5

The Laws of Motion

CHAPTER OUTLINE

5.1 The Concept of Force
5.2 Newton's First Law and Inertial Frames
5.3 Mass
5.4 Newton's Second Law
5.5 The Gravitational Force and Weight
5.6 Newton's Third Law
5.7 Some Applications of Newton's Laws
5.8 Forces of Friction

ANSWERS TO QUESTIONS

Q5.1 (a) The force due to gravity of the earth pulling down on the ball—the reaction force is the force due to gravity of the ball pulling up on the earth. The force of the hand pushing up on the ball—reaction force is ball pushing down on the hand.

(b) The only force acting on the ball in free-fall is the gravity due to the earth—the reaction force is the gravity due to the ball pulling on the earth.

Q5.2 The resultant force is zero, as the acceleration is zero.

***Q5.3** Answer (b). An air track or air table is a wonderful thing. It exactly cancels out the force of the Earth's gravity on the gliding object, to display free motion and to imitate the effect of being far away in space.

Q5.4 When the bus starts moving, the mass of Claudette is accelerated by the force of the back of the seat on her body. Clark is standing, however, and the only force on him is the friction between his shoes and the floor of the bus. Thus, when the bus starts moving, his feet start accelerating forward, but the rest of his body experiences almost no accelerating force (only that due to his being attached to his accelerating feet!). As a consequence, his body tends to stay almost at rest, according to Newton's first law, relative to the ground. Relative to Claudette, however, he is moving toward her and falls into her lap. Both performers won Academy Awards.

***Q5.5** Shake your hands. In particular, move one hand down fast and then stop your hand abruptly. The water drops keep moving down, according to Newton's first law, and leave your hand. This method is particularly effective for fat, large-mass, high-inertia water drops.

Q5.6 First ask, "Was the bus moving forward or backing up?" If it was moving forward, the passenger is lying. A fast stop would make the suitcase fly toward the front of the bus, not toward the rear. If the bus was backing up at any reasonable speed, a sudden stop could not make a suitcase fly far. Fine her for malicious litigiousness.

***Q5.7** (a) The air inside pushes outward on each patch of rubber, exerting a force perpendicular to that section of area. The air outside pushes perpendicularly inward, but not quite so strongly. (b) As the balloon takes off, all of the sections of rubber feel essentially the same outward forces as before, but the now-open hole at the opening on the west side feels no force. The vector sum of the forces on the rubber is to the east. The small-mass balloon moves east with a large acceleration. (c) Hot combustion products in the combustion chamber push outward on all the walls of the chamber, but there is nothing for them to push on at the open rocket nozzle. The net force exerted by the gases on the chamber is up if the nozzle is pointing down. This force is larger than the gravitational force on the rocket body, and makes it accelerate upward.

13794_05_ch05_p093-126.indd 93 1/3/07 5:16:39 PM

***Q5.8** A portion of each leaf of grass extends above the metal bar. This portion must accelerate in order for the leaf to bend out of the way. The leaf's mass is small, but when its acceleration is very large, the force exerted by the bar on the leaf puts the leaf under tension large enough to shear it off.

Q5.9 The molecules of the floor resist the ball on impact and push the ball back, upward. The actual force acting is due to the forces between molecules that allow the floor to keep its integrity and to prevent the ball from passing through. Notice that for a ball passing through a window, the molecular forces weren't strong enough.

***Q5.10** The child exerts an upward force on the ball while it is in her hand, but the question is about the ball moving up after it leaves her hand. At those moments, her hand exerts no force on the ball, just as you exert no force on the bathroom scale when you are standing in the shower.
(a) If there were a force greater than the weight of the ball, the ball would accelerate upward, not downward. (b) If there were a force equal to the weight of the ball, the ball would move at constant velocity, but really it slows down as it moves up. (c) The "force of the throw" can be described as zero, because it shows up as zero on a force sensor stuck to her palm. (d) The ball moves up at any one moment because it was moving up the previous moment. A limited downward acceleration acting over a short time has not taken away all of its upward velocity. We could say it moves up because of 'history' or 'pigheadedness' or 'inertia.'

***Q5.11** Since they are on the order of a thousand times denser than the surrounding air, we assume the snowballs are in free fall. The net force on each is the gravitational force exerted by the Earth, which does not depend on their speed or direction of motion but only on the snowball mass. Thus we can rank the missiles just by mass: d > a = e > b > c.

Q5.12 It is impossible to string a horizontal cable without its sagging a bit. Since the cable has a mass, gravity pulls it downward. A vertical component of the tension must balance the weight for the cable to be in equilibrium. If the cable were completely horizontal, then there would be no vertical component of the tension to balance the weight.

Some physics teachers demonstrate this by asking a beefy student to pull on the ends of a cord supporting a can of soup at its center. Some get two burly young men to pull on opposite ends of a strong rope, while the smallest person in class gleefully mashes the center of the rope down to the table. Point out the beauty of sagging suspension-bridge cables. With a laser and an optical lever, demonstrate that the mayor makes the courtroom table sag when he sits on it, and the judge bends the bench. Give them "I make the floor sag" buttons, available to instructors who use this manual and whose classes use the textbook. Estimate the cost of an infinitely strong cable, and the truth will always win.

***Q5.13** The clever boy bends his knees to lower his body, then starts to straighten his knees to push his body up—that is when the branch breaks. When his legs are giving his body upward acceleration, the branch is exerting on him a force greater than his weight. He is just then exerting on the branch an equal-size downward force greater than his weight.

***Q5.14** Yes. The table bends down more to exert a larger upward force. The deformation is easy to see for a block of foam plastic. The sag of a table can be displayed with, for example, an optical lever.

Q5.15 As the barbell goes through the bottom of a cycle, the lifter exerts an upward force on it, and the scale reads the larger upward force that the floor exerts on them together. Around the top of the weight's motion, the scale reads less than average. If the iron is moving upward, the lifter can declare that she has thrown it, just by letting go of it for a moment, so our answer applies also to this case.

***Q5.16** (a) Yes, as exerted by a vertical wall on a ladder leaning against it. (b) Yes, as exerted by a hammer driving a tent stake into the ground. (c) Yes, as the ball accelerates upward in bouncing from the floor. (d) No; the two forces describe the same interaction.

Q5.17 As the sand leaks out, the acceleration increases. With the same driving force, a decrease in the mass causes an increase in the acceleration.

***Q5.18** (a) larger: the tension in A must accelerate two blocks and not just one. (b) equal. Whenever A moves by 1 cm, B moves by 1 cm. The two blocks have equal speeds at every instant and have equal accelerations. (c) yes, backward, equal. The force of cord B on block 1 is the tension in the cord.

Q5.19 As a man takes a step, the action is the force his foot exerts on the Earth; the reaction is the force of the Earth on his foot. In the second case, the action is the force exerted on the girl's back by the snowball; the reaction is the force exerted on the snowball by the girl's back. The third action is the force of the glove on the ball; the reaction is the force of the ball on the glove. The fourth action is the force exerted on the window by the air molecules; the reaction is the force on the air molecules exerted by the window. We could in each case interchange the terms 'action' and 'reaction.'

***Q5.20** (a) Smaller. Block 2 is not in free fall, but pulled backward by string tension. (b) The same. Whenever one block moves by 1 cm, the other block moves by 1 cm. The blocks have equal speeds at every instant and have equal accelerations. (c) The same. The light string exerts forces equal in magnitude on both blocks—the tension in the string.

Q5.21 The tension in the rope when pulling the car is twice that in the tug-of-war. One could consider the car as behaving like another team of twenty more people.

***Q5.22** (b) Newton's 3rd law describes all objects, breaking or whole. The force that the locomotive exerted on the wall is the same as that exerted by the wall on the locomotive. The framing around the wall could not exert so strong a force on the section of the wall that broke out.

Q5.23 The sack of sand moves up with the athlete, regardless of how quickly the athlete climbs. Since the athlete and the sack of sand have the same weight, the acceleration of the system must be zero.

***Q5.24** (i) b. In this case the compressional force on the bug's back only has to be large enough to accelerate the smaller block. (ii) d. and (iii) d. These two forces are equal, as described by Newton's third law.

Q5.25 An object cannot exert a force on itself. If it could, then objects would be able to accelerate themselves, without interacting with the environment. You cannot lift yourself by tugging on your bootstraps.

***Q5.26** answer (b) 200 N must be greater than the force of friction for the box's acceleration to be forward.

***Q5.27** Static friction exerted by the road is the force making the car accelerate forward. Burning gasoline can provide energy for the motion, but only external forces—forces exerted by objects outside—can accelerate the car. If the road surface were icy, the engine would make the tires spin. The rubber contacting the ice would be moving toward the rear of the car. When the road is not icy, static friction opposes this relative sliding motion by exerting a force on the rubber toward the front of the car. If the car is under control and not skidding, the relative speed is zero along the lines where the rubber meets the road, and static friction acts rather than kinetic friction.

***Q5.28** (i) answer d. The stopping distance will be the same if the mass of the truck is doubled. The normal force and the frictional force both double, so the backward acceleration remains the same as without the load. (ii) answer g. The stopping distance will decrease by a factor of four if the initial speed is cut in half.

***Q5.29** Answer (d). Formulas a, b, f, and g have the wrong units for speed. Formula c would give an imaginary answer. Formula e would imply that a more slippery table, with smaller μ, would require a larger original speed, when really it would require a smaller original speed.

***Q5.30** Answer (e). All the other possibilities would make the total force on the crate be different from zero.

Q5.31 If you slam on the brakes, your tires will skid on the road. The force of kinetic friction between the tires and the road is less than the maximum static friction force. Anti-lock brakes work by "pumping" the brakes (much more rapidly that you can) to minimize skidding of the tires on the road.

Q5.32 As you pull away from a stoplight, friction is the force that accelerates forward a box of tissues on the level floor of the car. At the same time, friction exerted by the ground on the tires of the car accelerates the car forward. When you take a step forward, friction exerted by the floor on your shoes causes your acceleration.

***Q5.33** (a) B (b) B (c) B Note that the mass of the woman is more than one-half that of the man. A free-body diagram of the pulley is the best guide for explanation. (d) A.

SOLUTIONS TO PROBLEMS

Section 5.1 **The Concept of Force**

Section 5.2 **Newton's First Law and Inertial Frames**

Section 5.3 **Mass**

Section 5.4 **Newton's Second Law**

Section 5.5 **The Gravitational Force and Weight**

Section 5.6 **Newton's Third Law**

P5.1

$$m = 3.00 \text{ kg}$$

$$\vec{\mathbf{a}} = \left(2.00\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}}\right) \text{ m/s}^2$$

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}} = \boxed{\left(6.00\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}}\right) \text{ N}}$$

$$\left|\sum \vec{\mathbf{F}}\right| = \sqrt{(6.00)^2 + (15.0)^2} \text{ N} = \boxed{16.2 \text{ N}}$$

P5.2 For the same force F, acting on different masses

$$F = m_1 a_1$$

and

$$F = m_2 a_2$$

(a) $\dfrac{m_1}{m_2} = \dfrac{a_2}{a_1} = \boxed{\dfrac{1}{3}}$

(b) $F = \left(m_1 + m_2\right)a = 4m_1 a = m_1\left(3.00 \text{ m/s}^2\right)$

$a = \boxed{0.750 \text{ m/s}^2}$

P5.3 $m = 4.00\text{ kg}$, $\vec{\mathbf{v}}_i = 3.00\hat{\mathbf{i}}\text{ m/s}$, $\vec{\mathbf{v}}_8 = \left(8.00\hat{\mathbf{i}} + 10.0\hat{\mathbf{j}}\right)\text{ m/s}$, $t = 8.00\text{ s}$

$$\vec{\mathbf{a}} = \frac{\Delta\vec{\mathbf{v}}}{t} = \frac{5.00\hat{\mathbf{i}} + 10.0\hat{\mathbf{j}}}{8.00}\text{ m/s}^2$$

$$\vec{\mathbf{F}} = m\vec{\mathbf{a}} = \boxed{\left(2.50\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}}\right)\text{ N}}$$

$$F = \sqrt{(2.50)^2 + (5.00)^2} = \boxed{5.59\text{ N}}$$

P5.4 (a) Let the x axis be in the original direction of the molecule's motion.

$$v_f = v_i + at: \quad -670\text{ m/s} = 670\text{ m/s} + a\left(3.00 \times 10^{-13}\text{ s}\right)$$

$$a = \boxed{-4.47 \times 10^{15}\text{ m/s}^2}$$

(b) For the molecule, $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$. Its weight is negligible.

$$\vec{\mathbf{F}}_{\text{wall on molecule}} = 4.68 \times 10^{-26}\text{ kg}\left(-4.47 \times 10^{15}\text{ m/s}^2\right) = -2.09 \times 10^{-10}\text{ N}$$

$$\vec{\mathbf{F}}_{\text{molecule on wall}} = \boxed{+2.09 \times 10^{-10}\text{ N}}$$

P5.5 (a) $\sum F = ma$ and $v_f^2 = v_i^2 + 2ax_f$ or $a = \dfrac{v_f^2 - v_i^2}{2x_f}$

Therefore,

$$\sum F = m\frac{\left(v_f^2 - v_i^2\right)}{2x_f}$$

$$\sum F = 9.11 \times 10^{-31}\text{ kg}\frac{\left[\left(7.00 \times 10^5\text{ m/s}^2\right)^2 - \left(3.00 \times 10^5\text{ m/s}^2\right)^2\right]}{2(0.050\,0\text{ m})} = \boxed{3.64 \times 10^{-18}\text{ N}}$$

(b) The gravitational force exerted by the Earth on the electron is its weight,

$$F_g = mg = \left(9.11 \times 10^{-31}\text{ kg}\right)\left(9.80\text{ m/s}^2\right) = 8.93 \times 10^{-30}\text{ N}$$

The accelerating force is $\boxed{4.08 + 10^{11}\text{ times the weight of the electron}}$.

P5.6 (a) $F_g = mg = 120\text{ lb} = (4.448\text{ N/lb})(120\text{ lb}) = \boxed{534\text{ N down}}$

(b) $m = \dfrac{F_g}{g} = \dfrac{534\text{ N}}{9.80\text{ m/s}^2} = \boxed{54.5\text{ kg}}$

P5.7 Imagine a quick trip by jet, on which you do not visit the rest room and your perspiration is just canceled out by a glass of tomato juice. By subtraction, $\left(F_g\right)_p = mg_p$ and $\left(F_g\right)_C = mg_C$ give

$$\Delta F_g = m\left(g_p - g_C\right)$$

For a person whose mass is 88.7 kg, the change in weight is

$$\Delta F_g = 88.7\text{ kg}(9.809\,5 - 9.780\,8) = \boxed{2.55\text{ N}}$$

A precise balance scale, as in a doctor's office, reads the same in different locations because it compares you with the standard masses on its beams. A typical bathroom scale is not precise enough to reveal this difference.

P5.8 We find acceleration:

$$\vec{\mathbf{r}}_f - \vec{\mathbf{r}}_i = \vec{\mathbf{v}}_i t + \frac{1}{2}\vec{\mathbf{a}}t^2$$

$$4.20\ \mathrm{m}\hat{\mathbf{i}} - 3.30\ \mathrm{m}\hat{\mathbf{j}} = 0 + \frac{1}{2}\vec{\mathbf{a}}(1.20\ \mathrm{s})^2 = 0.720\ \mathrm{s}^2\vec{\mathbf{a}}$$

$$\vec{\mathbf{a}} = \left(5.83\hat{\mathbf{i}} - 4.58\hat{\mathbf{j}}\right)\ \mathrm{m/s^2}$$

Now $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ becomes

$$\vec{\mathbf{F}}_g + \vec{\mathbf{F}}_2 = m\vec{\mathbf{a}}$$

$$\vec{\mathbf{F}}_2 = 2.80\ \mathrm{kg}\left(5.83\hat{\mathbf{i}} - 4.58\hat{\mathbf{j}}\right)\ \mathrm{m/s^2} + (2.80\ \mathrm{kg})\left(9.80\ \mathrm{m/s^2}\right)\hat{\mathbf{j}}$$

$$\vec{\mathbf{F}}_2 = \boxed{\left(16.3\hat{\mathbf{i}} + 14.6\hat{\mathbf{j}}\right)\ \mathrm{N}}$$

P5.9 (a) $\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \left(20.0\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}}\right)\ \mathrm{N}$

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}: \quad 20.0\hat{\mathbf{i}} + 15.0\hat{\mathbf{j}} = 5.00\vec{\mathbf{a}}$$

$$\vec{\mathbf{a}} = \left(4.00\hat{\mathbf{i}} + 3.00\hat{\mathbf{j}}\right)\ \mathrm{m/s^2}$$

or

$$\boxed{a = 5.00\ \mathrm{m/s^2}\ \text{at}\ \theta = 36.9°}$$

(b)

$$F_{2x} = 15.0\cos 60.0° = 7.50\ \mathrm{N}$$

$$F_{2y} = 15.0\sin 60.0° = 13.0\ \mathrm{N}$$

$$\vec{\mathbf{F}}_2 = \left(7.50\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}}\right)\ \mathrm{N}$$

$$\sum \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \left(27.5\hat{\mathbf{i}} + 13.0\hat{\mathbf{j}}\right)\ \mathrm{N} = m\vec{\mathbf{a}} = 5.00\vec{\mathbf{a}}$$

$$\vec{\mathbf{a}} = \boxed{\left(5.50\hat{\mathbf{i}} + 2.60\hat{\mathbf{j}}\right)\ \mathrm{m/s^2} = 6.08\ \mathrm{m/s^2}\ \text{at}\ 25.3°}$$

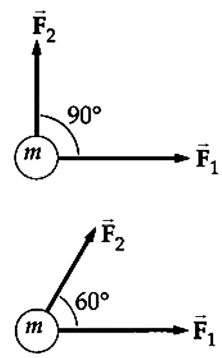


FIG. P5.9

***P5.10** (a) force exerted by spring on hand, to the left; force exerted by spring on wall, to the right. (b) force exerted by wagon on handle, downward to the left. Force exerted by wagon on planet, upward. Force exerted by wagon on ground, downward. (c) Force exerted by football on player, downward to the right. Force exerted by football on planet, upward. (d) Force exerted by small-mass object on large-mass object, to the left. (e) Force exerted by negative charge on positive charge, to the left. (f) Force exerted by iron on magnet, to the left.

P5.11 (a) You and the earth exert equal forces on each other: $m_y g = M_e a_e$. If your mass is 70.0 kg,

$$a_e = \frac{(70.0\ \mathrm{kg})\left(9.80\ \mathrm{m/s^2}\right)}{5.98\times 10^{24}\ \mathrm{kg}} = \boxed{\sim 10^{-22}\ \mathrm{m/s^2}}$$

(b) You and the planet move for equal time intervals according to $x = \frac{1}{2}at^2$. If the seat is 50.0 cm high,

$$\sqrt{\frac{2x_y}{a_y}} = \sqrt{\frac{2x_e}{a_e}}$$

$$x_e = \frac{a_e}{a_y}x_y = \frac{m_y}{m_e}x_y = \frac{70.0\ \mathrm{kg}(0.500\ \mathrm{m})}{5.98\times 10^{24}\ \mathrm{kg}}\boxed{\sim 10^{-23}\ \mathrm{m}}$$

***P5.12** The free-body diagrams (a) and (b) are included in the following diagram. The action–reaction pairs (c) are shown joined by the dashed lines.

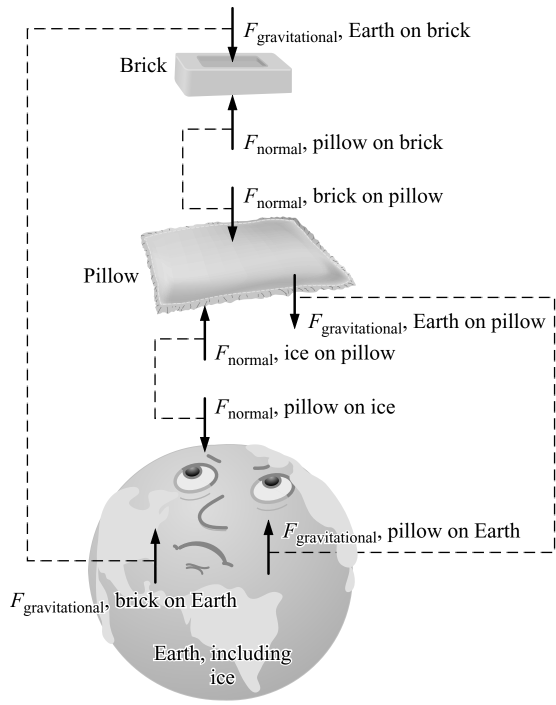


FIG. P5.12

P5.13 (a) $\boxed{15.0 \text{ lb up}}$ to counterbalance the Earth's force on the block

(b) $\boxed{5.00 \text{ lb up}}$ The forces on the block are now the Earth pulling down with 15 lb and the rope pulling up with 10 lb.

(c) $\boxed{0}$ The block now accelerates up away from the floor.

P5.14 $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ reads

$$\left(-2.00\hat{\mathbf{i}} + 2.00\hat{\mathbf{j}} + 5.00\hat{\mathbf{i}} - 3.00\hat{\mathbf{j}} - 45.0\hat{\mathbf{i}}\right) \text{ N} = m\left(3.75 \text{ m/s}^2\right)\hat{\mathbf{a}}$$

where $\hat{\mathbf{a}}$ represents the direction of $\vec{\mathbf{a}}$

$$\left(-42.0\hat{\mathbf{i}} - 1.00\hat{\mathbf{j}}\right) \text{ N} = m\left(3.75 \text{ m/s}^2\right)\hat{\mathbf{a}}$$

$$\sum \vec{\mathbf{F}} = \sqrt{(42.0)^2 + (1.00)^2} \text{ N at } \tan^{-1}\left(\frac{1.00}{42.0}\right) \text{ below the } -x \text{ axis}$$

$$\sum \vec{\mathbf{F}} = 42.0 \text{ N at } 181° = m\left(3.75 \text{ m/s}^2\right)\hat{\mathbf{a}}$$

For the vectors to be equal, their magnitudes and their directions must be equal.

(a) Therefore $\boxed{\hat{\mathbf{a}} \text{ is at } 181°}$ counterclockwise from the x axis

(b) $m = \dfrac{42.0 \text{ N}}{3.75 \text{ m/s}^2} = \boxed{11.2 \text{ kg}}$

(d) $\vec{\mathbf{v}}_f = \vec{\mathbf{v}}_i + \vec{\mathbf{a}}t = 0 + \left(3.75 \text{ m/s}^2 \text{ at } 181°\right)10.0 \text{ s}$ so $\vec{\mathbf{v}}_f = 37.5 \text{ m/s at } 181°$

$\vec{\mathbf{v}}_f = 37.5 \text{ m/s } \cos 181°\hat{\mathbf{i}} + 37.5 \text{ m/s } \sin 181°\hat{\mathbf{j}}$ so $\vec{\mathbf{v}}_f = \boxed{\left(-37.5\hat{\mathbf{i}} - 0.893\hat{\mathbf{j}}\right) \text{ m/s}}$

(c) $\left|\vec{\mathbf{v}}_f\right| = \sqrt{37.5^2 + 0.893^2} \text{ m/s} = \boxed{37.5 \text{ m/s}}$

Section 5.7 Some Applications of Newton's Laws

***P5.15** As the worker through the pole exerts on the lake bottom a force of 240 N downward at 35° behind the vertical, the lake bottom through the pole exerts a force of 240 N upward at 35° ahead of the vertical. With the *x* axis horizontally forward, the pole force on the boat is

$$240\text{ N}\cos 35°\hat{\mathbf{j}} + 240\text{ N}\sin 35°\hat{\mathbf{i}} = 138\text{ N}\hat{\mathbf{i}} + 197\text{ N}\hat{\mathbf{j}}$$

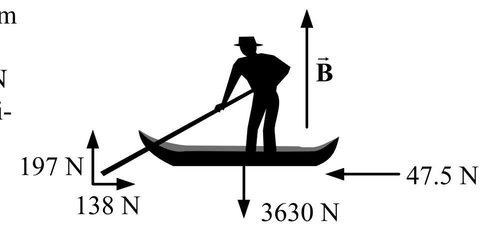


FIG. P5.15

The gravitational force of the whole Earth on boat and worker is $F_g = mg = 370\text{ kg}\left(9.8\text{ m/s}^2\right) = 3630\text{ N}$ down. The acceleration of the boat is purely horizontal, so $\sum F_y = ma_y$ gives $+B + 197\text{ N} - 3630\text{ N} = 0$.

(a) The buoyant force is $B = \boxed{3.43\times 10^3\text{ N}}$.

(b) The acceleration is given by $\sum F_x = ma_x$: $\quad +138\text{ N} - 47.5\text{ N} = (370\text{ kg})a$; $a = \dfrac{90.2\text{ N}}{370\text{ kg}} = 0.244\text{ m/s}^2$. According to the constant-acceleration model,

$$v_{xf} = v_{xi} + a_x t = 0.857\text{ m/s} + \left(0.244\text{ m/s}^2\right)(0.450\text{ s}) = 0.967\text{ m/s}$$

$$\vec{\mathbf{v}}_f = \boxed{0.967\hat{\mathbf{i}}\text{ m/s}}$$

P5.16 $v_x = \dfrac{dx}{dt} = 10t,\ v_y = \dfrac{dy}{dt} = 9t^2$

$a_x = \dfrac{dv_x}{dt} = 10,\ a_y = \dfrac{dv_y}{dt} = 18t$

At $t = 2.00\text{ s},\ a_x = 10.0\text{ m/s}^2,\ a_y = 36.0\text{ m/s}^2$

$\sum F_x = ma_x$: $\quad 3.00\text{ kg}\left(10.0\text{ m/s}^2\right) = 30.0\text{ N}$

$\sum F_y = ma_y$: $\quad 3.00\text{ kg}\left(36.0\text{ m/s}^2\right) = 108\text{ N}$

$$\sum F = \sqrt{F_x^2 + F_y^2} = \boxed{112\text{ N}}$$

P5.17 $m = 1.00\text{ kg}$

$mg = 9.80\text{ N}$

$\tan\alpha = \dfrac{0.200\text{ m}}{25.0\text{ m}}$

$\alpha = 0.458°$

Balance forces,

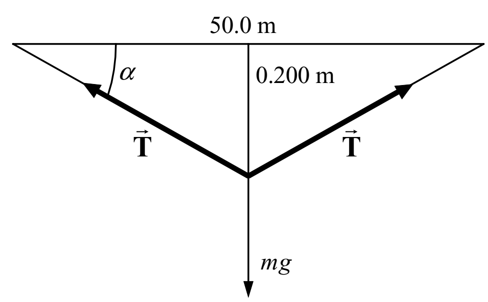


FIG. P5.17

$$2T\sin\alpha = mg$$

$$T = \frac{9.80\text{ N}}{2\sin\alpha} = \boxed{613\text{ N}}$$

***P5.18** (a)

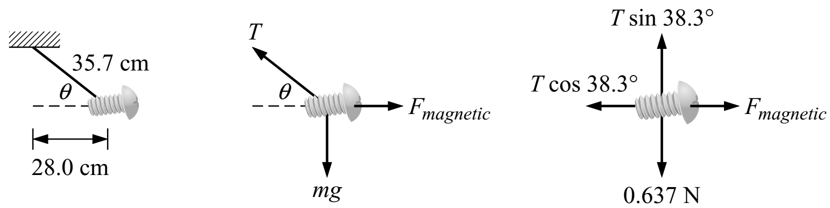


FIG. P5.18

The first diagram shows the geometry of the situation and lets us find the angle of the string with the horizontal: $\cos\theta = 28/35.7 = 0.784$ $\theta = 38.3°$. The second diagram is the free body diagram, and the third diagram is the same free body diagram with some calculated results already shown, including 0.065 kg (9.8 m/s^2) = 0.637 N.

(b) $\sum F_x = ma_x$: $-T\cos 38.3° + F_{magnetic} = 0$

$\sum F_y = ma_y$: $+T\sin 38.3° - 0.637\text{ N} = 0$

from the second equation, $T = 0.637\text{ N}/\sin 38.3° = \boxed{1.03\text{ N}}$

(c) Now $F_{magnetic} = 1.03\text{ N}\cos 38.3° = \boxed{0.805\text{ N to the right}}$.

***P5.19** (a) $P\cos 40° - n = 0$ and $P\sin 40° - 220\text{ N} = 0$
$P = 342$ N and $n = 262$ N

(b) $P - n\cos 40° - 220\text{ N}\sin 40° = 0$ and $n\sin 40 - 220\text{ N}\cos 40° = 0$
$n = 262$ N and $P = 342$ N.

(c) The results agree. The methods are basically of the same level of difficulty. Each involves one equation on one unknown and one equation in two unknowns. If we are interested in finding n without finding P, method (b) is simpler.

P5.20 From equilibrium of the sack: $T_3 = F_g$ (1)

From $\sum F_y = 0$ for the knot: $T_1\sin\theta_1 + T_2\sin\theta_2 = F_g$ (2)

From $\sum F_x = 0$ for the knot: $T_1\cos\theta_1 = T_2\cos\theta_2$ (3)

Eliminate $T_2 = T_2 = T_1\cos\theta_1/\cos\theta_2$ and solve for T_1

$$T_1 = \frac{F_g\cos\theta_2}{(\sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2)} = \frac{F_g\cos\theta_2}{\sin(\theta_1+\theta_2)}$$

$$T_3 = F_g = \boxed{325\text{ N}}$$

$$T_1 = F_g\left(\frac{\cos 25.0°}{\sin 85.0°}\right) = \boxed{296\text{ N}}$$

$$T_2 = T_1\left(\frac{\cos\theta_1}{\cos\theta_2}\right) = 296\text{ N}\left(\frac{\cos 60.0°}{\cos 25.0°}\right) = \boxed{163\text{ N}}$$

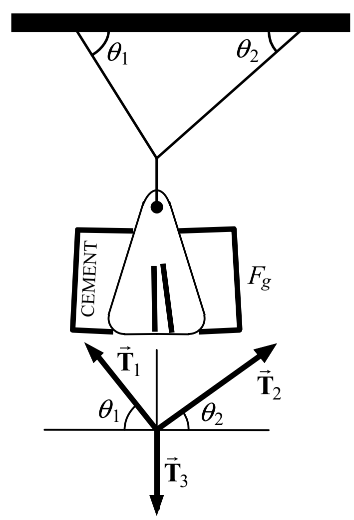


FIG. P5.20

P5.21 See the solution for T_1 in Problem 5.20. The equation indicates that the tension is directly proportional to F_g. As $\theta_1 + \theta_2$ approaches zero (as the angle between the two upper ropes approaches 180°) the tension goes to infinity. Making the right-hand rope horizontal maximizes the tension in the left-hand rope, according to the proportionality of T_1 to $\cos\theta_2$.

P5.22 (a) An explanation proceeding from fundamental physical principles will be best for the parents and for you. Consider forces on the bit of string touching the weight hanger as shown in the free-body diagram:

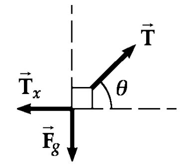


FIG. P5.22

Horizontal Forces: $\sum F_x = ma_x$: $-T_x + T\cos\theta = 0$

Vertical Forces: $\sum F_y = ma_y$: $-F_g + T\sin\theta = 0$

You need only the equation for the vertical forces to find that the tension in the string is given by $T = \boxed{\dfrac{F_g}{\sin\theta}}$. The force the child feels gets smaller, changing from T to $T\cos\theta$, while the counterweight hangs on the string. On the other hand, the kite does not notice what you are doing and the tension in the main part of the string stays constant. You do not need a level, since you learned in physics lab to sight to a horizontal line in a building. Share with the parents your estimate of the experimental uncertainty, which you make by thinking critically about the measurement, by repeating trials, practicing in advance and looking for variations and improvements in technique, including using other observers. You will then be glad to have the parents themselves repeat your measurements.

(b) $T = \dfrac{F_g}{\sin\theta} = \dfrac{0.132\text{ kg}\left(9.80\text{ m/s}^2\right)}{\sin 46.3°} = \boxed{1.79\text{ N}}$

***P5.23** (a) Isolate either mass

$$T + mg = ma = 0$$
$$|T| = |mg|$$

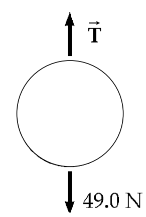


FIG. P5.23(a) and (b)

The scale reads the tension T, so

$$T = mg = 5.00\text{ kg}\left(9.80\text{ m/s}^2\right) = \boxed{49.0\text{ N}}$$

(b) The solution to part (a) is also the solution to (b).

(c) Isolate the pulley

$$\vec{T}_2 + 2\vec{T}_1 = 0$$
$$T_2 = 2|T_1| = 2mg = \boxed{98.0\text{ N}}$$

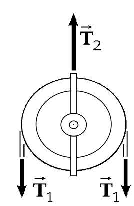


FIG. P5.23(c)

(d) $\sum \vec{F} = \vec{n} + \vec{T} + m\vec{g} = 0$

Take the component along the incline

$$n_x + T_x + mg_x = 0$$

or

$$0 + T - mg\sin 30.0° = 0$$
$$T = mg\sin 30.0° = \frac{mg}{2} = \frac{5.00(9.80)}{2}$$
$$= \boxed{24.5\text{ N}}$$

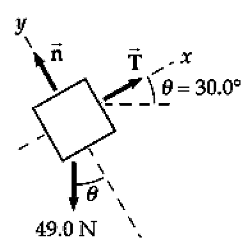


FIG. P5.23(d)

P5.24 The two forces acting on the block are the normal force, n, and the weight, mg. If the block is considered to be a point mass and the x axis is chosen to be parallel to the plane, then the free body diagram will be as shown in the figure to the right. The angle θ is the angle of inclination of the plane. Applying Newton's second law for the accelerating system (and taking the direction up the plane as the positive x direction) we have

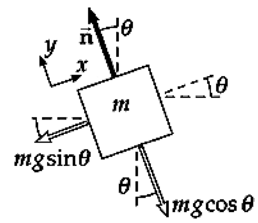


FIG. P5.24

$$\sum F_y = n - mg\cos\theta = 0: \quad n = mg\cos\theta$$

$$\sum F_x = -mg\sin\theta = ma: \quad a = -g\sin\theta$$

(a) When $\theta = 15.0°$

$$a = \boxed{-2.54\ \text{m/s}^2}$$

(b) Starting from rest

$$v_f^2 = v_i^2 + 2a(x_f - x_i) = 2ax_f$$
$$|v_f| = \sqrt{2ax_f} = \sqrt{2(-2.54\ \text{m/s}^2)(-2.00\ \text{m})} = \boxed{3.18\ \text{m/s}}$$

P5.25 Choose a coordinate system with $\hat{\mathbf{i}}$ East and $\hat{\mathbf{j}}$ North.

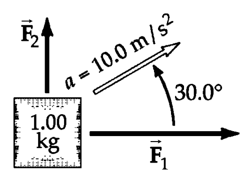


FIG. P5.25

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}} = 1.00\ \text{kg}(10.0\ \text{m/s}^2)\ \text{at}\ 30.0°$$

$$(5.00\ \text{N})\hat{\mathbf{j}} + \vec{\mathbf{F}}_1 = (10.0\ \text{N})\angle 30.0° = (5.00\ \text{N})\hat{\mathbf{j}} + (8.66\ \text{N})\hat{\mathbf{i}}$$

$$\therefore F_1 = \boxed{8.66\ \text{N (East)}}$$

P5.26 First, consider the block moving along the horizontal. The only force in the direction of movement is T. Thus, $\sum F_x = ma$

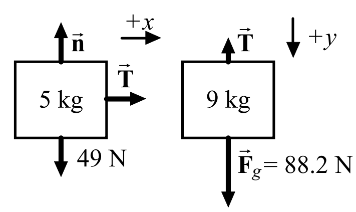


FIG. P5.26

$$T = (5\ \text{kg})a \qquad (1)$$

Next consider the block that moves vertically. The forces on it are the tension T and its weight, 88.2 N.

We have $\sum F_y = ma$

$$88.2\ \text{N} - T = (9\ \text{kg})a \qquad (2)$$

Note that both blocks must have the same magnitude of acceleration. Equations (1) and (2) can be added to give $88.2\ \text{N} = (14\ \text{kg})a$. Then

$$\boxed{a = 6.30\ \text{m/s}^2 \text{ and } T = 31.5\ \text{N}}$$

***P5.27** (a) and (b) The slope of the graph of upward velocity versus time is the acceleration of the person's body. At both time 0 and time 0.5 s, this slope is (18 cm/s)/0.6 s = 30 cm/s^2.

For the person's body, $\Sigma F_y = ma_y$: $\quad +F_{\text{bar}} - 64\ \text{kg}(9.8\ \text{m/s}^2) = 64\ \text{kg}\ (0.3\ \text{m/s}^2)$

Note that there is no floor touching the person to exert a normal force. Note that he does not exert any extra force 'on himself.' Solving, $F_{\text{bar}} = \boxed{646\ \text{N}}$ up.

continued on next page

(c) a_y = slope of v_y versus t graph = 0 at t = 1.1 s. The person is moving with maximum speed and is momentarily in equilibrium:

$$+F_{\text{bar}} - 64\text{ kg }(9.8\text{ m/s}^2) = 0 \qquad F_{\text{bar}} = \boxed{627\text{ N}}\text{ up.}$$

(d) a_y = slope of v_y versus t graph = (0 − 24 cm/s)/(1.7 s − 1.3 s) = −60 cm/s^2

$$+F_{\text{bar}} - 64\text{ kg}(9.8\text{ m/s}^2) = 64\text{ kg }(-0.6\text{ m/s}^2) \qquad F_{\text{bar}} = \boxed{589\text{ N}}\text{ up.}$$

P5.28 $m_1 = 2.00\text{ kg},\ m_2 = 6.00\text{ kg},\ \theta = 55.0°$

(a) $\sum F_x = m_2 g\sin\theta - T = m_2 a$

and

$$T - m_1 g = m_1 a$$
$$a = \frac{m_2 g\sin\theta - m_1 g}{m_1 + m_2} = \boxed{3.57\ \text{m/s}^2}$$

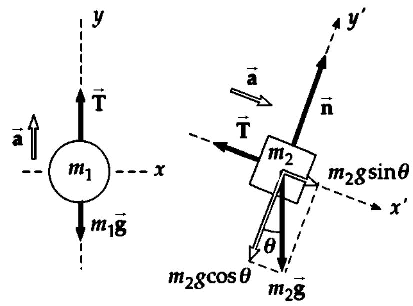


FIG. P5.28

(b) $T = m_1(a+g) = \boxed{26.7\text{ N}}$

(c) Since $v_i = 0,\ v_f = at = (3.57\ \text{m/s}^2)(2.00\text{ s}) = \boxed{7.14\ \text{m/s}}$.

P5.29 After it leaves your hand, the block's speed changes only because of one component of its weight:

$$\sum F_x = ma_x \qquad -mg\sin 20.0° = ma$$
$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

Taking $v_f = 0,\ v_i = 5.00\ \text{m/s}$, and $a = -g\sin(20.0°)$ gives

$$0 = (5.00)^2 - 2(9.80)\sin(20.0°)(x_f - 0)$$

or

$$x_f = \frac{25.0}{2(9.80)\sin(20.0°)} = \boxed{3.73\text{ m}}$$

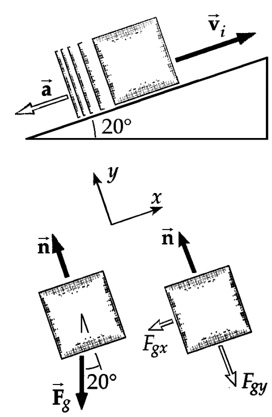


FIG. P5.29

P5.30 As the man rises steadily the pulley turns steadily and the tension in the rope is the same on both sides of the pulley. Choose man-pulley-and-platform as the system:

$$\sum F_y = ma_y$$
$$+T - 950\text{ N} = 0$$
$$T = 950\text{ N}$$

The worker must pull on the rope with force $\boxed{950\text{ N}}$.

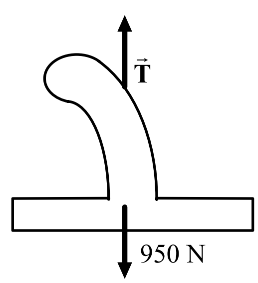


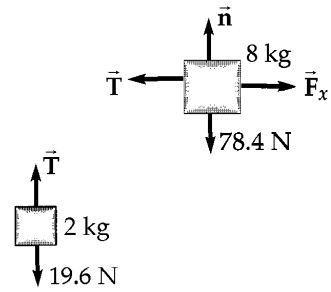
FIG. P5.30

P5.31 Forces acting on 2.00 kg block:

$$T - m_1 g = m_1 a \qquad (1)$$

Forces acting on 8.00 kg block:

$$F_x - T = m_2 a \qquad (2)$$



(a) Eliminate T and solve for a:

$$a = \frac{F_x - m_1 g}{m_1 + m_2}$$

$$\boxed{a > 0 \text{ for } F_x > m_1 g = 19.6 \text{ N}}$$

(b) Eliminate a and solve for T:

$$T = \frac{m_1}{m_1 + m_2}\left(F_x + m_2 g\right)$$

$$\boxed{T = 0 \text{ for } F_x \le -m_2 g = -78.4 \text{ N}}$$

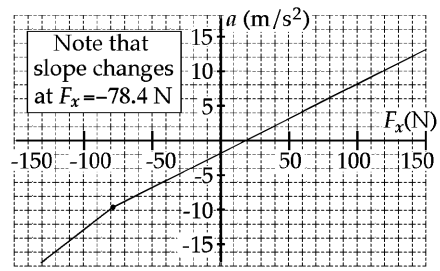


FIG. P5.31

(c)

F_x, N	–100	–78.4	–50.0	0	50.0	100
a_x, m/s^2	–12.5	–9.80	–6.96	–1.96	3.04	8.04

P5.32 (a) Pulley P_1 has acceleration a_2.

Since m_1 moves *twice* the distance P_1 moves in the same time, m_1 has twice the acceleration of P_1, i.e., $\boxed{a_1 = 2a_2}$.

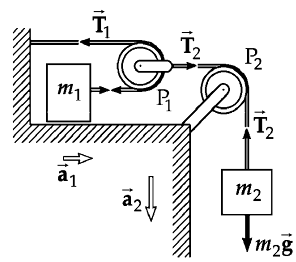


FIG. P5.32

(b) From the figure, and using

$$\sum F = ma: \quad m_2 g - T_2 = m_2 a_2 \qquad (1)$$

$$T_1 = m_1 a_1 = 2m_1 a_2 \qquad (2)$$

$$T_2 - 2T_1 = 0 \qquad (3)$$

Equation (1) becomes $m_2 g - 2T_1 = m_2 a_2$. This equation combined with Equation (2) yields

$$\frac{T_1}{m_1}\left(2m_1 + \frac{m_2}{2}\right) = m_2 g$$

$$\boxed{T_1 = \frac{m_1 m_2}{2m_1 + \frac{1}{2}m_2} g} \text{ and } \boxed{T_2 = \frac{m_1 m_2}{m_1 + \frac{1}{4}m_2} g}$$

(c) From the values of T_1 and T_2 we find that

$$a_1 = \frac{T_1}{m_1} = \boxed{\frac{m_2 g}{2m_1 + \frac{1}{2}m_2}} \text{ and } a_2 = \frac{1}{2}a_1 = \boxed{\frac{m_2 g}{4m_1 + m_2}}$$

P5.33 First, we will compute the needed accelerations:

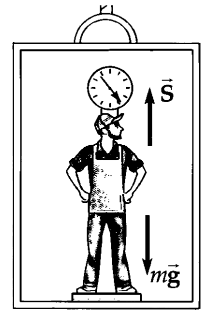


FIG. P5.33

(1) Before it starts to move: $a_y = 0$

(2) During the first 0.800 s: $a_y = \dfrac{v_{yf} - v_{yi}}{t} = \dfrac{1.20 \text{ m/s} - 0}{0.800 \text{ s}}$
$= 1.50 \text{ m/s}^2$

(3) While moving at constant velocity: $a_y = 0$

(4) During the last 1.50 s: $a_y = \dfrac{v_{yf} - v_{yi}}{t} = \dfrac{0 - 1.20 \text{ m/s}}{1.50 \text{ s}}$
$= -0.800 \text{ m/s}^2$

Newton's second law is: $\sum F_y = ma_y$

$$+S - (72.0 \text{ kg})(9.80 \text{ m/s}^2) = (72.0 \text{ kg})a_y$$
$$S = 706 \text{ N} + (72.0 \text{ kg})a_y$$

(a) When $a_y = 0$, $S = \boxed{706 \text{ N}}$.

(b) When $a_y = 1.50 \text{ m/s}^2$, $S = \boxed{814 \text{ N}}$.

(c) When $a_y = 0$, $S = \boxed{706 \text{ N}}$.

(d) When $a_y = -0.800 \text{ m/s}^2$, $S = \boxed{648 \text{ N}}$.

P5.34 Both blocks move with acceleration $a = \left(\dfrac{m_2 - m_1}{m_2 + m_1}\right)g$:

$$a = \left(\frac{7 \text{ kg} - 2 \text{ kg}}{7 \text{ kg} + 2 \text{ kg}}\right) 9.8 \text{ m/s}^2 = 5.44 \text{ m/s}^2$$

(a) Take the upward direction as positive for m_1.

$$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i): \quad 0 = (-2.4 \text{ m/s})^2 + 2(5.44 \text{ m/s}^2)(x_f - 0)$$
$$x_f = -\frac{5.76 \text{ m}^2/\text{s}^2}{2(5.44 \text{ m/s}^2)} = -0.529 \text{ m}$$
$$x_f = \boxed{0.529 \text{ m below its initial level}}$$

(b) $v_{xf} = v_{xi} + a_x t$: $\quad v_{xf} = -2.40 \text{ m/s} + (5.44 \text{ m/s}^2)(1.80 \text{ s})$

$$v_{xf} = \boxed{7.40 \text{ m/s upward}}$$

Section 5.8 **Forces of Friction**

P5.35 $\sum F_y = ma_y$: $+n - mg = 0$

$f_s \le \mu_s n = \mu_s mg$

This maximum magnitude of static friction acts so long as the tires roll without skidding.

$$\sum F_x = ma_x: \quad -f_s = ma$$

The maximum acceleration is

$$a = -\mu_s g$$

The initial and final conditions are: $x_i = 0$, $v_i = 50.0\ \text{mi/h} = 22.4\ \text{m/s}$, $v_f = 0$

$$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right): \quad -v_i^2 = -2\mu_s g x_f$$

(a) $x_f = \dfrac{v_i^2}{2\mu g}$

$$x_f = \frac{(22.4\ \text{m/s})^2}{2(0.100)\left(9.80\ \text{m/s}^2\right)} = \boxed{256\ \text{m}}$$

(b) $x_f = \dfrac{v_i^2}{2\mu g}$

$$x_f = \frac{(22.4\ \text{m/s})^2}{2(0.600)\left(9.80\ \text{m/s}^2\right)} = \boxed{42.7\ \text{m}}$$

P5.36 For equilibrium: $f = F$ and $n = F_g$. Also, $f = \mu n$ i.e.,

$$\mu = \frac{f}{n} = \frac{F}{F_g}$$

$$\mu_s = \frac{75.0\ \text{N}}{25.0(9.80)\ \text{N}} = \boxed{0.306}$$

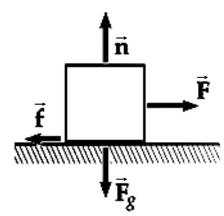


FIG. P5.36

and

$$\mu_k = \frac{60.0\ \text{N}}{25.0(9.80)\ \text{N}} = \boxed{0.245}$$

***P5.37** (a) The car's acceleration in stopping is given by $v_{xf}^2 = v_{xi}^2 + 2\,a_x(x_f - x_i)$ $0 = (20\ \text{m/s})^2 + 2\,a_x(45\ \text{m} - 0)$ $\quad a_x = -4.44\ \text{m/s}^2$.

For the book not to slide on the horizontal seat we need

$$\sum F_x = ma_x: \quad -f_s = ma = 3.8\ \text{kg}(-4.44\ \text{m/s}^2) \quad f_s = 16.9\ \text{N}$$

$$\sum F_y = ma_y: \quad n - mg = 0 \quad n = 3.8\ \text{kg}(9.8\ \text{m/s}^2) = 37.2\ \text{N}$$

To test whether the book starts to slide, we see if this required static friction force is available in the allowed range

$$f_s \le \mu_s n = 0.65(37.2\ \text{N}) = 24.2\ \text{N}$$

Because 16.9 N is less than 24.2 N, $\boxed{\text{the book does not start to slide}}$.

(b) The actual friction force is 16.9 N backwards, and the whole force exerted by the seat on the book is $\boxed{16.9\ \text{N backward} + 37.2\ \text{N upward}}$ = 40.9 N upward and backward at 65.6° with the horizontal.

P5.38 If all the weight is on the rear wheels,

(a) $F = ma$: $\mu_s mg = ma$
But

$$\Delta x = \frac{at^2}{2} = \frac{\mu_s gt^2}{2}$$

so $\mu_s = \dfrac{2\Delta x}{gt^2}$:

$$\mu_s = \frac{2(0.250\text{ mi})(1\,609\text{ m/mi})}{(9.80\text{ m/s}^2)(4.96\text{ s})^2} = \boxed{3.34}$$

(b) Time would increase, as the wheels would skid and only kinetic friction would act; or perhaps the car would flip over.

P5.39 $m = 3.00\text{ kg}$, $\theta = 30.0°$, $x = 2.00\text{ m}$, $t = 1.50\text{ s}$

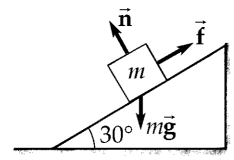


FIG. P5.39

(a) $x = \dfrac{1}{2}at^2$:

$$2.00\text{ m} = \frac{1}{2}a(1.50\text{ s})^2$$

$$a = \frac{4.00}{(1.50)^2} = \boxed{1.78\text{ m/s}^2}$$

$\sum \vec{\mathbf{F}} = \vec{\mathbf{n}} + \vec{\mathbf{f}} + m\vec{\mathbf{g}} = m\vec{\mathbf{a}}$:

Along x: $0 - f + mg\sin 30.0° = ma$

$f = m(g\sin 30.0° - a)$

Along y: $n + 0 - mg\cos 30.0° = 0$

$n = mg\cos 30.0°$

(b) $\mu_k = \dfrac{f}{n} = \dfrac{m(g\sin 30.0° - a)}{mg\cos 30.0°}$, $\mu_k = \tan 30.0° - \dfrac{a}{g\cos 30.0°} = \boxed{0.368}$

(c) $f = m(g\sin 30.0° - a)$, $f = 3.00(9.80\sin 30.0° - 1.78) = \boxed{9.37\text{ N}}$

(d) $v_f^2 = v_i^2 + 2a(x_f - x_i)$

where

$$x_f - x_i = 2.00\text{ m}$$

$$v_f^2 = 0 + 2(1.78)(2.00) = 7.11\text{ m}^2/\text{s}^2$$

$$v_f = \sqrt{7.11\text{ m}^2/\text{s}^2} = \boxed{2.67\text{ m/s}}$$

P5.40 $m_{\text{suitcase}} = 20.0\text{ kg}$, $F = 35.0\text{ N}$

$$\sum F_x = ma_x: \quad -20.0\text{ N} + F\cos\theta = 0$$
$$\sum F_y = ma_y: \quad +n + F\sin\theta - F_g = 0$$

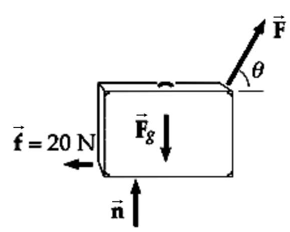


FIG. P5.40

(a) $F\cos\theta = 20.0\text{ N}$

$$\cos\theta = \frac{20.0\text{ N}}{35.0\text{ N}} = 0.571$$

$\boxed{\theta = 55.2°}$

(b) $n = F_g - F\sin\theta = [196 - 35.0(0.821)]\text{ N}$

$\boxed{n = 167\text{ N}}$

P5.41 $T - f_k = 5.00a$ (for 5.00 kg mass)

$9.00g - T = 9.00a$ (for 9.00 kg mass)

Adding these two equations gives:

$$9.00(9.80) - 0.200(5.00)(9.80) = 14.0a$$
$$a = 5.60 \text{ m/s}^2$$
$$\therefore T = 5.00(5.60) + 0.200(5.00)(9.80)$$
$$= \boxed{37.8 \text{ N}}$$

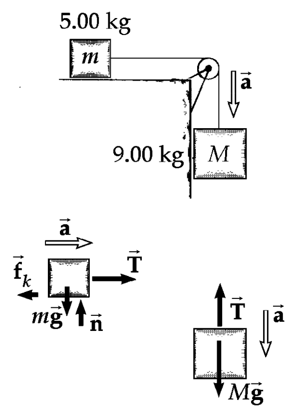


FIG. P5.41

P5.42 Let a represent the positive magnitude of the acceleration $-a\hat{\mathbf{j}}$ of m_1, of the acceleration $-a\hat{\mathbf{i}}$ of m_2, and of the acceleration $+a\hat{\mathbf{j}}$ of m_3. Call T_{12} the tension in the left rope and T_{23} the tension in the cord on the right.

For m_1, $\sum F_y = ma_y$ $\quad +T_{12} - m_1 g = -m_1 a$

For m_2, $\sum F_x = ma_x$ $\quad -T_{12} + \mu_k n + T_{23} = -m_2 a$

and $\sum F_y = ma_y$ $\quad n - m_2 g = 0$

for m_3, $\sum F_y = ma_y$ $\quad T_{23} - m_3 g = +m_3 a$

we have three simultaneous equations

$$-T_{12} + 39.2 \text{ N} = (4.00 \text{ kg})a$$
$$+T_{12} - 0.350(9.80 \text{ N}) - T_{23} = (1.00 \text{ kg})a$$
$$+T_{23} - 19.6 \text{ N} = (2.00 \text{ kg})a$$

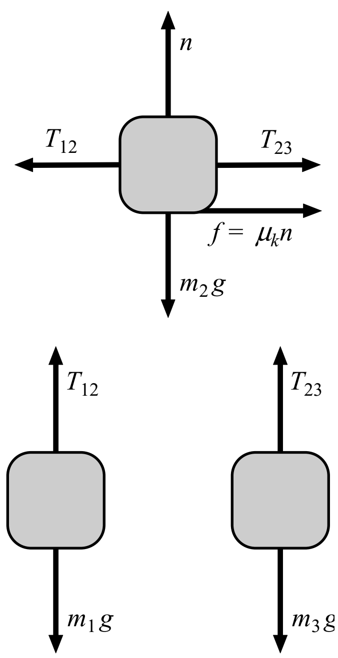


FIG. P5.42

(a) Add them up:

$$+39.2 \text{ N} - 3.43 \text{ N} - 19.6 \text{ N} = (7.00 \text{ kg})a$$

$$a = \boxed{2.31 \text{ m/s}^2\text{, down for } m_1\text{, left for } m_2\text{, and up for } m_3}$$

(b) Now $-T_{12} + 39.2 \text{ N} = (4.00 \text{ kg})(2.31 \text{ m/s}^2)$

$$\boxed{T_{12} = 30.0 \text{ N}}$$

and $T_{23} - 19.6 \text{ N} = (2.00 \text{ kg})(2.31 \text{ m/s}^2)$

$$\boxed{T_{23} = 24.2 \text{ N}}$$

P5.43 (a) See the figure adjoining

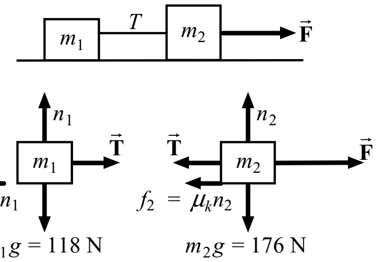


FIG. P5.43

(b) $68.0 - T - \mu m_2 g = m_2 a$ (Block #2)

$T - \mu m_1 g = m_1 a$ (Block #1)

Adding,

$$68.0 - \mu(m_1 + m_2)g = (m_1 + m_2)a$$

$$a = \frac{68.0}{(m_1 + m_2)} - \mu g = \boxed{1.29\ \text{m/s}^2}$$

$$T = m_1 a + \mu m_1 g = \boxed{27.2\ \text{N}}$$

P5.44 (a) To find the maximum possible value of P, imagine impending upward motion as case 1. Setting

$$\sum F_x = 0: \quad P\cos 50.0° - n = 0$$

$$f_{s,\,\max} = \mu_s n: \quad f_{s,\,\max} = \mu_s P\cos 50.0°$$
$$= 0.250(0.643)P = 0.161P$$

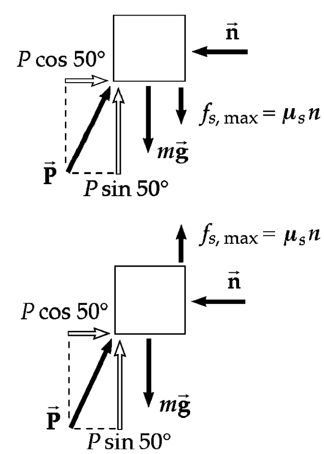


FIG. P5.44

Setting

$$\sum F_y = 0: \quad P\sin 50.0° - 0.161P - 3.00(9.80) = 0$$

$$P_{\max} = \boxed{48.6\ \text{N}}$$

To find the minimum possible value of P, consider impending downward motion. As in case 1,

$$f_{s,\,\max} = 0.161P$$

Setting

$$\sum F_y = 0: \quad P\sin 50.0° + 0.161P - 3.00(9.80) = 0$$

$$P_{\min} = \boxed{31.7\ \text{N}}$$

(b) $\boxed{\text{If } P > 48.6 \text{ N, the block slides up the wall. If } P < 31.7 \text{ N, the block slides down the wall.}}$

(c) We repeat the calculation as in part (a) with the new angle. Consider impending upward motion as case 1. Setting

$$\sum F_x = 0: \quad P\cos 13° - n = 0$$

$$f_{s,\,\max} = \mu_s n: \quad f_{s,\,\max} = \mu_s P\cos 13°$$

Setting

$$= 0.250(0.974)P = 0.244P$$

$$\sum F_y = 0: \quad P\sin 13° - 0.244P - 3.00(9.80) = 0$$

$$P_{\max} = -1580\ \text{N}$$

The push cannot really be negative. However large or small it is, it cannot produce upward motion. To find the minimum possible value of P, consider impending downward motion. As in case 1,

$$f_{s,\,\max} = 0.244P$$

Setting

$$\sum F_y = 0: \quad P\sin 13° + 0.244P - 3.00(9.80) = 0$$

$$P_{\min} = \boxed{62.7\ \text{N}}$$

$\boxed{P \geq 62.7 \text{ N. The block cannot slide up the wall. If } P < 62.7 \text{ N, the block slides down the wall.}}$

***P5.45** (a) If P is too small, static friction will prevent the block from moving. We will find the value of P when motion is just ready to begin:

$\Sigma F_y = ma_y$: $-P \sin 37° - 0.42 \text{ kg } 9.8 \text{ m/s}^2 + n = 0$ $\quad n = 4.12 \text{ N} + P \sin 37°$

with motion impending we read the equality sign in

$f_s = \mu_s n = 0.72(4.12 \text{ N} + P \sin 37°) = 2.96 \text{ N} + 0.433\, P$

$\Sigma F_x = ma_x$: $\quad P \cos 37° - f = 0 \quad P \cos 37° - 2.96 \text{ N} - 0.433P = 0 \quad P = 8.11 \text{ N}$

Thus $\boxed{a = 0 \text{ if } P \leq 8.11 \text{ N}}$. If $P > 8.11$ N, the block starts moving. Immediately kinetic friction acts, so it controls the acceleration we measure. We have again $n = 4.12 \text{ N} + P \sin 37°$

$f_k = \mu_k n = 0.34(4.12 \text{ N} + P \sin 37°) = 1.40 \text{ N} + 0.205\, P$

$\Sigma F_x = ma_x$: $\quad P \cos 37° - f = 0.42 \text{ kg } a \quad a = (P \cos 37° - 1.40 \text{ N} - 0.205\, P)/0.42 \text{ kg}$

$$\boxed{a = 1.41\, P - 3.33 \quad \text{where } a \text{ is in m/s}^2 \text{ when } P \text{ is in N, to the right if } P > 8.11 \text{ N}}$$

(b) Since 5 N is less than 8.11 N, $a = \boxed{0}$.

(c) $f_s \leq \mu_s n$ does not tell us the value of the friction force. We know that it must counterbalance 5 N cos 37° = 3.99 N, to hold the block at rest. The friction force here is $\boxed{\text{3.99 N horizontally backward}}$.

(d) $a = 1.41(10) - 3.33 = \boxed{10.8 \text{ m/s}^2 \text{ to the right}}$

(e) From part (a), $f = 1.40 \text{ N} + 0.205(10) = \boxed{3.45 \text{ N to the left}}$.

(f) The acceleration is zero for all values of P less than 8.11 N. When P passes this threshold, the acceleration jumps to its minimum nonzero value of 8.14 m/s². From there it increases linearly with P toward arbitrarily high values.

P5.46 We must consider separately the disk when it is in contact with the roof and when it has gone over the top into free fall. In the first case, we take x and y as parallel and perpendicular to the surface of the roof:

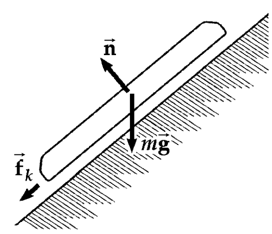


FIG. P5.46

$$\sum F_y = ma_y: \quad +n - mg\cos\theta = 0$$
$$n = mg\cos\theta$$

then friction is $f_k = \mu_k n = \mu_k mg\cos\theta$

$$\sum F_x = ma_x: \quad -f_k - mg\sin\theta = ma_x$$
$$a_x = -\mu_k g\cos\theta - g\sin\theta = (-0.4\cos 37° - \sin 37°)9.8 \text{ m/s}^2 = -9.03 \text{ m/s}^2$$

The Frisbee goes ballistic with speed given by

$$v_{xf}^2 = v_{xi}^2 + 2a_x\left(x_f - x_i\right) = (15 \text{ m/s})^2 + 2\left(-9.03 \text{ m/s}^2\right)(10 \text{ m} - 0) = 44.4 \text{ m}^2/\text{s}^2$$
$$v_{xf} = 6.67 \text{ m/s}$$

For the free fall, we take x and y horizontal and vertical:

$$v_{yf}^2 = v_{yi}^2 + 2a_y\left(y_f - y_i\right)$$
$$0 = \left(6.67 \text{ m/s } \sin 37°\right)^2 + 2\left(-9.8 \text{ m/s}^2\right)\left(y_f - 10 \text{ m } \sin 37°\right)$$
$$y_f = 6.02 \text{ m} + \frac{(4.01 \text{ m/s})^2}{19.6 \text{ m/s}^2} = \boxed{6.84 \text{ m}}$$

P5.47 Since the board is in equilibrium, $\sum F_x = 0$ and we see that the normal forces must be the same on both sides of the board. Also, if the minimum normal forces (compression forces) are being applied, the board is on the verge of slipping and the friction force on each side is

$$f = (f_s)_{\max} = \mu_s n$$

The board is also in equilibrium in the vertical direction, so

$$\sum F_y = 2f - F_g = 0, \text{ or } f = \frac{F_g}{2}$$

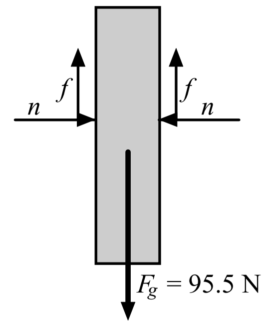


FIG. P5.47

The minimum compression force needed is then

$$n = \frac{f}{\mu_s} = \frac{F_g}{2\mu_s} = \frac{95.5 \text{ N}}{2(0.663)} = \boxed{72.0 \text{ N}}$$

P5.48 Take $+x$ in the direction of motion of the tablecloth. For the mug:

$$\sum F_x = ma_x \quad 0.1 \text{ N} = 0.2 \text{ kg } a_x$$
$$a_x = 0.5 \text{ m/s}^2$$

Relative to the tablecloth, the acceleration of the mug is $0.5 \text{ m/s}^2 - 3 \text{ m/s}^2 = -2.5 \text{ m/s}^2$. The mug reaches the edge of the tablecloth after time given by

$$\Delta x = v_{xi} t + \frac{1}{2} a_x t^2$$
$$-0.3 \text{ m} = 0 + \frac{1}{2}\left(-2.5 \text{ m/s}^2\right) t^2$$
$$t = 0.490 \text{ s}$$

The motion of the mug relative to tabletop is over distance

$$\frac{1}{2} a_x t^2 = \frac{1}{2}\left(0.5 \text{ m/s}^2\right)(0.490 \text{ s})^2 = \boxed{0.060\,0 \text{ m}}$$

The tablecloth slides 36 cm over the table in this process.

***P5.49** (a) When the truck has the greatest acceleration it can without the box sliding, the force of friction on the box is forward and is described by $f_s = \mu_s n$.
We also have $\Sigma F_x = ma_x$: $\quad +f_s = ma \qquad \Sigma F_y = ma_y$: $\quad +n - mg = 0$
Combining by substitution gives $\mu_s mg = ma \qquad a = 0.3\ (9.8 \text{ m/s}^2) = \boxed{2.94 \text{ m/s}^2}$ forward.

(b) The truck is accelerating forward rapidly and exerting a forward force of kinetic friction on the box, making the box accelerate forward more slowly;
$n = mg \quad f_k = \mu_k\, mg = ma \qquad a = \mu_k\, g = 0.25\ (9.8 \text{ m/s}^2) = \boxed{2.45 \text{ m/s}^2}$ forward.

(c) Now take the x axis along the direction of motion and the y axis perpendicular to the slope.
We have $\Sigma F_y = ma_y$: $\quad +n - mg \cos 10° = 0 \qquad +n = mg \cos 10° \qquad f_s = \mu_s\, mg \cos 10°$
$\Sigma F_x = ma_x$: $\quad +f_s - mg \sin 10° = ma$
$a = \mu_s\, g \cos 10° - g \sin 10° = 0.3(9.8 \text{ m/s}^2) \cos 10° - (9.8 \text{ m/s}^2) \sin 10° =$
$\boxed{1.19 \text{ m/s}^2 \text{ up the incline}}$

(d) This time kinetic friction acts:
$\Sigma F_y = ma_y$: $\quad +n - mg \cos 10° = 0 \qquad +n = mg \cos 10° \qquad f_k = \mu_k\, mg \cos 10°$
$\Sigma F_x = ma_x$: $\quad +f_k - mg \sin 10° = ma$
$a = \mu_k\, g \cos 10° - g \sin 10° = [0.25 \cos 10° - \sin 10°]9.8 \text{ m/s}^2 = \boxed{0.711 \text{ m/s}^2 \text{ up the incline}}$

continued on next page

(e) Model the box as in equilibrium (total force equals zero) with motion impending (static friction equals coefficient times normal force).

$\Sigma F_y = ma_y$: $\quad +n - mg\cos\theta = 0 \qquad +n = mg\cos\theta \qquad f_s = \mu_s mg\cos\theta$

$\Sigma F_x = ma_x$: $\quad +f_s - mg\sin\theta = ma = 0 \qquad \mu_s mg\cos\theta - mg\sin\theta = 0$

$\mu_s = \sin\theta/\cos\theta = \tan\theta \qquad \theta = \tan^{-1} 0.3 = \boxed{16.7°}$

(f) The mass makes no difference. Mathematically, the mass has divided out in each determination of acceleration and angle. Physically, if several packages of dishes were placed in the truck, they would all slide together, whether they were tied to one another or not.

Additional Problems

***P5.50** (a) Directly $n = 63.7\text{ N}\cos 13° = 62.1\text{ N}$

$$f_k = 0.36(62.1\text{ N}) = 22.3\text{ N}$$

Now adding $+T + 14.3\text{ N} - 22.3\text{ N} = (6.5\text{ kg})a$ and $-T + 37.2\text{ N} = (3.8\text{ kg})a$ gives

$37.2\text{ N} - 8.01\text{ N} = (10.3\text{ kg})a$

$$\boxed{a = 2.84\text{ m/s}^2}$$

Then $T = 37.2\text{ N} - 3.8\text{ kg}(2.84\text{ m/s}^2) = \boxed{26.5\text{ N}}$.

(b) We recognize the equations are describing a 6.5-kg block on an incline at 13° with the horizontal. It has coefficient of friction 0.36 with the incline. It is pulled forward, which is down the incline, by the tension in a cord running to a hanging 3.8-kg object.

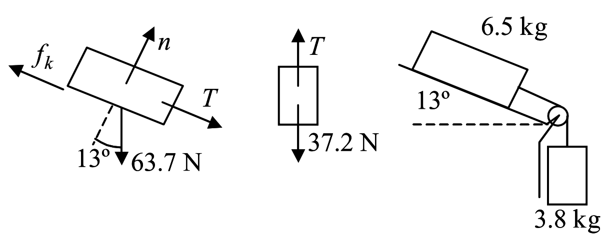


FIG. P5.50

P5.51 (a) see figure to the right

(b) First consider Pat and the chair as the system. Note that *two* ropes support the system, and $T = 250$ N in each rope. Applying $\sum F = ma \quad 2T - 480 = ma$, where

$$m = \frac{480}{9.80} = 49.0\text{ kg}$$

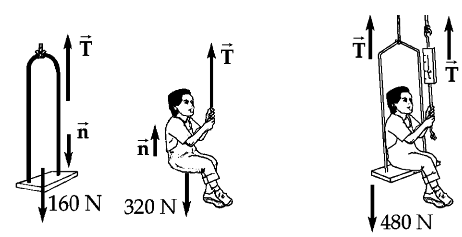


FIG. P5.51

Solving for a gives

$$a = \frac{500 - 480}{49.0} = \boxed{0.408\text{ m/s}^2}$$

(c) $\sum F = ma$ on Pat:

$$\sum F = n + T - 320 = ma,\text{ where } m = \frac{320}{9.80} = 32.7\text{ kg}$$

$n = ma + 320 - T = 32.7(0.408) + 320 - 250 = \boxed{83.3\text{ N}}$.

***P5.52** (a) As soon as Pat passes the rope to the other child,

$\boxed{\text{Pat and the seat, with total weight 480 N, will accelerate down and the other child, only 440 N, will accelerate up.}}$

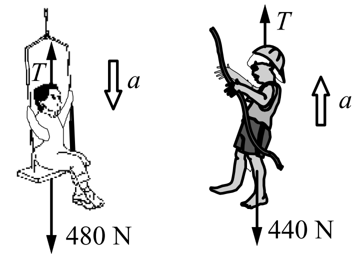


FIG. 5.52

We have $+480\text{ N} - T = \dfrac{480\text{ N}}{9.8\text{ m/s}^2}a$ and $+T - 440\text{ N} = \dfrac{440\text{ N}}{9.8\text{ m/s}^2}a$

Adding,

$$+480\text{ N} - T + T - 440\text{ N} = (49.0\text{ kg} + 44.9\text{ kg})a$$

$$a = \frac{40\text{ N}}{93.9\text{ kg}} = \boxed{0.426\text{ m/s}^2 = a}$$

The rope tension is $T = 440\text{ N} + 44.9\text{ kg}(0.426\text{ m/s}^2) = 459\text{ N}$.

(b) In problem 51, a rope tension of 250 N does not make the rope break. In part (a), the rope is strong enough to support tension 459 N. But now the tension everywhere in the rope is 480 N, so it can exceed the breaking strength of the rope.

The tension in the chain supporting the pulley is $480 + 480\text{ N} = 960\text{ N}$, so that chain may break first.

P5.53 $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ gives the object's acceleration

$$\vec{\mathbf{a}} = \frac{\sum F}{m} = \frac{(8.00\hat{\mathbf{i}} - 4.00t\hat{\mathbf{j}})\text{ N}}{2.00\text{ kg}}$$

$$\vec{\mathbf{a}} = (4.00\text{ m/s}^2)\hat{\mathbf{i}} - (2.00\text{ m/s}^3)t\hat{\mathbf{j}} = \frac{d\vec{\mathbf{v}}}{dt}$$

Its velocity is

$$\int_{v_i}^{v} d\vec{\mathbf{v}} = \vec{\mathbf{v}} - \vec{\mathbf{v}}_i = \vec{\mathbf{v}} - 0 = \int_0^t \vec{\mathbf{a}}\,dt$$

$$\vec{\mathbf{v}} = \int_0^t \left[(4.00\text{ m/s}^2)\hat{\mathbf{i}} - (2.00\text{ m/s}^3)t\hat{\mathbf{j}}\right]dt$$

$$\vec{\mathbf{v}} = (4.00t\text{ m/s}^2)\hat{\mathbf{i}} - (1.00t^2\text{ m/s}^3)\hat{\mathbf{j}}$$

(a) We require $|\vec{\mathbf{v}}| = 15.0 \text{ m/s}$, $|\vec{\mathbf{v}}|^2 = 225 \text{ m}^2/\text{s}^2$

$$16.0t^2 \text{ m}^2/\text{s}^4 + 1.00t^4 \text{ m}^2/\text{s}^6 = 225 \text{ m}^2/\text{s}^2$$
$$1.00t^4 + 16.0 \text{ s}^2 t^2 - 225 \text{ s}^4 = 0$$
$$t^2 = \frac{-16.0 \pm \sqrt{(16.0)^2 - 4(-225)}}{2.00} = 9.00 \text{ s}^2$$
$$t = \boxed{3.00 \text{ s}}$$

Take $\vec{\mathbf{r}}_i = 0$ at $t = 0$. The position is

$$\vec{\mathbf{r}} = \int_0^t \vec{\mathbf{v}}dt = \int_0^t \left[\left(4.00t \text{ m/s}^2\right)\hat{\mathbf{i}} - \left(1.00t^2 \text{ m/s}^3\right)\hat{\mathbf{j}}\right]dt$$
$$\vec{\mathbf{r}} = \left(4.00 \text{ m/s}^2\right)\frac{t^2}{2}\hat{\mathbf{i}} - \left(1.00 \text{ m/s}^3\right)\frac{t^3}{3}\hat{\mathbf{j}}$$

at $t = 3$ s we evaluate.

(b) $\vec{\mathbf{r}} = \boxed{\left(18.0\hat{\mathbf{i}} - 9.00\hat{\mathbf{j}}\right) \text{ m}}$

(c) So $|\vec{\mathbf{r}}| = \sqrt{(18.0)^2 + (9.00)^2} \text{ m} = \boxed{20.1 \text{ m}}$

P5.54 (a) We write $\sum F_x = ma_x$ for each object.

$$18 \text{ N} - P = (2 \text{ kg})a$$
$$P - Q = (3 \text{ kg})a$$
$$Q = (4 \text{ kg})a$$

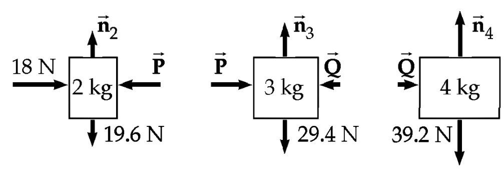


FIG. P5.54

Adding gives $18 \text{ N} = (9 \text{ kg})a$ so

.
$$a = \boxed{2.00 \text{ m/s}^2}$$

(b) $Q = 4 \text{ kg}\left(2 \text{ m/s}^2\right) = \boxed{8.00 \text{ N net force on the 4 kg}}$

$P - 8 \text{ N} = 3 \text{ kg}\left(2 \text{ m/s}^2\right) = \boxed{6.00 \text{ N net force on the 3 kg}}$ and $P = 14 \text{ N}$

$18 \text{ N} - 14 \text{ N} = 2 \text{ kg}\left(2 \text{ m/s}^2\right) = \boxed{4.00 \text{ N net force on the 2 kg}}$

continued on next page

(c) From above, $Q = \boxed{8.00\text{ N}}$ and $P = \boxed{14.0\text{ N}}$

(d) The 3-kg block models the heavy block of wood. The contact force on your back is represented by Q, which is much less than the force F. The difference between F and Q is the net force causing acceleration of the 5-kg pair of objects. The acceleration is real and nonzero, but lasts for so short a time that it never is associated with a large velocity. The frame of the building and your legs exert forces, small relative to the hammer blow, to bring the partition, block, and you to rest again over a time large relative to the hammer blow. This problem lends itself to interesting lecture demonstrations. One person can hold a lead brick in one hand while another hits the brick with a hammer.

***P5.55** (a) Take the rope and block together as the system:

$$\Sigma F_x = ma_x: \quad +12\text{ N} = (4\text{ kg} + m_1)a \qquad a = \boxed{12\text{N}/(4\text{ kg} + m_1)\text{ forward}}$$

(b) The rope tension varies along the massive rope, with the value 12 N at the front end and a value we call T_{back} at the back end. Take the block alone as the system:

$$\Sigma F_x = ma_x: \quad +T_{back} = (4\text{ kg})a = 4\text{ kg}(12\text{N}/(4\text{ kg} + m_1) = \boxed{12\text{ N}/(1 + m_1/4\text{ kg})\text{ forward}}$$

(c) We substitute $m_1 = 0.8$ kg: $a = 12\text{N}/(4\text{ kg} + 0.8\text{ kg}) = \boxed{2.50\text{ m/s}^2\text{ forward}}$

$$T_{back} = 12\text{ N}/(1 + 0.8/4) = \boxed{10.0\text{ N forward}}$$

(d) As $m_1 \to \infty$, $\quad 12\text{ N}/(1 + m_1/4)$ $\boxed{\text{goes to zero}}$

(e) As $m_1 \to 0$, $\quad 12\text{ N}/(1 + m_1/4)$ $\boxed{\text{goes to 12 N}}$

(f) $\boxed{\text{A cord of negligible mass has constant tension along its length.}}$

***P5.56** (a) Choose the black glider plus magnet as the system.

$$\Sigma F_x = ma_x: \quad +0.823\text{ N} = 0.24\text{ kg }a \qquad a = \boxed{3.43\text{ m/s}^2\text{ toward the scrap iron}}$$

(b) The analysis in part (a) applies here with no change. $a_{black} =$ $\boxed{3.43\text{ m/s}^2\text{ toward the scrap iron}}$.

For the green glider with the scrap iron,

$$\Sigma F_x = ma_x: \quad +0.823\text{ N} = 0.12\text{ kg }a \qquad a = \boxed{6.86\text{ m/s}^2\text{ toward the magnet}}$$

P5.57 (a) First, we note that $F = T_1$. Next, we focus on the mass M and write $T_5 = Mg$. Next, we focus on the bottom pulley and write $T_5 = T_2 + T_3$. Finally, we focus on the top pulley and write $T_4 = T_1 + T_2 + T_3$.

Since the pulleys are not starting to rotate and are frictionless, $T_1 = T_3$, and $T_2 = T_3$. From this information, we have $T_5 = 2T_2$, so $T_2 = \frac{Mg}{2}$.

Then $\boxed{T_1 = T_2 = T_3 = \frac{Mg}{2}}$, and $\boxed{T_4 = \frac{3Mg}{2}}$,

and $\boxed{T_5 = Mg}$.

(b) Since $F = T_1$, we have $\boxed{F = \frac{Mg}{2}}$.

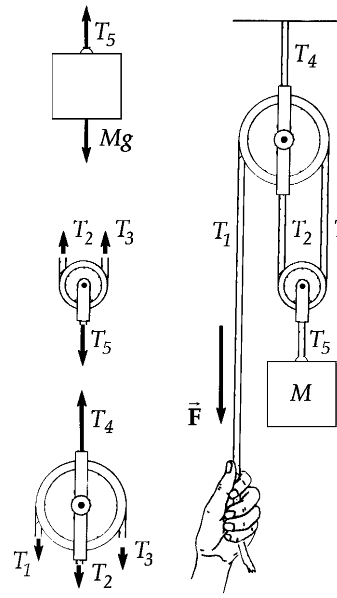


FIG. P5.57

***P5.58** (a) The cord makes angle θ with the horizontal where $\tan\theta = 0.1/0.4 \qquad \theta = 14.0°$.

$\Sigma F_y = ma_y$: $\quad + 10$ N sin 14.0° − 2.2 kg 9.8 m/s² + $n = 0 \qquad n = 19.1$ N

$f_k = \mu_k n = 0.4(19.1\text{ N}) = 7.65\text{ N}$

$\Sigma F_x = ma_x$: $\quad + 10$ N cos 14.0° − 7.65 N = 2.2 kg $a \qquad a = \boxed{0.931\text{ m/s}^2}$

(b) When x is large we have $n = 21.6$ N, $f_k = 8.62$ N and $a = (10\text{ N} - 8.62\text{ N})/2.2\text{ kg} = 0.625\text{ m/s}^2$. As x decreases, the acceleration increases gradually, passes through a maximum, and then drops more rapidly, becoming negative. At $x = 0$ it reaches the value $a = [0 - 0.4(21.6\text{ N} - 10\text{ N})]/2.2\text{ kg} = -2.10\text{ m/s}^2$.

(c) We carry through the same calculations as in part (a) for a variable angle, for which $\cos\theta = x[x^2 + (.1\text{m})^2]^{-1/2}$ and $\sin\theta = 0.1\text{ m}[x^2 + (.1\text{m})^2]^{-1/2}$ We find

$$a = \frac{10\text{ N}\,x\left[x^2+0.1^2\right]^{-1/2} - 0.4\left(21.6\text{ N} - 10\text{ N}\,0.1\left[x^2+0.1^2\right]^{-1/2}\right)}{2.2\text{ kg}}$$

$$a = 4.55\,x\left[x^2+0.1^2\right]^{-1/2} - 3.92 + 0.182\left[x^2+0.1^2\right]^{-1/2}$$

Now to maximize a we take its derivative with respect to x and set it equal to zero:

$$\frac{da}{dx} = 4.55\left(x^2+0.1^2\right)^{-1/2} + 4.55x\left(-\tfrac{1}{2}\right)2x\left(x^2+0.1^2\right)^{-3/2} + 0.182\left(-\tfrac{1}{2}\right)2x\left(x^2+0.1^2\right)^{-3/2} = 0$$

$$4.55\left(x^2+0.1^2\right) - 4.55x^2 - 0.182x = 0 \qquad x = \boxed{0.250\text{ m}}$$

At this point $a = 4.55\ (0.25)\left[0.25^2+0.1^2\right]^{-1/2} - 3.92 + 0.182\left[0.25^2+0.1^2\right]^{-1/2} = \boxed{0.976\text{ m/s}^2}$

(d) We solve

$$0 = 4.55\,x\left[x^2+0.1^2\right]^{-1/2} - 3.92 + 0.182\left[x^2+0.1^2\right]^{-1/2}$$

$$3.92\left[x^2+0.1^2\right]^{1/2} = 4.55x + 0.182$$

$$15.4\left[x^2+0.1^2\right] = 20.7x^2 + 1.65x + 0.0331$$

$5.29x^2 + 1.65x - 0.121 = 0$ only the positive root is directly meaningful: $x = \boxed{0.0610\text{ m}}$

***P5.59** (a) The cable does not stretch: Whenever one car moves 1 cm, the other moves 1 cm.

$\boxed{\text{At any instant they have the same velocity and at all instants they have the same acceleration.}}$

(b) Consider the BMW as object.
$\sum F_y = ma_y$: $\quad +T - (1461\text{ kg})(9.8\text{ m/s}^2) = 1461\text{ kg }(1.25\text{ m/s}^2)$ $\qquad T = \boxed{1.61 \times 10^4\text{ N}}$

(c) Consider both cars as object.
$\sum F_y = ma_y$: $\quad +T_{above} - (1461\text{ kg} + 1207\text{ kg})(9.8\text{ m/s}^2) = (1461\text{ kg} + 1207\text{ kg})\ (1.25\text{ m/s}^2)$

$T_{above} = \boxed{2.95 \times 10^4\text{ N}}$

(d) The Ferrari pulls up on the middle section of cable with 16.1 kN. The BMW pulls down on the middle section of cable with 16.1 kN. The net force on the middle section of cable is $\boxed{0}$. The current velocity is 3.50 m/s up. After 0.01 s the acceleration of 1.25 m/s² gives the cable additional velocity 0.0125 m/s, for a total of $\boxed{3.51\text{ m/s upward}}$.

The 3.50 m/s in 3.51 m/s needs no dynamic cause; the motion of the cable continues on its own, as described by the law of 'inertia' or 'pigheadedness.' The 0.01 m/s of extra upward speed must be caused by some total upward force on the section of cable. But because the cable's mass is very small compared to a thousand kilograms, the force is very small compared to 1.61×10^4 N, the nearly uniform tension of this section of cable.

***P5.60** For the system to start to move when released, the force tending to move m_2 down the incline, $m_2 g\sin\theta$, must exceed the maximum friction force which can retard the motion:

$$f_{\max} = f_{1,\max} + f_{2,\max} = \mu_{s,1} n_1 + \mu_{s,2} n_2$$
$$f_{\max} = \mu_{s,1} m_1 g + \mu_{s,2} m_2 g\cos\theta$$

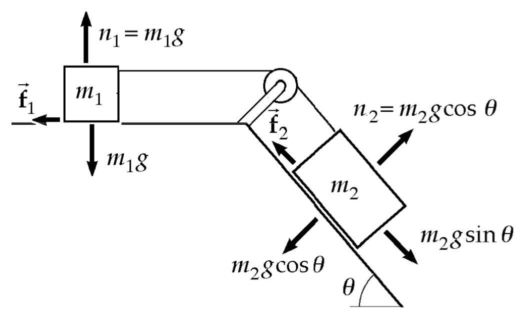


FIG. P5.60

From the table of coefficients of friction in the text, we take $\mu_{s,1} = 0.610$ (aluminum on steel) and $\mu_{s,2} = 0.530$ (copper on steel). With

$$m_1 = 2.00\text{ kg},\ m_2 = 6.00\text{ kg},\ \theta = 30.0°$$

the maximum friction force is found to be $f_{\max} = 38.9$ N. This exceeds the force tending to cause the system to move, $m_2 g\sin\theta = 6.00\text{ kg}\left(9.80\text{ m/s}^2\right)\sin 30° = 29.4$ N. Hence,

$\boxed{\text{the system will not start to move when released}}$.

The friction forces increase in magnitude until the total friction force retarding the motion, $f = f_1 + f_2$, equals the force tending to set the system in motion. That is, until

$$\boxed{f = m_2 g\sin\theta = 29.4\text{ N}}$$

P5.61 (a) The crate is in equilibrium, just before it starts to move. Let the normal force acting on it be n and the friction force, f_s.

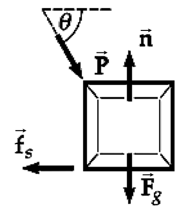


FIG. P5.61

Resolving vertically:

$$n = F_g + P\sin\theta$$

Horizontally:

$$P\cos\theta = f_s$$

But,

$$f_s \le \mu_s n$$

i.e.,

$$P\cos\theta \le \mu_s\left(F_g + P\sin\theta\right)$$

or

$$P\left(\cos\theta - \mu_s\sin\theta\right) \le \mu_s F_g$$

Divide by $\cos\theta$:

$$P\left(1-\mu_s\tan\theta\right) \le \mu_s F_g\sec\theta$$

Then

$$\boxed{P_{\text{minimum}} = \frac{\mu_s F_g\sec\theta}{1-\mu_s\tan\theta}}$$

(b) $P = \dfrac{0.400(100\text{ N})\sec\theta}{1-0.400\tan\theta}$

$\theta(\text{deg})$	0.00	15.0	30.0	45.0	60.0
$P(N)$	40.0	46.4	60.1	94.3	260

If the angle were $68.2°$ or more, the expression for P would go to infinity and motion would become impossible.

P5.62 (a) Following the in-chapter example about a block on a frictionless incline, we have

$$a = g\sin\theta = \left(9.80\text{ m/s}^2\right)\sin 30.0°$$

$$\boxed{a = 4.90\text{ m/s}^2}$$

(b) The block slides distance x on the incline, with $\sin 30.0° = \dfrac{0.500\text{ m}}{x}$

$x = 1.00\text{ m}$: $v_f^2 = v_i^2 + 2a\left(x_f - x_i\right) = 0 + 2\left(4.90\text{ m/s}^2\right)(1.00\text{ m})$

$v_f = \boxed{3.13\text{ m/s}}$ after time $t_s = \dfrac{2x_f}{v_f} = \dfrac{2(1.00\text{ m})}{3.13\text{ m/s}} = 0.639\text{ s}$

continued on next page

(c) Now in free fall $y_f - y_i = v_{yi}t + \frac{1}{2}a_y t^2$:

$$-2.00 = (-3.13\ \text{m/s})\sin 30.0° t - \frac{1}{2}(9.80\ \text{m/s}^2)t^2$$

$$(4.90\ \text{m/s}^2)t^2 + (1.56\ \text{m/s})t - 2.00\ \text{m} = 0$$

$$t = \frac{-1.56\ \text{m/s} \pm \sqrt{(1.56\ \text{m/s})^2 - 4(4.90\ \text{m/s}^2)(-2.00\ \text{m})}}{9.80\ \text{m/s}^2}$$

Only the positive root is physical

$$t = 0.499\ \text{s}$$

$$x_f = v_x t = [(3.13\ \text{m/s})\cos 30.0°](0.499\ \text{s}) = \boxed{1.35\ \text{m}}$$

(d) total time $= t_s + t = 0.639\ \text{s} + 0.499\ \text{s} = \boxed{1.14\ \text{s}}$

(e) The mass of the block makes no difference.

***P5.63** (a) The net force on the cushion is in a fixed direction, downward and forward making angle $\tan^{-1}(F/mg)$ with the vertical. Starting from rest, it will move along this line with (b) increasing speed. Its velocity changes in magnitude.

(c) Since the line of motion is in the direction of the net force, they both make the same angle with the horizontal: $x/8\ \text{m} = F/mg = 2.40\ \text{N}/(1.2\ \text{kg})(9.8\ \text{m/s}^2)$ so $x = \boxed{1.63\ \text{m}}$

(d) The cushion will move along a parabola. The axis of the parabola is parallel to the dashed line in the problem figure. If the cushion is thrown in direction above the dashed line, its path will be concave downward, to make its velocity become more and more nearly parallel to the dashed line over time. If the cushion is thrown down more steeply, its path will be concave upward, again making its velocity turn toward the fixed direction of its acceleration.

P5.64

t(s)	t^2(s^2)	x(m)
0	0	0
1.02	1.04 0	0.100
1.53	2.34 1	0.200
2.01	4.04 0	0.350
2.64	6.97 0	0.500
3.30	10.89	0.750
3.75	14.06	1.00

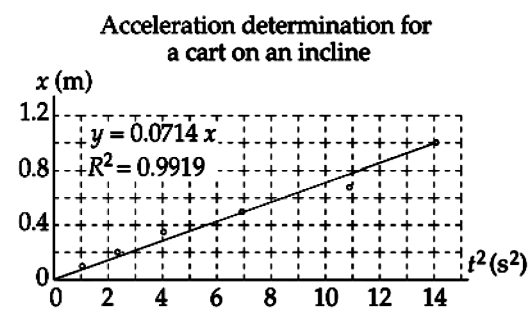


FIG. P5.64

From $x = \frac{1}{2}at^2$ the slope of a graph of x versus t^2 is $\frac{1}{2}a$, and

$$a = 2 \times \text{slope} = 2(0.071\,4\ \text{m/s}^2) = \boxed{0.143\ \text{m/s}^2}$$

From $a' = g\sin\theta$,

$$a' = 9.80\ \text{m/s}^2\left(\frac{1.77\,4}{127.1}\right) = 0.137\ \text{m/s}^2\text{, different by 4\%.}$$

The difference is accounted for by the uncertainty in the data, which we may estimate from the third point as

$$\frac{0.350 - (0.071\,4)(4.04)}{0.350} = 18\%$$

Thus the acceleration values agree.

P5.65 With motion impending,

$$n + T\sin\theta - mg = 0$$

$$f = \mu_s\left(mg - T\sin\theta\right)$$

and

$$T\cos\theta - \mu_s mg + \mu_s T\sin\theta = 0$$

so

$$T = \frac{\mu_s mg}{\cos\theta + \mu_s \sin\theta}$$

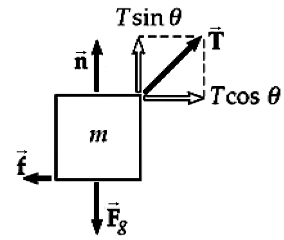


FIG. P5.65

To minimize T, we maximize $\cos\theta + \mu_s\sin\theta$

$$\frac{d}{d\theta}\left(\cos\theta + \mu_s\sin\theta\right) = 0 = -\sin\theta + \mu_s\cos\theta$$

(a) $\theta = \tan^{-1}\mu_s = \tan^{-1}0.350 = \boxed{19.3°}$

(b) $T = \dfrac{0.350\left(1.30\text{ kg}\right)\left(9.80\text{ m/s}^2\right)}{\cos 19.3° + 0.350\sin 19.3°} = \boxed{4.21\text{ N}}$

***P5.66** (a) When block 2 moves down 1 cm, block 1 moves 2 cm forward, so block 1 always has twice the speed of block 2, and $\boxed{a_1 = 2a_2}$ relates the magnitudes of the accelerations.

(b) Let T represent the uniform tension in the cord. For block 1 as object,
$\sum F_x = m_1 a_1$: $T = m_1(2a_2)$
For block 2 as object, $\sum F_y = m_1 a_1$: $T + T - (1.3\text{ kg})(9.8\text{ m/s}^2) = (1.3\text{ kg})(-a_2)$
To solve simultaneously we substitute for T: $4m_1a_2 + (1.3\text{ kg})a_2 = 12.7\text{ N}$
$\boxed{a_2 = 12.7\text{ N }(1.30\text{ kg} + 4m_1)^{-1}\text{ down}}$

(c) $a_2 = 12.7\text{ N }(1.30\text{ kg} + 4[0.55\text{ kg}])^{-1}\text{ down} = \boxed{3.64\text{ m/s}^2\text{ down}}$

(d) a_2 approaches $12.7\text{ N}/1.3\text{ kg} = \boxed{9.80\text{ m/s}^2\text{ down}}$

(e) $\boxed{a_2\text{ approaches zero}}$.

(f) From $2T = 12.74\text{ N} + 0$, $\boxed{T = 6.37\text{ N}}$

(g) Yes. As m_1 approaches zero, block 2 is essentially in free fall. As m_2 becomes negligible compared to m_1, the system is nearly in equilibrium.

P5.67 $\sum F = ma$

For m_1: $T = m_1 a$

For m_2: $T - m_2 g = 0$

Eliminating T, $a = \dfrac{m_2 g}{m_1}$

For all 3 blocks:

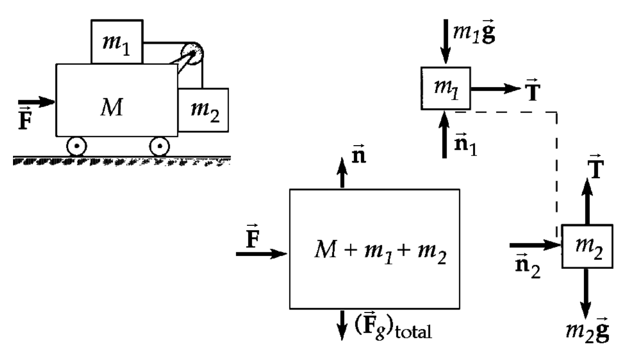


FIG. P5.67

$$F = \left(M + m_1 + m_2\right)a = \boxed{\left(M + m_1 + m_2\right)\left(\frac{m_2 g}{m_1}\right)}$$

P5.68 Throughout its up and down motion after release the block has

$$\sum F_y = ma_y: \quad +n - mg\cos\theta = 0$$
$$n = mg\cos\theta$$

Let $\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$ represent the force of table on incline. We have

$$\sum F_x = ma_x: \quad +R_x - n\sin\theta = 0$$
$$R_x = mg\cos\theta\sin\theta$$
$$\sum F_y = ma_y: \quad -Mg - n\cos\theta + R_y = 0$$
$$R_y = Mg + mg\cos^2\theta$$

$$\boxed{\vec{\mathbf{R}} = mg\cos\theta\sin\theta \text{ to the right} + \left(M + m\cos^2\theta\right)g \text{ upward}}$$

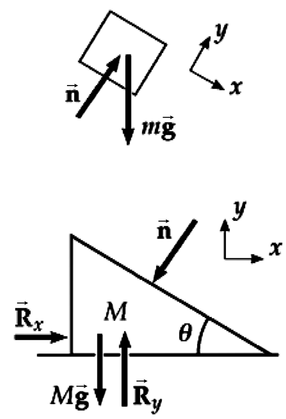


FIG. P5.68

P5.69 Choose the x axis pointing down the slope.

$$v_f = v_i + at: \quad 30.0 \text{ m/s} = 0 + a(6.00 \text{ s})$$
$$a = 5.00 \text{ m/s}^2$$

Consider forces on the toy.

$$\sum F_x = ma_x: \quad mg\sin\theta = m\left(5.00 \text{ m/s}^2\right)$$
$$\theta = \boxed{30.7°}$$
$$\sum F_y = ma_y: \quad -mg\cos\theta + T = 0$$
$$T = mg\cos\theta = (0.100)(9.80)\cos 30.7°$$
$$T = \boxed{0.843 \text{ N}}$$

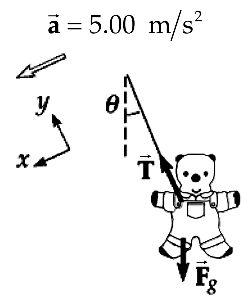


FIG. P5.69

P5.70 $\sum F_y = ma_y$: $n - mg\cos\theta = 0$

or

$$n = 8.40(9.80)\cos\theta$$
$$n = (82.3\text{ N})\cos\theta$$

$\sum F_x = ma_x$: $mg\sin\theta = ma$

or

$$a = g\sin\theta$$
$$a = \left(9.80\ \text{m/s}^2\right)\sin\theta$$

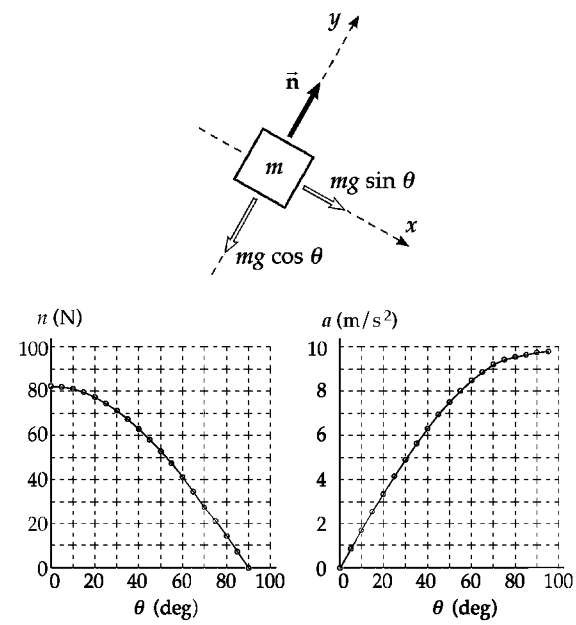


FIG. P5.70

θ, deg	n, N	a, m/s^2
0.00	82.3	0.00
5.00	82.0	0.854
10.0	81.1	1.70
15.0	79.5	2.54
20.0	77.4	3.35
25.0	74.6	4.14
30.0	71.3	4.90
35.0	67.4	5.62
40.0	63.1	6.30
45.0	58.2	6.93
50.0	52.9	7.51
55.0	47.2	8.03
60.0	41.2	8.49
65.0	34.8	8.88
70.0	28.2	9.21
75.0	21.3	9.47
80.0	14.3	9.65
85.0	7.17	9.76
90.0	0.00	9.80

At 0°, the normal force is the full weight and the acceleration is zero. At 90°, the mass is in free fall next to the vertical incline.

P5.71 (a) Apply Newton's second law to two points where butterflies are attached on either half of mobile (other half the same, by symmetry)

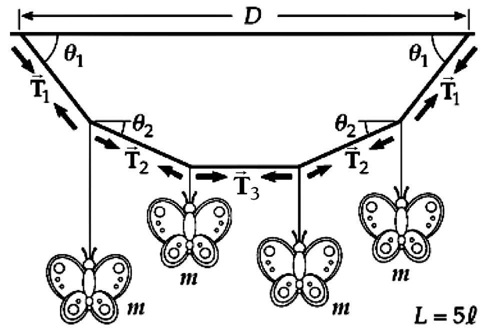


FIG. P5.71

(1) $T_2\cos\theta_2 - T_1\cos\theta_1 = 0$
(2) $T_1\sin\theta_1 - T_2\sin\theta_2 - mg = 0$
(3) $T_2\cos\theta_2 - T_3 = 0$
(4) $T_2\sin\theta_2 - mg = 0$

Substituting (4) into (2) for $T_2\sin\theta_2$,

$$T_1\sin\theta_1 - mg - mg = 0$$

Then

$$\boxed{T_1 = \frac{2mg}{\sin\theta_1}}$$

Substitute (3) into (1) for $T_2\cos\theta_2$:

$$T_3 - T_1\cos\theta_1 = 0,\ T_3 = T_1\cos\theta_1$$

Substitute value of T_1:

$$T_3 = 2mg\frac{\cos\theta_1}{\sin\theta_1} = \boxed{\frac{2mg}{\tan\theta_1} = T_3}$$

From Equation (4),

$$T_2 = \frac{mg}{\sin\theta_2}$$

(b) Divide (4) by (3):

$$\frac{T_2\sin\theta_2}{T_2\cos\theta_2} = \frac{mg}{T_3}$$

Substitute value of T_3:

$$\tan\theta_2 = \frac{mg\tan\theta_1}{2mg},\ \boxed{\theta_2 = \tan^{-1}\left(\frac{\tan\theta_1}{2}\right)}$$

Then we can finish answering part (a):

$$\boxed{T_2 = \frac{mg}{\sin\left[\tan^{-1}\left(\frac{1}{2}\tan\theta_1\right)\right]}}$$

(c) D is the horizontal distance between the points at which the two ends of the string are attached to the ceiling.

$$D = 2\ell\cos\theta_1 + 2\ell\cos\theta_2 + \ell \text{ and } L = 5\ell$$

$$D = \frac{L}{5}\left\{2\cos\theta_1 + 2\cos\left[\tan^{-1}\left(\frac{1}{2}\tan\theta_1\right)\right] + 1\right\}$$

ANSWERS TO EVEN PROBLEMS

P5.2 (a) 1/3 (b) 0.750 m/s^2

P5.4 (a) 4.47×10^{15} m/s^2 away from the wall (b) 2.09×10^{-10} N toward the wall

P5.6 (a) 534 N down (b) 54.5 kg

P5.8 $\left(16.3\hat{\mathbf{i}} + 14.6\hat{\mathbf{j}}\right)$ N

P5.10 (a) Force exerted by spring on hand, to the left; force exerted by spring on wall, to the right. (b) Force exerted by wagon on handle, downward to the left. Force exerted by wagon on planet, upward. Force exerted by wagon on ground, downward. (c) Force exerted by football on player, downward to the right. Force exerted by football on planet, upward. (d) Force exerted by small-mass object on large-mass object, to the left. (e) Force exerted by negative charge on positive charge, to the left. (f) Force exerted by iron on magnet, to the left.

P5.12 see the solution

P5.14 (a) 181° (b) 11.2 kg (c) 37.5 m/s (d) $\left(-37.5\hat{\mathbf{i}} - 0.893\hat{\mathbf{j}}\right)$ m/s

P5.16 112 N

P5.18 (a) see the solution (b) 1.03 N (c) 0.805 N to the right

P5.20 $T_1 = 296$ N; $T_2 = 163$ N; $T_3 = 325$ N

P5.22 (a) see the solution (b) 1.79 N

P5.24 see the solution (a) 2.54 m/s^2 down the incline (b) 3.18 m/s

P5.26 see the solution 6.30 m/s^2; 31.5 N

P5.28 see the solution (a) 3.57 m/s^2 (b) 26.7 N (c) 7.14 m/s

P5.30 950 N

P5.32 (a) $a_1 = 2a_2$ (b) $T_1 = \dfrac{m_1 m_2 g}{2m_1 + m_2/2}$; $T_2 = \dfrac{m_1 m_2 g}{m_1 + m_2/4}$ (c) $a_1 = \dfrac{m_2 g}{2m_1 + m_2/2}$; $a_2 = \dfrac{m_2 g}{4m_1 + m_2}$

P5.34 (a) 0.529 m (b) 7.40 m/s upward

P5.36 $\mu_s = 0.306$; $\mu_k = 0.245$

P5.38 (a) 3.34 (b) time would increase

P5.40 see the solution (a) 55.2° (b) 167 N

P5.42 (a) 2.31 m/s^2 down for m_1, left for m_2 and up for m_3 (b) 30.0 N and 24.2 N

P5.44 (a) Any value between 31.7 N and 48.6 N (b) If $P > 48.6$ N, the block slides up the wall. If $P < 31.7$ N, the block slides down the wall. (c) $P \geq 62.7$ N. The block cannot slide up the wall. If $P < 62.7$ N, the block slides down the wall.

P5.46 6.84 m

P5.48 0.060 0 m

P5.50 (a) $a = 2.84\ \text{m/s}^2$; $T = 26.5$ N (b) A 3.80-kg object and a 6.50-kg object are joined by a light string passing over a light frictionless pulley. The 3.80-kg object is hanging and tows the heavier object down a ramp inclined at 13.0°, with which it has coefficient of kinetic friction 0.360. See the solution.

P5.52 (a) Pat and the seat accelerate down at $0.426\ \text{m/s}^2$. The other child accelerates up off the ground at the same rate. (b) The tension throughout the rope becomes 480 N, larger than 250 N.

P5.54 (a) $2.00\ \text{m/s}^2$ to the right (b) 8.00 N right on 4 kg; 6.00 N right on 3 kg; 4.00 N right on 2 kg (c) 8.00 N between 4 kg and 3 kg; 14.0 N between 2 kg and 3 kg (d) see the solution

P5.56 (a) $3.43\ \text{m/s}^2$ toward the endstop (b) $3.43\ \text{m/s}^2$ toward the green glider; $6.86\ \text{m/s}^2$ toward the black glider

P5.58 (a) $0.931\ \text{m/s}^2$ (b) From a value of $0.625\ \text{m/s}^2$ for large x, the acceleration gradually increases, passes through a maximum, and then drops more rapidly, becoming negative and reaching $-2.10\ \text{m/s}^2$ at $x = 0$. (c) $0.976\ \text{m/s}^2$ at $x = 25.0$ cm (d) 6.10 cm.

P5.60 They do not; 29.4 N

P5.62 (a) $4.90\ \text{m/s}^2$ (b) 3.13 m/s at 30.0° below the horizontal (c) 1.35 m (d) 1.14 s (e) No

P5.64 see the solution; $0.143\ \text{m/s}^2$ agrees with $0.137\ \text{m/s}^2$

P5.66 (a) When block 2 moves down 1 cm, block 1 moves 2 cm forward, so block 1 always has twice the speed of block 2, and $a_1 = 2\,a_2$. (b) $a_2 = 12.7\ \text{N}\,(1.30\ \text{kg} + 4m_1)^{-1}$ down (c) $3.64\ \text{m/s}^2$ down (d) a_2 approaches $9.80\ \text{m/s}^2$ down (e) a_2 approaches zero. (f) 6.37 N (g) Yes. As m_1 approaches zero, block 2 is essentially in free fall. As m_2 becomes negligible compared to m_1, the system is nearly in equilibrium.

P5.68 $mg\cos\theta\sin\theta$ to the right $+\left(M + m\cos^2\theta\right)g$ upward

P5.70 see the solution