CHAPTER 4: Dynamics: Newton's Laws of Motion

Answers to Questions

1. The child tends to remain at rest (Newton's 1st Law), unless a force acts on her. The force is applied to the wagon, not the child, and so the wagon accelerates out from under the child, making it look like the child falls backwards relative to the wagon. If the child is standing in the wagon, the force of friction between the child and the bottom of the wagon will produce an acceleration of the feet, pulling the feet out from under the child, also making the child fall backwards.

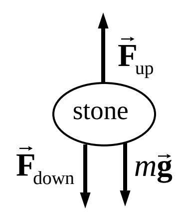
2. If the acceleration of an object is zero, then by Newton's second law, the *net* force must be zero. There can be forces acting on the object as long as the vector sum of the forces is zero.

3. (*a*) A force is needed to bounce the ball back up, because the ball changes direction, and so accelerates. If the ball accelerates, there must be a force.
(*b*) The pavement exerts the force on the golf ball.

4. By Newton's 3rd law, the desk or wall exerts a force on your foot equal in magnitude to the force with which you hit the desk or wall. If you hit the desk or wall with a large force, then there will be a large force on your foot, causing pain. Only a force <u>on</u> your foot causes pain.

5. When giving a sharp pull, the key is the suddenness of the application of the force. When a large, sudden force is applied to the bottom string, the bottom string will have a large tension in it. Because of the stone's inertia, the upper string does not immediately experience the large force. The bottom string must have more tension in it, and will break first.

   If a slow and steady pull is applied, the tension in the bottom string increases. We approximate that condition as considering the stone to be in equilibrium until the string breaks. The free-body diagram for the stone would look like this diagram. While the stone is in equilibrium, Newton's 2nd law states that $F_{up} = F_{down} + mg$. Thus the tension in the upper string is going to be larger than the tension in the lower string because of the weight of the stone, and so the upper string will break first.



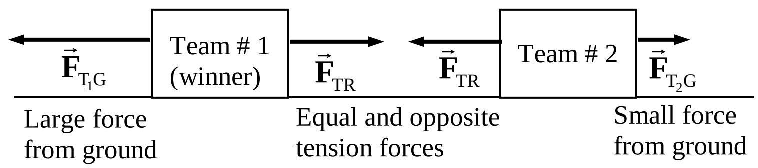
6. Only the pounds reading would be correct. The spring scale works on the fact that a certain **<u>force</u>** (the weight of the object being weighed) will stretch the spring a certain distance. That distance is proportional to the product of the mass and the acceleration due to gravity. Since the acceleration due to gravity is smaller by a factor of 6 on the moon, the weight of the object is smaller by a factor of 6, and the spring will be pulled to only one-sixth of the distance that it was pulled on the Earth. The mass itself doesn't change when moving to the Moon, and so a mass reading on the Moon would be incorrect.

7. Let us find the acceleration of the Earth, assuming the mass of the freely falling object is $m = 1$ kg. If the mass of the Earth is M, then the acceleration of the Earth would be found using Newton's 3rd law and Newton's 2nd law.

   $$F_{\text{Earth}} = F_{\text{object}} \quad \rightarrow \quad Ma_{\text{Earth}} = mg \quad \rightarrow \quad a_{\text{Earth}} = g\,m/M$$

   Since the Earth has a mass that is on the order of 10^{25} kg, then the acceleration of the Earth is on the order of $10^{-25}g$, or about $10^{-24}\ \text{m/s}^2$. This tiny acceleration is undetectable.

8. In a tug of war, the team that pushes hardest against the ground wins. It is true that both teams have the same force on them due to the tension in the rope. But the winning team pushes harder against the ground and thus the ground pushes harder on the winning team, making a net unbalanced force. The free body diagram below illustrates this. The forces are $\vec{\mathbf{F}}_{\mathrm{T_1G}}$, the force on team 1 from the ground, $\vec{\mathbf{F}}_{\mathrm{T_2G}}$, the force on team 2 from the ground, and $\vec{\mathbf{F}}_{\mathrm{TR}}$, the force on each team from the rope. Thus the net force on the winning team $\left(\vec{\mathbf{F}}_{\mathrm{T_1G}} - \vec{\mathbf{F}}_{\mathrm{TR}}\right)$ is in the winning direction.



9. If you are at rest, the net force on you is zero. Hence the ground exerts a force on you exactly equal to your weight. The two forces acting on you sum to zero, and so you don't accelerate. If you squat down and then push with a larger force against the ground, the ground then pushes back on you with a larger force by Newton's third law, and you <u>can</u> then rise into the air.

10. The truck bed exerts a force of static friction on the crate, causing the crate to accelerate.

11. Assume your weight is W. If you weighed yourself on an inclined plane that is inclined at angle θ, the bathroom scale would read the magnitude of the normal force between you and the plane, which would be $W\cos\theta$.

Solutions to Problems

1. Use Newton's second law to calculate the force.

$$\sum F = ma = (60.0\text{ kg})\left(1.25\text{ m/s}^2\right) = \boxed{75.0\text{ N}}$$

2. Use Newton's second law to calculate the tension.

$$\sum F = F_{\mathrm{T}} = ma = (960\text{ kg})\left(1.20\text{ m/s}^2\right) = \boxed{1.15\times10^3\text{ N}}$$

3. The average force on the pellet is its mass times its average acceleration. The average acceleration is found from Eq. 2-11c. For the pellet, $v_0 = 0$, $v = 125\text{ m/s}$, and $x - x_0 = 0.800\text{ m}$.

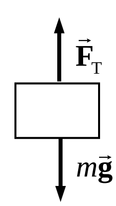
$$a_{avg} = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{(125\text{ m/s})^2 - 0}{2(0.800\text{ m})} = 9770\text{ m/s}^2$$

$$F_{avg} = ma_{avg} = \left(7.00\times10^{-3}\text{ kg}\right)\left(9770\text{ m/s}^2\right) = \boxed{68.4\text{ N}}$$

4. Choose UP to be the positive direction. Write Newton's 2nd law for the elevator.

$$\sum F = F_{\mathrm{T}} - mg = ma \quad \rightarrow$$

$$a = \frac{F_{\mathrm{T}} - mg}{m} = \frac{21{,}750\text{ N} - (2125\text{ kg})\left(9.80\text{ m/s}^2\right)}{2125\text{ kg}} = 0.4353\text{ m/s}^2 \approx \boxed{0.44\text{ m/s}^2}$$



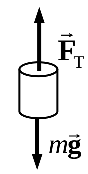
5. (*a*) Use Eq. 2-11c to find the speed of the person just before striking the ground. Take down to be the positive direction. For the person, $v_0 = 0$, $y - y_0 = 3.9\text{ m}$, and $a = 9.8\,\text{m/s}^2$.

$$v^2 - v_0^2 = 2a(y - y_0) \quad \rightarrow \quad v = \sqrt{2a(y-y_0)} = \sqrt{2(9.8\,\text{m/s}^2)(3.9\text{ m})} = 8.743 = \boxed{8.7\,\text{m/s}}$$

(*b*) For the deceleration, use Eq. 2-11c to find the average deceleration, choosing down to be positive.

$$v_0 = 8.743\,\text{m/s} \qquad v = 0 \qquad y - y_0 = 0.70\text{ m} \qquad v^2 - v_0^2 = 2a(y - y_0) \quad \rightarrow$$

$$a = \frac{-v_0^2}{2\Delta y} = \frac{-(8.743\,\text{m/s})^2}{2(0.70\text{ m})} = -54.6\,\text{m/s}^2$$



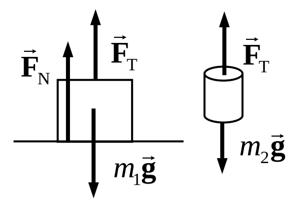
The average force on the torso (F_T) due to the legs is found from Newton's 2nd law. See the free body diagram. Down is positive.

$$F_\text{net} = mg - F_\text{T} = ma \quad \rightarrow$$

$$F_\text{T} = mg - ma = m(g - a) = (42\text{ kg})(9.8\,\text{m/s}^2 - -54.6\,\text{m/s}^2) = \boxed{2.7\times10^3\text{ N}}.$$

The force is upward.

6. Free body diagrams for the box and the weight are shown below. The tension exerts the same magnitude of force on both objects.



(*a*) If the weight of the hanging weight is less than the weight of the box, the objects will not move, and the tension will be the same as the weight of the hanging weight. The acceleration of the box will also be zero, and so the sum of the forces on it will be zero. For the box,

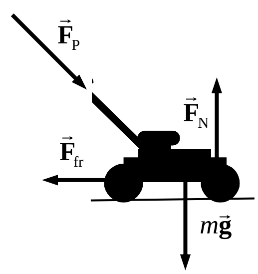
$$F_\text{N} + F_\text{T} - m_1 g = 0 \quad \rightarrow \quad F_\text{N} = m_1 g - F_\text{T} = m_1 g - m_2 g = 77.0\text{N} - 30.0\text{ N} = \boxed{47.0\text{ N}}$$

(*b*) The same analysis as for part (*a*) applies here.

$$F_\text{N} = m_1 g - m_2 g = 77.0\text{ N} - 60.0\text{ N} = \boxed{17.0\text{ N}}$$

(*c*) Since the hanging weight has more weight than the box on the table, the box on the table will be lifted up off the table, and normal force of the table on the box will be $\boxed{0\text{ N}}$.

7. (*a*) We assume that the mower is being pushed to the right. $\vec{\mathbf{F}}_\text{fr}$ is the friction force, and $\vec{\mathbf{F}}_\text{P}$ is the pushing force along the handle.



(*b*) Write Newton's 2nd law for the horizontal direction. The forces must sum to 0 since the mower is not accelerating.

$$\sum F_x = F_\text{P}\cos 45.0^\circ - F_\text{fr} = 0 \quad \rightarrow$$

$$F_\text{fr} = F_\text{P}\cos 45.0^\circ = (88.0\text{ N})\cos 45.0^\circ = \boxed{62.2\text{ N}}$$

(*c*) Write Newton's 2nd law for the vertical direction. The forces must sum to 0 since the mower is not accelerating in the vertical direction.

$$\sum F_y = F_\text{N} - mg - F_\text{P}\sin 45.0^\circ = 0 \quad \rightarrow$$

$$F_\text{N} = mg + F_\text{P}\sin 45^\circ = (14.0\text{ kg})(9.80\,\text{m/s}^2) + (88.0\text{ N})\sin 45.0^\circ = \boxed{199\text{ N}}$$

(*d*) First use Eq. 2-11a to find the acceleration.

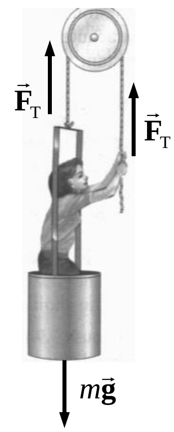
$$v - v_0 = at \quad \rightarrow \quad a = \frac{v - v_0}{t} = \frac{1.5\,\text{m/s} - 0}{2.5\text{ s}} = 0.60\,\text{m/s}^2$$

Now use Newton's 2nd law for the *x* direction to find the necessary pushing force.

$$\sum F_x = F_P \cos 45.0^\circ - F_f = ma \quad \rightarrow$$

$$F_P = \frac{F_f + ma}{\cos 45.0^\circ} = \frac{62.2\ \text{N} + (14.0\ \text{kg})(0.60\ \text{m/s}^2)}{\cos 45.0^\circ} = \boxed{99.9\ \text{N}}$$

8. The window washer pulls down on the rope with her hands with a tension force F_T, so the rope pulls up on her hands with a tension force F_T. The tension in the rope is also applied at the other end of the rope, where it attaches to the bucket. Thus there is another force F_T pulling up on the bucket. The bucket-washer combination thus has a net force of $2F_T$ upwards. See the adjacent free-body diagram, showing only forces <u>on</u> the bucket-washer combination, not forces exerted <u>by</u> the combination (the pull down on the rope by the person) or internal forces (normal force of bucket on person).



(*a*) Write Newton's 2nd law in the vertical direction, with up as positive. The net force must be zero if the bucket and washer have a constant speed.

$$\sum F = F_T + F_T - mg = 0 \;\rightarrow\; 2F_T = mg \;\rightarrow$$

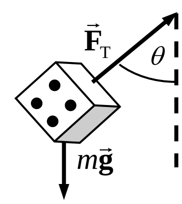
$$F_T = \frac{mg}{2} = \frac{(65\ \text{kg})(9.8\ \text{m/s}^2)}{2} = \boxed{320\ \text{N}}$$

(*b*) Now the force is increased by 15%, so $F_T = 320\ \text{N}(1.15) = 368\ \text{N}$. Again write Newton's 2nd law, but with a non-zero acceleration.

$$\sum F = F_T + F_T - mg = ma \quad \rightarrow$$

$$a = \frac{2F_T - mg}{m} = \frac{2(368\ \text{N}) - (65\ \text{kg})(9.80\ \text{m/s}^2)}{65\ \text{kg}} = \boxed{1.5\ \text{m/s}^2}$$

9. Consider a free-body diagram of the dice. The car is moving to the right. The acceleration of the dice is found from Eq. 2-11a.



$$v = v_0 + = a_x t \quad \rightarrow \quad a_x = \frac{v - v_0}{t} = \frac{28\ \text{m/s} - 0}{6.0\ \text{s}} = 4.67\ \text{m/s}^2$$

Now write Newton's 2nd law for both the vertical (*y*) and horizontal (*x*) directions.

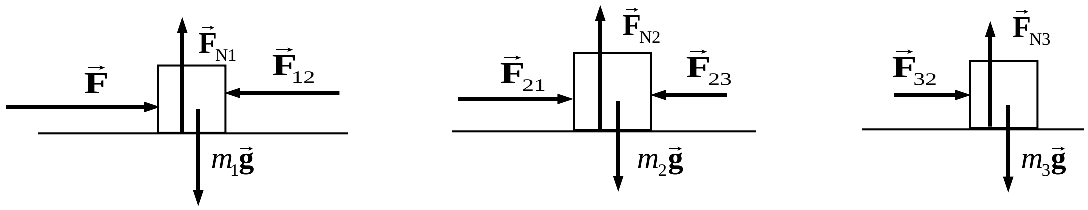
$$\sum F_y = F_T \cos\theta - mg = 0 \quad \rightarrow \quad F_T = \frac{mg}{\cos\theta} \qquad \sum F_x = F_T \sin\theta = ma_x$$

Substitute the expression for the tension from the *y* equation into the *x* equation.

$$ma_x = F_T \sin\theta = \frac{mg}{\cos\theta}\sin\theta = mg\tan\theta \quad \rightarrow \quad a_x = g\tan\theta$$

$$\theta = \tan^{-1}\frac{a_x}{g} = \tan^{-1}\frac{4.67\ \text{m/s}^2}{9.8\ \text{m/s}^2} = \boxed{25^\circ}$$

10. (*a*) In the free-body diagrams below, $\vec{\mathbf{F}}_{12}$ = force on block 1 exerted by block 2, $\vec{\mathbf{F}}_{21}$ = force on block 2 exerted by block 1, $\vec{\mathbf{F}}_{23}$ = force on block 2 exerted by block 3, and $\vec{\mathbf{F}}_{32}$ = force on block 3 exerted by block 2. The magnitudes of $\vec{\mathbf{F}}_{21}$ and $\vec{\mathbf{F}}_{12}$ are equal, and the magnitudes of $\vec{\mathbf{F}}_{23}$ and $\vec{\mathbf{F}}_{32}$ are equal, by Newton's 3rd law.



(*b*) All of the vertical forces on each block add up to zero, since there is no acceleration in the vertical direction. Thus for each block, $F_N = mg$. For the horizontal direction, we have

$$\sum F = F - F_{12} + F_{21} - F_{23} + F_{32} = F = (m_1 + m_2 + m_3)a \quad \rightarrow \quad \boxed{a = \frac{F}{m_1 + m_2 + m_3}}$$

(*c*) For each block, the net force must be *ma* by Newton's 2nd law. Each block has the same acceleration since they are in contact with each other.

$$\boxed{F_{1net} = \frac{m_1 F}{m_1 + m_2 + m_3}} \qquad \boxed{F_{2net} = \frac{m_2 F}{m_1 + m_2 + m_3}} \qquad \boxed{F_{3net} = \frac{m_3 F}{m_1 + m_2 + m_3}}$$

(*d*) From the free-body diagram, we see that for m_3, $F_{32} = F_{3net} = \boxed{\dfrac{m_3 F}{m_1 + m_2 + m_3}}$. And by Newton's 3rd law, $F_{32} = F_{23} = F_{3net} = \boxed{\dfrac{m_3 F}{m_1 + m_2 + m_3}}$. Of course, $\vec{\mathbf{F}}_{23}$ and $\vec{\mathbf{F}}_{32}$ are in opposite directions.

Also from the free-body diagram, we see that for m_1,

$$F - F_{12} = F_{1net} = \frac{m_1 F}{m_1 + m_2 + m_3} \ \rightarrow\ F_{12} = F - \frac{m_1 F}{m_1 + m_2 + m_3} \ \rightarrow\ \boxed{F_{12} = \frac{(m_2 + m_3)F}{m_1 + m_2 + m_3}}.$$

By Newton's 3rd law, $F_{12} = F_{21} = \boxed{\dfrac{(m_2 + m_3)F}{m_1 + m_2 + m_3}}$.

(*e*) Using the given values, $a = \dfrac{F}{m_1 + m_2 + m_3} = \dfrac{96.0\text{ N}}{36.0\text{ kg}} = \boxed{2.67\,\text{m/s}^2}$. Since all three masses are the same value, the net force on each mass is $F_{net} = ma = (12.0\text{ kg})(2.67\,\text{m/s}^2) = 32.0\text{ N}$.

This is also the value of F_{32} and F_{23}. The value of F_{12} and F_{21} is

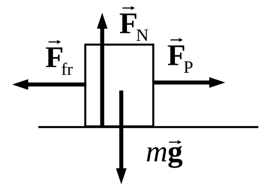
$$F_{12} = F_{21} = (m_2 + m_3)a = (24\text{ kg})(2.67\,\text{m/s}^2) = 64.0\text{ N}.$$

To summarize:

$$F_{\text{net 1}} = F_{\text{net 2}} = F_{\text{net 3}} = \boxed{32.0\text{ N}} \qquad F_{12} = F_{21} = \boxed{64.0\text{ N}} \qquad F_{23} = F_{32} = \boxed{32.0\text{ N}}$$

The values make sense in that in order of magnitude, we should have $F > F_{21} > F_{32}$, since F is the net force pushing the entire set of blocks, F_{12} is the net force pushing the right two blocks, and F_{23} is the net force pushing the right block only.

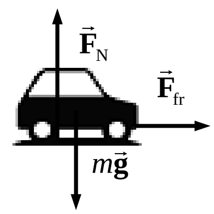
11. A free-body diagram for the crate is shown. The crate does not accelerate vertically, and so $F_N = mg$. The crate does not accelerate horizontally, and so $F_P = F_{fr}$. Putting this together, we have



$$F_P = F_{fr} = \mu_k F_N = \mu_k mg = (0.30)(35\text{ kg})(9.8\,\text{m/s}^2) = 103 = \boxed{1.0\times10^2\text{ N}}$$

If the coefficient of kinetic friction is zero, then the horizontal force required is $\boxed{0\text{ N}}$, since there is no friction to counteract. Of course, it would take a force to START the crate moving, but once it was moving, no further horizontal force would be necessary to maintain the motion.

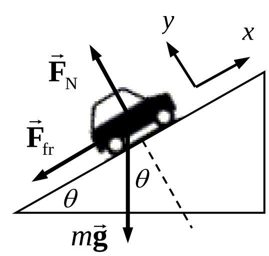
12. A free-body diagram for the accelerating car is shown. The car does not accelerate vertically, and so $F_N = mg$. The static frictional force is the accelerating force, and so $F_{fr} = ma$. If we assume the maximum acceleration, then we need the maximum force, and so the static frictional force would be its maximum value of $\mu_s F_N$. Thus we have



$$F_{fr} = ma \quad\rightarrow\quad \mu_s F_N = ma \quad\rightarrow\quad \mu_s mg = ma \quad\rightarrow$$

$$a = \mu_s g = 0.80(9.8\,\text{m/s}^2) = \boxed{7.8\,\text{m/s}^2}$$

13. See the included free-body diagram. To find the maximum angle, assume that the car is just ready to slide, so that the force of static friction is a maximum. Write Newton's 2nd law for both directions. Note that for both directions, the net force must be zero since the car is not accelerating.

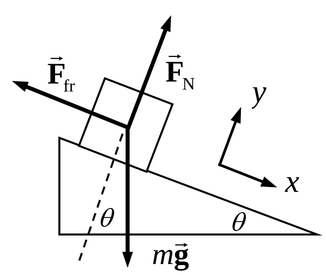


$$\sum F_y = F_N - mg\cos\theta = 0 \quad\rightarrow\quad F_N = mg\cos\theta$$

$$\sum F_x = mg\sin\theta - F_{fr} = 0 \quad\rightarrow\quad mg\sin\theta = F_{fr} = \mu_s F_N = \mu_s mg\cos\theta$$

$$\mu_s = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta = 0.8 \quad\rightarrow\quad \theta = \tan^{-1}0.8 = 39^\circ = \boxed{40^\circ} \quad (1\text{ sig fig})$$

14. Start with a free-body diagram. Write Newton's 2nd law for each direction.



$$\sum F_x = mg\sin\theta - F_{fr} = ma_x$$

$$\sum F_y = F_N - mg\cos\theta = ma_y = 0$$

Notice that the sum in the *y* direction is 0, since there is no motion (and hence no acceleration) in the *y* direction. Solve for the force of friction.

$$mg\sin\theta - F_{fr} = ma_x \quad\rightarrow$$

$$F_{fr} = mg\sin\theta - ma_x = (15.0\text{ kg})\left[(9.80\,\text{m/s}^2)(\sin 32^\circ) - 0.30\,\text{m/s}^2\right] = 73.40\text{ N} \approx \boxed{73\text{ N}}$$

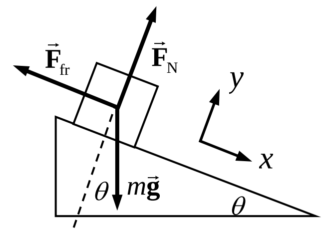
Now solve for the coefficient of kinetic friction. Note that the expression for the normal force comes from the *y* direction force equation above.

$$F_{fr} = \mu_k F_N = \mu_k mg\cos\theta \quad\rightarrow\quad \mu_k = \frac{F_{fr}}{mg\cos\theta} = \frac{73.40\text{ N}}{(15.0\text{ kg})(9.80\,\text{m/s}^2)(\cos 32^\circ)} = \boxed{0.59}$$

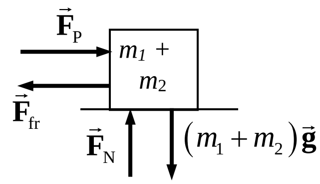
15. (*a*) Here is a free-body diagram for the box at rest on the plane. The force of friction is a STATIC frictional force, since the box is at rest.

(*b*) If the box were sliding down the plane, the only change is that the force of friction would be a KINETIC frictional force.

(*c*) If the box were sliding up the plane, the force of friction would be a KINETIC frictional force, and it would point down the plane, in the opposite direction to that shown in the diagram.



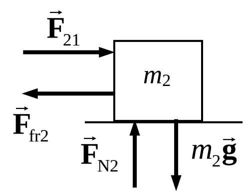
16. (*a*) Since the two blocks are in contact, they can be treated as a single object as long as no information is needed about internal forces (like the force of one block pushing on the other block). Since there is no motion in the vertical direction, it is apparent that $F_{\text{N}} = (m_1 + m_2)g$, and so $F_{\text{fr}} = \mu_k F_{\text{N}} = \mu_k (m_1 + m_2) g$. Write Newton's 2nd law for the horizontal direction.



$$\sum F_x = F_{\text{P}} - F_{\text{fr}} = (m_1 + m_2)a \quad \rightarrow$$

$$a = \frac{F_{\text{P}} - F_{\text{fr}}}{m_1 + m_2} = \frac{F_{\text{P}} - \mu_k (m_1 + m_2) g}{m_1 + m_2} = \frac{620\text{ N} - (0.15)(185\text{ kg})(9.8\,\text{m/s}^2)}{185\text{ kg}} = \boxed{1.9\,\text{m/s}^2}$$

(*b*) To solve for the contact forces between the blocks, an individual block must be analyzed. Look at the free-body diagram for the second block. $\vec{\mathbf{F}}_{21}$ is the force of the first block pushing on the second block. Again, it is apparent that $F_{\text{N2}} = m_2 g$ and so $F_{\text{fr2}} = \mu_k F_{\text{N2}} = \mu_k m_2 g$. Write Newton's 2nd law for the horizontal direction.

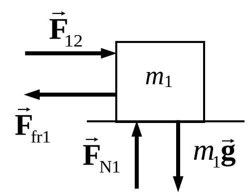


$$\sum F_x = F_{21} - F_{\text{fr2}} = m_2 a \quad \rightarrow$$

$$F_{21} = \mu_k m_2 g + m_2 a = (0.15)(110\text{ kg})(9.8\,\text{m/s}^2) + (110\text{ kg})(1.9\,\text{m/s}^2) = \boxed{3.7 \times 10^2\,\text{N}}$$

By Newton's 3rd law, there will also be a 370 N force to the left on block # 1 due to block # 2.

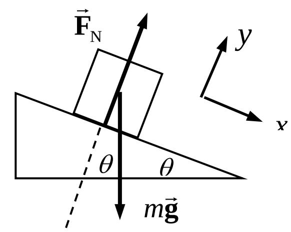
(*c*) If the crates are reversed, the acceleration of the system will remain the same – the analysis from part (a) still applies. We can also repeat the analysis from part (b) to find the force of one block on the other, if we simply change m_1 to m_2 in the free-body diagram and the resulting equations. The result would be



$$\sum F_x = F_{12} - F_{\text{fr1}} = m_1 a \quad \rightarrow$$

$$F_{12} = \mu_k m_1 g + m_1 a = (0.15)(75\text{ kg})(9.8\,\text{m/s}^2) + (75\text{ kg})(1.9\,\text{m/s}^2) = \boxed{2.5 \times 10^2\,\text{N}}$$

17. (*a*) Consider the free-body diagram for the carton on the frictionless surface. There is no acceleration in the *y* direction. Write Newton's 2nd law for the *x* direction.



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

Use Eq. 2-11c with $v_0 = -3.0\,\text{m/s}$ and $v = 0\,\text{m/s}$ to find the distance that it slides before stopping.

$$v^2 - v_0^2 = 2a\left(x - x_0\right) \quad\rightarrow$$

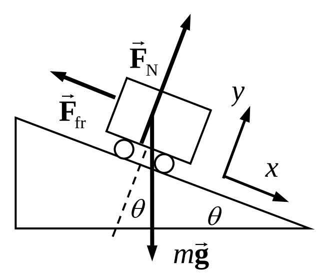
$$\left(x - x_0\right) = \frac{v^2 - v_0^2}{2a} = \frac{0 - \left(-3.0\,\text{m/s}\right)^2}{2\left(9.8\,\text{m/s}^2\right)\sin 22.0^\circ} = \boxed{-1.2\text{ m}}$$

The negative sign means that the block is displaced up the plane, which is the negative direction.

(*b*) The time for a round trip can be found from Eq. 2-11a. The free-body diagram (and thus the acceleration) is the same whether the block is rising or falling. For the entire trip, $v_0 = -3.0\,\text{m/s}$ and $v = +3.0\,\text{m/s}$.

$$v = v_0 + at \quad\rightarrow\quad t = \frac{v - v_0}{a} = \frac{\left(3.0\,\text{m/s}\right) - \left(-3.0\,\text{m/s}\right)}{\left(9.8\,\text{m/s}^2\right)\sin 22^\circ} = \boxed{1.6\text{ s}}$$

18. See the free-body diagram for the descending roller coaster. It starts its descent with $v_0 = \left(6.0\,\text{km/h}\right)\left(\dfrac{1\,\text{m/s}}{3.6\,\text{km/h}}\right) = 1.667\,\text{m/s}$. The total displacement in the *x* direction is $x - x_0 = 45.0\text{ m}$. Write Newton's second law for both the *x* and *y* directions.



$$\sum F_y = F_N - mg\cos\theta = 0 \quad\rightarrow\quad F_N = mg\cos\theta$$

$$\sum F_x = ma = mg\sin\theta - F_{fr} = mg\sin\theta - \mu_k F_N = mg\sin\theta - \mu_k mg\cos\theta$$

$$a = \frac{mg\sin\theta - \mu_k mg\cos\theta}{m} = g\left(\sin\theta - \mu_k\cos\theta\right)$$

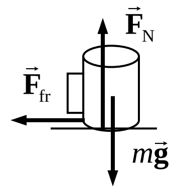
Now use Eq. 2-11c to solve for the final velocity.

$$v^2 - v_0^2 = 2a\left(x - x_0\right) \quad\rightarrow$$

$$v = \sqrt{v_0^2 + 2a\left(x - x_0\right)} = \sqrt{v_0^2 + 2g\left(\sin\theta - \mu_k\cos\theta\right)\left(x - x_0\right)}$$

$$= \sqrt{\left(1.667\,\text{m/s}\right)^2 + 2\left(9.8\,\text{m/s}^2\right)\left[\sin 45^\circ - \left(0.18\right)\cos 45^\circ\right]\left(45.0\text{ m}\right)}$$

$$= 22.68\,\text{m/s} \approx \boxed{23\,\text{m/s}} \approx 82\,\text{km/h}$$



19. A free-body diagram for the coffee cup is shown. Assume that the car is moving to the right, and so the acceleration of the car (and cup) will be to the left. The deceleration of the cup is caused by friction between the cup and the dashboard. For the cup to not slide on the dash, and to have the minimum deceleration time means the largest possible static frictional force is acting, so $F_{\mathrm{fr}} = \mu_s F_{\mathrm{N}}$. The normal force on the cup is equal to its weight, since there is no vertical acceleration. The horizontal acceleration of the cup is found from Eq. 2-11a, with a final velocity of zero.

$$v_0 = (45\,\mathrm{km/h})\left(\frac{1\,\mathrm{m/s}}{3.6\,\mathrm{km/h}}\right) = 12.5\,\mathrm{m/s}$$

$$v - v_0 = at \quad \rightarrow \quad a = \frac{v - v_0}{t} = \frac{0 - 12.5\,\mathrm{m/s}}{3.5\ \mathrm{s}} = -3.57\,\mathrm{m/s^2}$$

Write Newton's 2nd law for the horizontal forces, considering to the right to be positive.

$$\sum F_x = -F_{\mathrm{fr}} = ma \quad \rightarrow \quad ma = -\mu_s F_{\mathrm{N}} = -\mu_s mg \quad \rightarrow \quad \mu_s = -\frac{a}{g} = -\frac{(-3.57\,\mathrm{m/s^2})}{9.80\,\mathrm{m/s^2}} = \boxed{0.36}$$