $F_g = (8)(9.8) =$ **78.4 N**
- Moon (g = 1.6): $F_g = (8)(1.6) =$ **12.8 N**
- Mars (g = 3.7): $F_g = (8)(3.7) =$ **29.6 N**

Common error: *Treating mass and weight as the same thing. Mass NEVER changes with location; weight always does.*

Problem 3.

(a) Find F_{min} to start motion:

$N = mg = (8)(9.8) = 78.4$ N

Maximum static friction = $mu_s N = (0.45)(78.4) = 35.28$ N

F must exceed max static friction to initiate motion: $\mathbf{F_{min} = 35.3\ N}$

(b) Once moving with F = 35.28 N, kinetic friction takes over:

$f_k = mu_k N = (0.30)(78.4) = 23.52$ N

Net force = $F - f_k = 35.28 - 23.52 = 11.76$ N

$a = 11.76 / 8 =$ **1.47 m/s^2**

Common error: *Using mu_k to find the force needed to start motion. Always use mu_s to determine the threshold for initiating motion; switch to mu_k only once the block is already sliding.*

Problem 4.

(a) $a = F_{net} / m = 30 / 12 =$ **2.5 m/s^2**

(b) $v = v_0 + at = 0 + (2.5)(4) =$ **10 m/s**

(c) $d = v_0 t + ½at^2 = 0 + ½(2.5)(4^2) = (0.5)(2.5)(16) =$ **20 m**

Common error: *Forgetting to start from rest (v_0 = 0) and adding an extra term, or using the wrong kinematic equation when given a, t, and starting condition.*

Problem 5.

For an Atwood machine: $a = (m_2 - m_1) g / (m_1 + m_2)$

(a) $a = (14 - 9)(9.8) / (14 + 9) = 49 / 23 =$ **2.13 m/s^2**

(b) For the 9 kg block (rising): $T - m_1 g = m_1 a$

$T = m_1(g + a) = 9(9.8 + 2.13) = 9(11.93) =$ **107.4 N**

Check with the 14 kg block (falling): $m_2g - T = m_2a$

$14(9.8) - 107.4 = 137.2 - 107.4 = 29.8$ N; $m_2a = 14(2.13) = 29.8$ N ✓

Common error: *Using a bad sign convention and getting a negative answer with no idea what it means. Always assign POSITIVE direction as the way the heavier mass actually moves before writing either equation.*

Problem 6.

(a) $a = m_2g / (m_1 + m_2) = (3)(9.8) / (5 + 3) = 29.4 / 8 =$ **3.68 m/s²**

(b) $d = v_0t + ½at^2 = 0 + ½(3.68)(2.5^2) = (0.5)(3.68)(6.25) =$ **11.5 m**

Common error: *Treating the 5 kg block on the table as if it had its own driving force. On a frictionless table, the ONLY thing driving the system is the hanging mass's weight; the table block just adds to the system's inertia.*

Problem 7.

Set up x and y equilibrium equations at the sign. Angles are measured from the ceiling (horizontal).

Each rope's vertical component supports the weight; horizontal components must cancel.

Vertical: $T_1 \sin(35°) + T_2 \sin(60°) = mg = (18)(9.8) = 176.4$ N

Horizontal: $T_1 \cos(35°) = T_2 \cos(60°)$

$T_1(0.8192) = T_2(0.5) \rightarrow T_1 = 0.6105\, T_2$

Substitute into vertical equation:

$(0.6105\, T_2)(0.5736) + T_2(0.8660) = 176.4$

$0.3502\, T_2 + 0.8660\, T_2 = 176.4$

$1.2162\, T_2 = 176.4 \rightarrow$ **T_2 = 145.0 N**

$T_1 = 0.6105(145.0) =$ **88.5 N**

Common error: *Writing only the y-equation and ignoring the x-equation. With unequal angles, both equations are required — there is no symmetry to lean on.*

Problem 8.

At equilibrium, the spring's restoring force balances gravity:

$k \cdot x = mg$

$x = mg / k = (4)(9.8) / 400 = 39.2 / 400 =$ **0.098 m = 9.8 cm**

Common error: *Mixing up the sign convention on Hooke's Law. The magnitude k|x| balances mg at equilibrium — the negative sign in F = -kx tells you direction, not magnitude.*

Problem 9.

Block slides down, so kinetic friction acts UP the slope, opposing motion.

Along the slope (positive = down): $mg \sin(30°) - mu_k N = ma$

Normal force: $N = mg \cos(30°) = (7)(9.8)(0.866) = 59.41$ N

Friction: $f_k = mu_k N = (0.2)(59.41) = 11.88$ N

Net force down slope: $F_{net} = mg \sin(30°) - f_k = (7)(9.8)(0.5) - 11.88 = 34.3 - 11.88 = 22.42$ N

a = 22.42 / 7 = 3.20 m/s² down the slope

N = 59.4 N perpendicular to surface

Common error: *Using N = mg in the friction formula instead of N = mg cos(theta). On any incline, the normal force depends on the cosine of the angle, not just on mg.*

Problem 10.

Decompose the applied force (at 25° BELOW horizontal):

$F_x = 180 \cos(25°) = 180(0.9063) = 163.1$ N (horizontal)

F_y = 180 sin(25°) = 180(0.4226) = 76.1 N (DOWNWARD — adds to weight pressing on floor)

(a) Normal force: N = mg + F_y = (20)(9.8) + 76.1 = 196 + 76.1 = **272.1 N**

(b) Kinetic friction: f_k = mu_k N = (0.30)(272.1) = **81.6 N**

(c) Net horizontal force = F_x - f_k = 163.1 - 81.6 = 81.5 N

a = 81.5 / 20 = **4.07 m/s^2**

Common error: *Forgetting that the downward component of the push INCREASES the normal force, which in turn increases friction. A push below horizontal is self-sabotaging the harder you press.*

Problem 11.

Decompose both tensions into x and y components.

T_1 = 55 N at 35° (rightward, upward):

T_{1x} = 55 cos(35°) = 55(0.8192) = 45.06 N (right)

T_{1y} = 55 sin(35°) = 55(0.5736) = 31.55 N (up)

T_2 = 40 N at 50° (leftward, upward):

T_{2x} = 40 cos(50°) = 40(0.6428) = 25.71 N (left)

T_{2y} = 40 sin(50°) = 40(0.7660) = 30.64 N (up)

Net horizontal = 45.06 - 25.71 = 19.35 N (rightward)

Net vertical pull = 31.55 + 30.64 = 62.19 N (upward), but weight mg = (8)(9.8) = 78.4 N (downward)

Since 62.19 < 78.4, the block stays on the surface. Vertical acceleration = 0; only horizontal motion.

a = 19.35 / 8 = 2.42 m/s^2 to the right (toward T_1)

Common error: *Adding the two tension magnitudes directly (55 + 40 = 95) instead of decomposing them. Forces at different angles cannot be added like plain numbers — only their components in the same direction can.*

Problem 12.

First, test whether the block actually starts to move. Required friction to hold it:

$f_{required}$ = mg sin(25°) = (10)(9.8)(0.4226) = 41.41 N

Maximum available static friction:

N = mg cos(25°) = (10)(9.8)(0.9063) = 88.82 N

$f_{s,max}$ = mu_s N = (0.55)(88.82) = 48.85 N

Since $f_{s,max}$ (48.85 N) > $f_{required}$ (41.41 N), static friction is sufficient.

The block does NOT slide. It remains at rest.

Acceleration = **0**. Actual static friction = **41.41 N up the slope** (only as much as needed).

Common error: *Skipping the static-threshold check and jumping straight into the kinetic-friction formula, which gives a false 'acceleration' on a block that is actually at rest. Always test the static threshold first.*

Problem 13.

Scale reading = Normal force N from scale on person. Newton's 2nd Law on the person:

N - mg = ma → N = m(g + a) (taking up as positive)

(a) Accelerating UP at 2 m/s^2: N = 70(9.8 + 2) = 70(11.8) = **826 N**

(b) Accelerating DOWN at 3 m/s^2: a = -3, N = 70(9.8 - 3) = 70(6.8) = **476 N**

(c) Free fall: a = -9.8, N = 70(9.8 - 9.8) = **0 N** (apparent weightlessness)

Normal weight (at rest in elevator) would be 70(9.8) = 686 N — note all three answers differ from this.

Common error: *Using mg for the scale reading regardless of acceleration. The scale measures the normal force, which equals mg only when acceleration is zero.*

Problem 14.

(a) Treat A+B+C as one system: total mass = 1 + 2 + 3 = 6 kg

$a = F / m_{total} = 18 / 6 =$ **$3.0\ m/s^2$**

(b) Force A exerts on B = net force needed to accelerate B+C together:

$F_{AB} = (m_B + m_C)\ a = (2 + 3)(3.0) =$ **15 N**

(c) Force B exerts on C = net force needed to accelerate C alone:

$F_{BC} = m_C\ a = (3)(3.0) =$ **9 N**

(d) Newton's 2nd Law on block A alone:

$F_{net,A} = F - F_{BA}$ (where $F_{BA} = F_{AB}$ by Newton's 3rd Law) = 18 - 15 = 3 N

$a_A = 3 / 1 = 3.0\ m/s^2$ ✓ matches system acceleration

Common error: *Assuming the force A exerts on B equals the applied F (18 N). It does not — block A 'shields' some of the force by accelerating with its own mass. The contact force is only what is needed to accelerate everything DOWNSTREAM of it.*

Problem 15.

When the truck decelerates, the box tends to continue moving forward by inertia. Static friction on the box from the truck bed acts BACKWARD (opposing relative slipping). This friction is the only horizontal force on the box, so it is what decelerates the box.

Max static friction = mu_s N = mu_s mg = (0.55)(12)(9.8) = 64.68 N

Max deceleration of box = $f_{s,max} / m = 64.68 / 12 = 5.39\ m/s^2$

If the truck decelerates faster than the box can be slowed by friction alone, the box slides forward.

Max truck deceleration = mu_s g = (0.55)(9.8) = $5.39\ m/s^2$

Note: the box's mass cancels out — the answer is just mu_s g.

Common error: *Forgetting that friction on the box from the truck bed is what stops the box. If the truck decelerates harder than that friction can hold, the box keeps moving even as the truck slows.*

Problem 16.

Setup: 10 kg block on table (friction acts), 6 kg hanging (drives the system).

(a) Friction on table block: $f_k = mu_k\ m_1\ g = (0.25)(10)(9.8) = 24.5$ N

System eq: $m_2 g - f_k = (m_1 + m_2)\ a$

(6)(9.8) - 24.5 = 16 a → 58.8 - 24.5 = 16 a → 34.3 = 16 a

$a = 2.14\ m/s^2$

(b) From hanging mass eq: $m_2 g - T = m_2 a \rightarrow T = m_2(g - a) = 6(9.8 - 2.14) = 6(7.66) =$ **46.0 N**

(c) Time to fall 1.5 m from rest: $d = ½at^2$

$1.5 = ½(2.14)\ t^2 \rightarrow t^2 = 1.402 \rightarrow$ **t = 1.18 s**

Common error: *Applying the friction coefficient to the hanging mass instead of the block actually touching the table. Friction acts only at surfaces in contact.*

Problem 17.

For B to stay with A (no slipping), B must accelerate with A. The ONLY horizontal force on block B is static friction from A. So static friction is what accelerates B.

Max static friction on B: $f_{s,max} = mu_s\ N_B = mu_s\ m_B\ g = (0.40)(4)(9.8) = 15.68$ N

Max acceleration of B (before slipping): $a_{max} = f_{s,max} / m_B = 15.68 / 4 = 3.92\ m/s^2$

Alternative: $a_{max} = mu_s\ g = (0.40)(9.8) = 3.92\ m/s^2$ (the m_B cancels)

For the whole system (A + B together) at this acceleration:

$F_{max} = (m_A + m_B)\ a_{max} = (6 + 4)(3.92) =$ **39.2 N**

The force accelerating B is **static friction from A on B**, NOT the applied F directly.

Common error: *Assuming the applied force F acts on block B somehow. F is applied to A only — B accelerates entirely because of the static friction between A and B. That friction has a maximum, and once F demands more, B* *slips.*

Problem 18.

Compare driving forces (down-slope components of weight) on each side:

W_1 sin(30°) = (100)(0.5) = 50.0 N (down the 30° slope, pulls W_2 up)

W_2 sin(50°) = (180)(0.766) = 137.88 N (down the 50° slope, pulls W_1 up)

(a) W_2's component (137.88) > W_1's component (50.0), so **W_2 slides DOWN, W_1 slides UP**.

(b) Convert to mass: m_1 = 100/9.8 = 10.20 kg; m_2 = 180/9.8 = 18.37 kg

Friction on W_2 (opposes motion DOWN slope, so acts UP slope): f_{k2} = mu_k m_2 g cos(50°) = (0.20)(18.37)(9.8)(0.643) = 23.15 N

Friction on W_1 (opposes motion UP slope, so acts DOWN slope): f_{k1} = mu_k m_1 g cos(30°) = (0.20)(10.20)(9.8)(0.866) = 17.32 N

System equation (positive = direction of motion):

$[W_2 \sin(50°) - f_{k2}] - [W_1 \sin(30°) + f_{k1}] = (m_1 + m_2)\, a$

(137.88 - 23.15) - (50.0 + 17.32) = (10.20 + 18.37) a

114.73 - 67.32 = 28.57 a → 47.41 = 28.57 a → **a = 1.66 m/s^2**

(c) Tension: use m_1's equation along its slope (positive = up its slope):

$T - m_1 g \sin(30°) - f_{k1} = m_1\, a$

$T = m_1\, a + W_1 \sin(30°) + f_{k1}$ = (10.20)(1.66) + 50.0 + 17.32 = 16.93 + 67.32 = **84.3 N**

Common error: *Solving for acceleration before determining direction. With friction on both sides, plugging in the wrong direction gives a negative answer with no useful physical meaning. Always check direction with the sine-component comparison first.*

Problem 19.

Compare driving forces:

m_1 g sin(32°) = (15)(9.8)(0.530) = 77.91 N (m_1 wants to slide down)

m_2 g = (4)(9.8) = 39.2 N (m_2 wants to fall, pulls m_1 up)

(a) m_1's drive (77.91) > m_2's drive (39.2), so **m_1 slides DOWN the incline, m_2 rises**.

(b) Friction on m_1 opposes its downward slide → acts UP the slope:

f_k = mu_k m_1 g cos(32°) = (0.20)(15)(9.8)(0.848) = 24.93 N

System equation (positive = m_1 sliding down/m_2 rising):

$m_1 g \sin(32°) - f_k - m_2 g = (m_1 + m_2)\, a$

77.91 - 24.93 - 39.2 = 19 a → 13.78 = 19 a → **a = 0.725 m/s^2**

(c) Tension: from m_2's equation (positive = rising): $T - m_2 g = m_2 a$

$T = m_2(g + a)$ = 4(9.8 + 0.725) = 4(10.525) = **42.1 N**

(d) Time for m_2 to rise 1.5 m from rest: $d = ½at^2$

1.5 = ½(0.725) t^2 → t^2 = 4.138 → **t = 2.03 s**

Common error: *Treating the hanging mass's weight as if it always wins. When the incline mass is large enough and its angle is steep enough, the incline side actually drives the system — the hanging mass gets pulled UP.*

Problem 20.

Cable C hangs vertically and supports the sign alone, so T_C = Mg = (25)(9.8) = **245 N**.

At the junction, three forces act: T_A (up-left at 40° from ceiling), T_B (up-right at 55° from ceiling), and T_C pulling DOWN (the sign's weight transferred through cable C).

Vertical equilibrium: $T_A \sin(40°) + T_B \sin(55°) = T_C$ = 245 N

Horizontal equilibrium: $T_A \cos(40°) = T_B \cos(55°)$

$T_A(0.766) = T_B(0.5736) \rightarrow T_A = 0.7488\ T_B$

Substitute into vertical eq:

$(0.7488\ T_B)(0.6428) + T_B(0.8192) = 245$

$0.4814\ T_B + 0.8192\ T_B = 245$

$1.3006\ T_B = 245 \rightarrow$ $\mathbf{T_B = 188.4\ N}$

$\mathbf{T_A = 0.7488(188.4) = 141.1\ N}$

$\mathbf{T_C = 245\ N}$

Common error: *Forgetting that cable C carries the full weight by itself (it's the only vertical cable to the sign), then trying to split the sign's weight between all three cables. Treat the junction as the equilibrium point — not the sign itself.*

Problem 21.

(a) By **Newton's Third Law**, the station exerts a force of **300 N on the astronaut**, in the OPPOSITE direction (away from the station, pushing the astronaut backward).

(b) Astronaut's acceleration during push: $a_{astro} = F / m_{astro} = 300 / 65 = 4.615\ m/s^2$

Velocity after 0.4 s: $v_{astro} = a \cdot t = (4.615)(0.4) =$ **1.85 m/s** (away from station)

(c) Station's acceleration: $a_{station} = F / m_{station} = 300 / 8000 = 0.0375\ m/s^2$

Velocity after 0.4 s: $v_{station} = (0.0375)(0.4) =$ **0.015 m/s** (away from astronaut)

(d) Same force acted on both bodies (Newton's 3rd Law), but the station has 123× more mass than the astronaut, so its acceleration is 123× smaller (Newton's 2nd Law). Ratio check: $v_{astro}/v_{station} = 1.85/0.015 \approx 123$ ✓

Common error: *Concluding that 'equal forces means equal velocities.' Equal forces give EQUAL IMPULSE on each object, but the resulting velocity depends on mass — the lighter object always ends up moving much faster.*

Problem 22.

Set up tilted axes along the incline. The horizontal force F has components:

Along slope (UP the slope): F cos(35°) = 0.819 F

Into the surface (adds to normal force): F sin(35°) = 0.574 F

Gravity components: mg sin(35°) = (10)(9.8)(0.574) = 56.21 N down the slope; mg cos(35°) = (10)(9.8)(0.819) = 80.29 N into surface.

Normal force depends on F: N = mg cos(35°) + F sin(35°) = 80.29 + 0.574 F

Max static friction available: $f_{s,max} = mu_s N = 0.40\ (80.29 + 0.574\ F) = 32.12 + 0.230\ F$

(a) Find F_{min}: block on the verge of sliding DOWN. Friction acts UP the slope, at max:

$F\cos(35°) + f_{s,max} = mg\sin(35°)$

0.819 F + 32.12 + 0.230 F = 56.21

$1.049\ F = 24.09 \rightarrow$ $\mathbf{F_{min} = 23.0\ N}$

(b) Find F_{max}: block on the verge of sliding UP. Friction acts DOWN the slope, at max:

$F\cos(35°) - f_{s,max} = mg\sin(35°)$

0.819 F - 32.12 - 0.230 F = 56.21

$0.589\ F = 88.33 \rightarrow$ $\mathbf{F_{max} = 150.0\ N}$

(c) Block stays at rest for 23.0 N ≤ F ≤ 150.0 N.

Common error: *Treating friction as a fixed value instead of recognizing it can act in either direction up to its maximum. Friction adapts — it pushes UP the slope when the block wants to slide down, and DOWN the slope when the block wants to slide up. There are TWO failure modes here, not one.*

End of answer key. Found an error or have a question? Email feedback through auxlearning.com.