Chapter 2

Multiple choice questions

1. (c) The magnitude of the upward force exerted by the cable on the elevator $F_{\text{C on El}}$ is less than the magnitude of the downward force exerted by Earth on the elevator $F_{\text{E on El}}$. The cable and Earth are the only two objects interacting with the elevator. The fact that the upward moving elevator slows to a stop means that the acceleration is downward, implying a net force pointing downward on the elevator. Thus, $F_{\text{C on El}} < F_{\text{E on El}}$.

2. (c) The car is in a non-inertial reference frame because the book started moving without any extra objects interacting with it.

3. (a) An observer on the sidewalk would not see the child lurch forward but instead continues her motion.

4. (c) An observer on the sidewalk beside the car and road (in an inertial frame) can explain the phenomenon of whiplash using Newton's laws.

5. (c) According to Newton's second law, $\vec{a} = \sum \vec{F}/m$.

6. (d) You can throw some cargo out of the boat, so the water can exert an external force on the boat to make it move. According to Newton's third law, a system cannot propel itself into motion with purely internal forces, such as the examples given in (a), (b), and (c).

7. (d) Both (b) and (c) are correct. The total force exerted on the carriage is the sum of the forces exerted by the horse and the ground's surface in the horizontal direction. In addition, the net force on the horse is the sum of the ground's static friction force on its hooves and the force exerted by the carriage.

8. (a) According to Newton's first law, when the net external force exerted on the object is zero, the object continues moving at constant velocity or remains at rest.

9. (a) The spaceship will keep moving if there are no external forces exerted on it. If there is a constant force exerted on it in the direction of its motion, it speeds up with constant acceleration. On the other hand, if something exerts a force opposite its motion, it slows down with constant acceleration.

10. (b) By Newton’s third law, the gravitational force that Earth exerts on the apple is the same magnitude as the force that the apple exerts on Earth.

11. (a) The reading increases as he accelerates the heavy object up (increasing upward speed). When he reaches a constant speed, the scale reading returns briefly to the same reading as when standing stationary, and then decreases as he accelerates the heavy object down (going up but slowing down).

12. (d) As the cable breaks, the reading of the apparent weight will drop to zero instantly, since the elevator now is in free fall.

13. (b) Since $\vec{a} = \sum \vec{F}/m$, there must be other forces exerted on the crate so that the total force is reduced.

14. (a) The force exerted by Earth on an object is proportional to the mass of the object.

15. (c) A watch with second hand and a meter stick would allow you to measure the acceleration of the box. You can then deduce the mass of the box by applying Newton’s second law.

16. (c) The bird box weighs the same as the ball box, as long as the bird hovers inside the box and does not accelerate up or down.

17. (d) Both (b) and (c) are correct. The person sinking into the sand has a greater stopping distance. The upward acceleration of the person in the sand is less than on concrete, thus the force that the sand exerts on the person is less.

18. (c) From Newton’s first law, objects that are already in motion on a smooth surface will maintain the same motion, unless being acted upon by an external force.

Conceptual questions

19. (c) The velocity-versus-time graph has a constant positive slope that corresponds to a constant acceleration. Since $\vec{a} = \sum \vec{F}/m$, the force acting on the object is also constant in time.

20. Crumple zones are designed to absorb the impact of a head-on collision, decrease acceleration and increase the stopping distance, to minimize the force of impact from being transmitted to the occupants of the vehicle, thereby reducing chance of serious injuries.

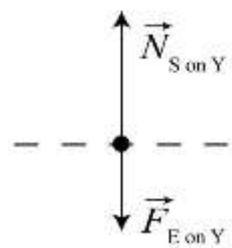
21. When landing on a firm surface, you can be seriously injured if you land stiff-legged. In a stiff-legged landing, your stopping time is very short (as short as 2 ms), which means a large acceleration and therefore, large force acting on your leg. By bending your knees

upon landing, you increase the stopping time and therefore reduce the acceleration and the force of the impact.

22. In all three cases, the forces that the truck exerts on the car and the car exerts on the truck are the same. This is a consequence of Newton's third law. However, the resulting acceleration of the car will be greater since it has smaller mass.

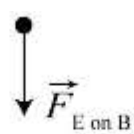
23. In all three cases, the forces that you exert on the sled and the sled exerts on you are the same. Again, this is a consequence of Newton's third law. The acceleration of you and the sled depends on the forward force exerted on you by Earth and the backward frictional force between the sled and the ground.

24. The reading of the scale is given by $N_{\text{S on Y}} = m(g+a)$, where a is the upward acceleration. The force diagram is shown to the right. The force diagram remains unchanged as long as the acceleration stays constant.

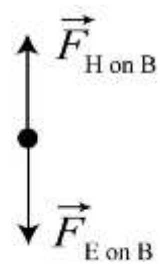


Problems

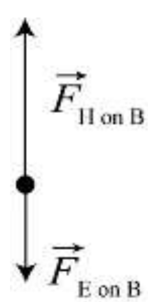
1. (1) The motion of a ball moving upward after leaving your hand is only under the influence of the force of gravity $\vec{F}_{\text{E on B}}$ (if we ignore air resistance), so the correct force diagram is (d).



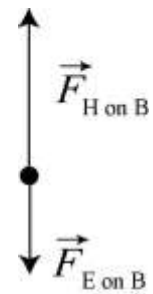
(2) When you hold a ball in your hand, you exert an upward force $\vec{F}_{\text{H on B}}$ on the ball, while the gravitational force exerted by Earth on the ball $\vec{F}_{\text{E on B}}$ points downward. The ball is in equilibrium, so the two forces have equal magnitudes but in opposite direction. The correct force diagram is (a).



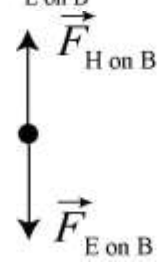
(3) As the ball undergoes free fall, the only force acting on it is the downward gravitational force $\vec{F}_{\text{E on B}}$. Thus, the correct force diagram is (d).



(4) The motion of throwing the ball upward results in a force $\vec{F}_{\text{H on B}}$ that accelerates the ball. This force is greater than the force of gravity $\vec{F}_{\text{E on B}}$ to give the ball an upward velocity upon releasing it. So the correct force diagram is (b).

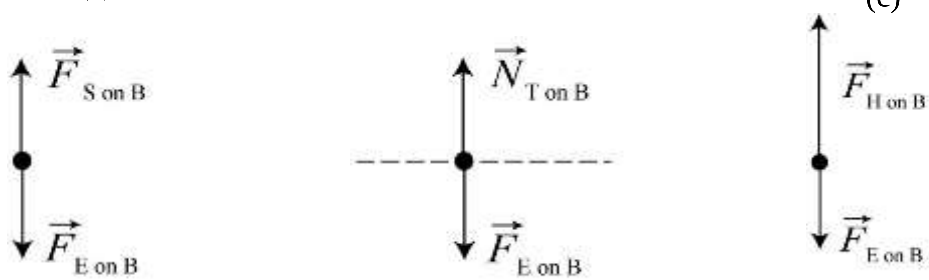


(5) When you lift a ball at a constant pace, the net force acting on the ball is zero. This means that the upward force $\vec{F}_{\text{H on B}}$ you exert has the same magnitude as the force of gravity $\vec{F}_{\text{E on B}}$ but points in the opposite direction. The correct force diagram is (a).



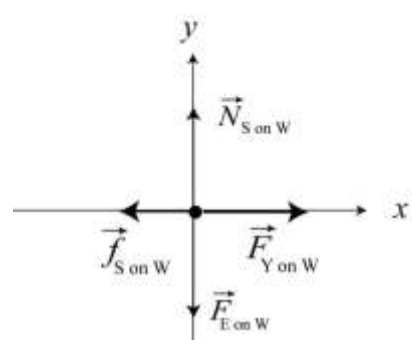
2. The force diagrams are shown below:

(a) (b) (c)

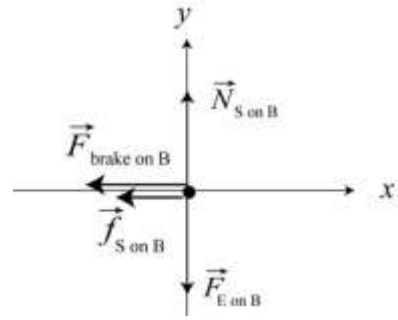


The forces involved are: (1) $\vec{F}_{\text{E on B}}$, the force exerted on the bag by Earth; (2) $\vec{F}_{\text{S on B}}$, the spring tension supporting the bag; (3) $\vec{N}_{\text{T on B}}$, upward normal force on the bag by table, and (4) $\vec{F}_{\text{H on B}}$, the upward force you exert to lift the ball.

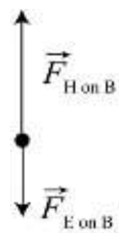
3. (a) The forces on the wagon are exerted by you ($\vec{F}_{\text{Y on W}}$) and Earth ($\vec{F}_{\text{E on W}}$). The surface provides an upward normal force $\vec{N}_{\text{S on W}}$. There is also friction $\vec{f}_{\text{S on W}}$ opposing the motion of the wagon.



(b) The forces on the bus are caused by your brake ($\vec{F}_{\text{brake on B}}$) and Earth ($\vec{F}_{\text{E on B}}$). The surface provides an upward normal force $\vec{N}_{\text{S on B}}$. There is also friction $\vec{f}_{\text{S on B}}$ opposing the motion of the bus.

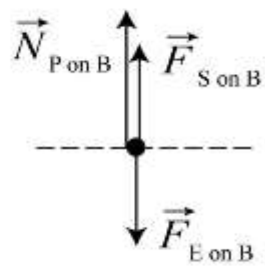


(c) The forces involved are: $\vec{F}_{\text{E on B}}$, the force exerted on the bag by Earth, and $\vec{F}_{\text{H on B}}$, the upward force you exert to lift the bag.



4. (a) The upward force by the spring, and the upward normal force by the platform scale exactly balance the downward gravitational force by Earth:

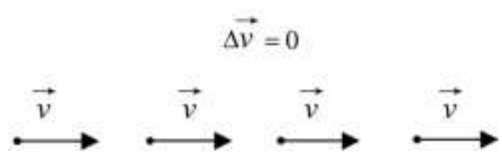
$$F_{\text{S on B}} + N_{\text{P on B}} = F_{\text{E on B}}$$



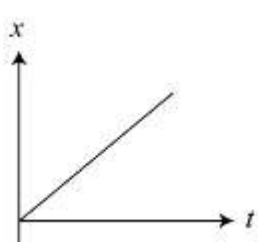
(b) The force exerted by the Earth is

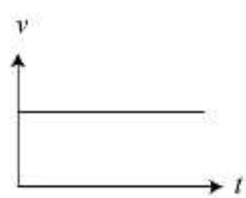
$$F_{\text{E on B}} = F_{\text{S on B}} + N_{\text{P on B}} = 17.6\ \text{N} + 25.7\ \text{N} = 43.3\ \text{N}$$

5. (a) For the block of ice sliding at constant velocity, its motion diagram is shown below. Note that the dots are all equally spaced and the velocity arrows are equally long and in the same direction.

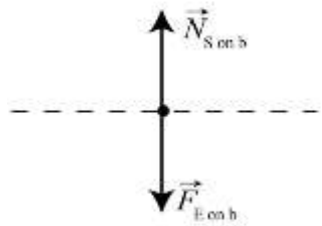


(b) The position and velocity-versus-time graphs are shown below:



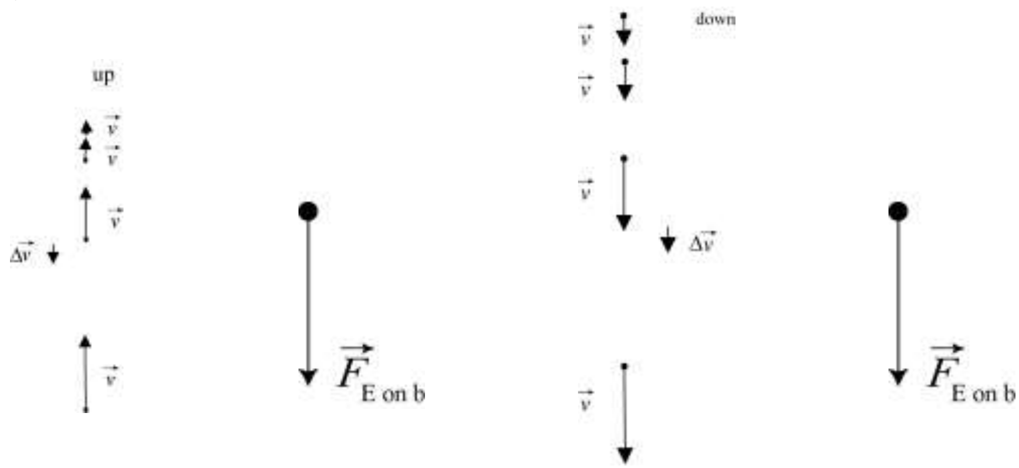


(c) The force diagram is shown below.



Since the net force on the block of ice remains zero at all time, the same force diagram can also be used.

6. (a) The motion and force diagrams for upward and downward motions are given below.

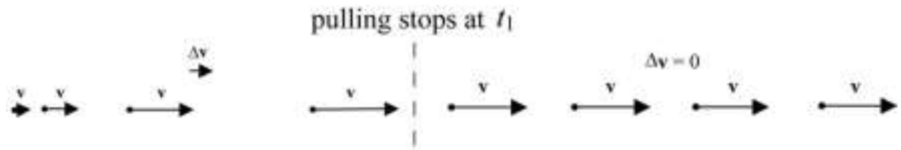


(b) The position-versus-time and velocity-versus-time graphs are shown below:

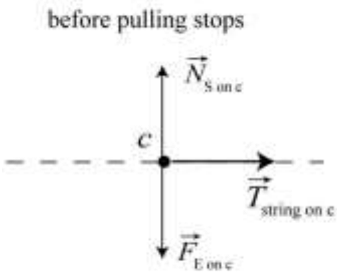
Mathematically, they can be represented by $y(t) = v_0 t - \frac{1}{2} g t^2$ and $v(t) = v_0 - gt$.

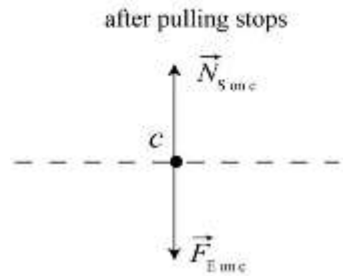
7. (a) After the pulling stops, the cart continues to move with constant velocity, in accordance to Newton's first law.

(b) The diagrams are shown below. We take the time when pulling stops to be t_1. The forces involved are the upward normal force $\vec{N}_{\text{s on c}}$ by the surface, the downward gravitational force exerted by Earth $\vec{F}_{\text{E on c}}$, and the tension in the string $\vec{T}_{\text{string on c}}$.

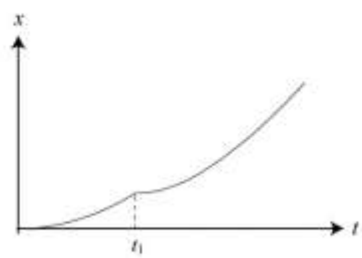


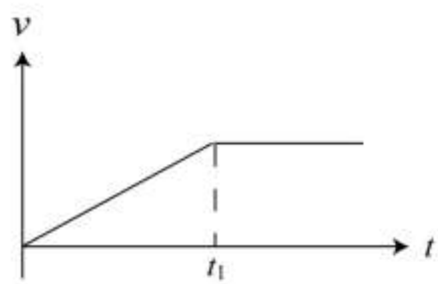
Force diagrams:





Graphs of position and velocity as function of time:





In sketching the figures above, we assume that the applied pulling force (and the corresponding acceleration) terminates abruptly at $t = t_1$. The object in cart is modeled as a point-like object, and factors such as friction and air resistances have been ignored.

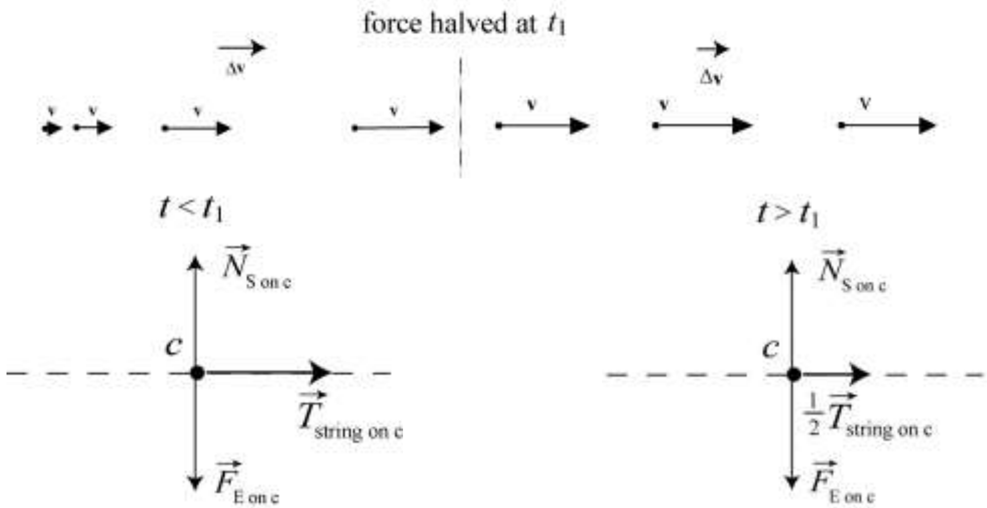
8. (a) The student mistakenly associates velocity with external force.

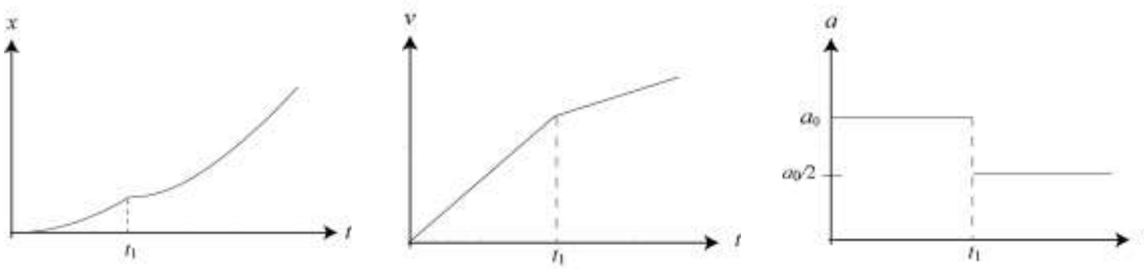
(b) You should disagree with him. Your friend is confusing velocity with acceleration. From Newton's second law, it is not velocity, but the acceleration that is proportional to the net force exerted on the cart.

(c) Let the cart rest on a long table with smooth (frictionless) surface. Attach a string to the cart, and connect the other end of the string to a metal block of mass *m* hung over a light, frictionless pulley. The metal block is initially suspended in air. When released, it will fall and provide the pulling force on the cart. Once the block reaches the ground, the pulling stops, and the cart will continue to move with constant speed.

9. (a) After the applied force has been reduced by half, the cart will continue to accelerate. If the initial acceleration is a_0, then the subsequent acceleration would be $a_0/2$.

(b) The diagrams are shown below. We take the time when pulling force is halved to be t_1. The forces involved are the upward normal force $\vec{N}_{\text{s on c}}$ by the surface, the downward gravitational force exerted by Earth $\vec{F}_{\text{E on c}}$, and the tension in the string $\vec{T}_{\text{string on c}}$.



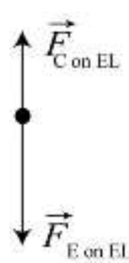


10. (a) Your friend mistakenly associates velocity with external force. It is the rate of change of velocity, or acceleration, that is associated with force.

(b) From Newton's second law, it is not velocity, but the acceleration that is proportional to the net force exerted on the cart.

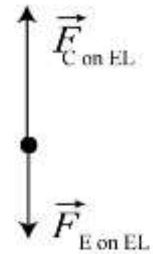
(c) Even though the tension in the string $\vec{T}_{\text{string on c}}$ has been halved, it still constitutes the net force acting on the cart. According to Newton's second law, the cart will continue to accelerate as long as the net force acting on it is non-zero.

11. (a) In this case, the force exerted by Earth on the elevator is greater than the force by the cable, $F_{\text{E on EL}} > F_{\text{C on EL}}$, so the elevator is moving down at a constant acceleration. The force diagram is shown to the right.



(b) In this case, the force exerted by Earth on the elevator is equal to the force by the cable, $F_{\text{E on EL}} = F_{\text{C on EL}}$. With a net force of zero, the acceleration is zero, and the elevator moves down at a constant speed. The force diagram is shown to the right.

(c) In this case, the force on elevator exerted by Earth is smaller than the force by the cable, $F_{\text{E on EL}} < F_{\text{C on EL}}$, and we have a net force pointing upward. The upward acceleration causes the elevator to slow down and come to a stop. The force diagram is shown to the right.

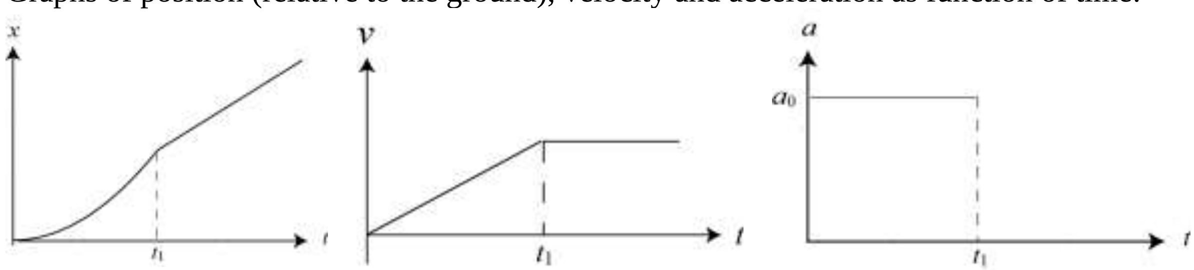


In our analysis, we have neglected the size of the elevator by treating it as a point-like object. In addition, air resistance has also been ignored.

12. The elevator will continue to move upward at a constant speed.

The diagrams are shown below. The forces involved are the upward force $\vec{F}_{\text{C on EL}}$ on the elevator by the cable, and the downward gravitational force exerted by Earth $\vec{F}_{\text{E on EL}}$. We take the time when the two forces balance ($F_{\text{C on EL}} = F_{\text{E on EL}}$) to be t_1.

Graphs of position (relative to the ground), velocity and acceleration as function of time:



In our analysis, we have neglected the size of the elevator by treating it as a point-like object. In addition, air resistance has also been ignored. We have also assumed that the acceleration reduces to zero abruptly at $t = t_1$.

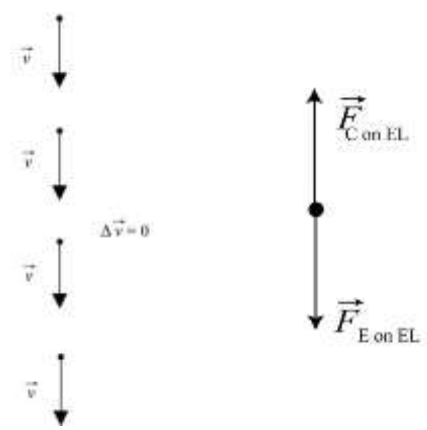
13. (a) Your friend mistakenly associates velocity with external force.

(b) You should disagree with him. From Newton's second law, it is not velocity, but the acceleration that is proportional to the net force exerted on the cart. Thus, a zero net force does not necessarily mean zero velocity.

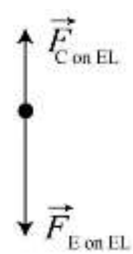
(c) At $t = t_1$ when the net force is abruptly reduced to zero, the elevator has an upward velocity. According to Newton's first law (law of inertia), when all the forces exerted on an object add to zero, the object continues moving at constant velocity or remain at rest.

14. The resultant forces exerted on both blocks are zero, since both are moving at constant velocity. Any non-zero net force would result in a non-zero acceleration, leading to a change in velocity.

15. The diagrams are shown to the right. The forces involved are the upward force $\vec{F}_{\text{C on EL}}$ on the elevator by the cable, and the downward gravitational force exerted by Earth $\vec{F}_{\text{E on EL}}$.
Two forces balance each other ($F_{\text{C on EL}} = F_{\text{E on EL}}$).

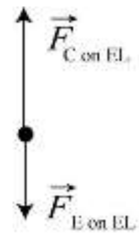


16. In case (a), the force on elevator exerted by Earth is greater than the force by the cable, $F_{\text{E on EL}} > F_{\text{C on EL}}$, so the elevator is moving down at a constant acceleration. The force diagram is shown to the right.



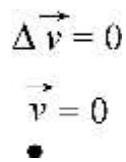
In case (b), the force on elevator exerted by Earth is equal to the force by the cable, $F_{\text{E on EL}} = F_{\text{C on EL}}$. With a net force of zero, the elevator moves down at a constant speed. The force diagram is shown to the right.

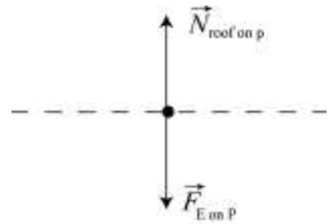
In case (c), the force on elevator exerted by Earth is smaller than the force by the cable, $F_{\text{E on EL}} < F_{\text{C on EL}}$, and we have a net force pointing upward. The upward acceleration causes the elevator to slow down and come to a stop. The force diagram is shown to the right.



One can certainly draw different motion diagrams for each case. The lengths of the arrows in the motion diagrams just need to increase, decrease, or stay the same, depending on whether the downward force is positive, negative, or zero.

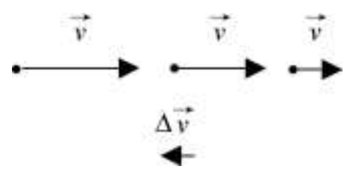
17. (a) The driver, who is in a non-inertial reference frame, sees the pie at rest, since in his frame, he sees no external object exerting a force on the pie.

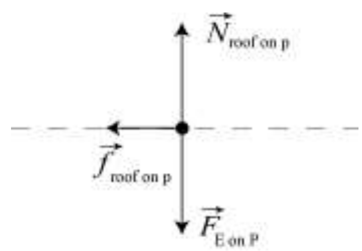




In the vertical direction, the force diagram has equal magnitude downward gravitational force by Earth and upward normal force that surface exerts on the pie.

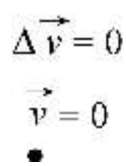
An observer on the ground, who is in an inertial reference frame, sees the pie moving forward but with decreasing velocity due to the force of friction.

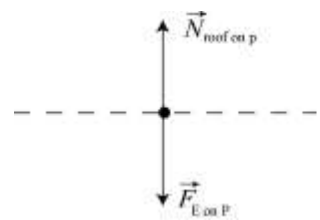




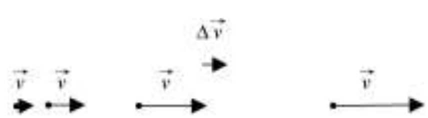
(b) After the light turns green, the van starts to accelerate from rest, and we have the following observations:

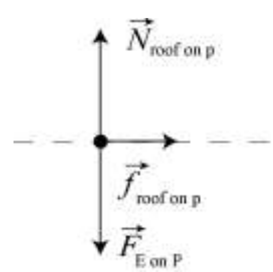
The driver, who is in a non-inertial reference frame, sees the pie at rest; no external object is exerting a force on the pie.





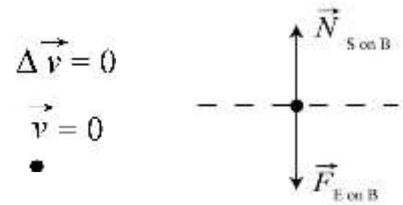
An observer on the ground, who is in an inertial reference frame, sees the pie and the car moving forward at an increasing speed.





(c) The velocity change arrows and force diagrams for both observers are consistent but this is necessary only for the inertial reference frame of the roadside observer.

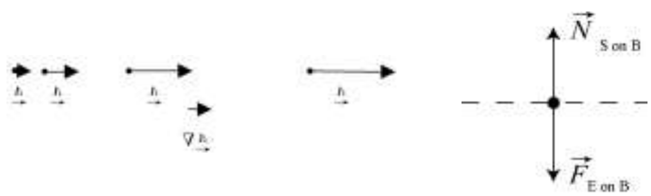
18. (a) The diagrams are shown to the right. The forces involved are the upward normal force $\vec{N}_{\text{S on B}}$ on the ball by the surface of train floor, and the downward gravitational force exerted by Earth $\vec{F}_{\text{E on B}}$.



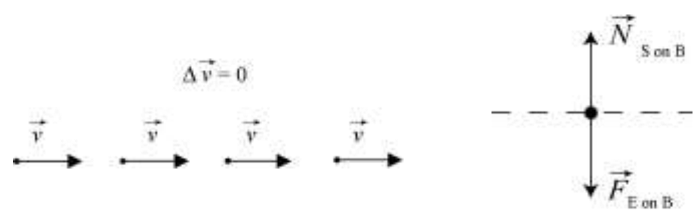
When the train is moving at a constant speed, the observer on the train sees the ball rest on the floor, while an observer on the platform sees the ball moving to the right at a constant speed. For both observers, the two forces balance each other ($N_{\text{S on B}} = F_{\text{E on B}}$).

(b) As the train approaches the station, it slows down (with a negative acceleration) and the ball starts to accelerate forward with respect to the floor.

The train passenger, who is in a non-inertial reference frame, sees the ball starting to move forward for no apparent reason; no external object is exerting a force on the ball.



An observer on the platform, who is in an inertial reference frame, sees the ball moving forward at a constant speed relative to her.



(c) The stationary observer on the platform is able to apply Newton's law to explain what happens to the ball. On the other hand, the train passenger who is in a non-inertial reference frame, will not be able to do so. He has to introduce "fictitious force" in order to explain the motion of the ball.

19. Whiplash usually occurs when your car is hit from behind by a second car. While your body gets pushed forward by the seat of your car, your head, however, is not directly pushed by the car along with your body in the absence of a headrest. Your head, with its inertia, tends to resist changes in its motion, and tries to remain still while your body is moving forward. This results in severe strain on your neck, and therefore whiplash.

For an observer in the car (a non-inertial frame), there seems to be a force that causes your head to be thrown back. But for an observer on the ground (an inertial frame), he sees your body getting thrown forward, while your head remains stationary.

20. Using Newton's second law ($F = ma$), we find the mass of the beam to be

$$m = \frac{F}{a} = \frac{100\ \text{N}}{0.10\ \text{m/s}^2} = 1000\ \text{kg}$$

To calculate the uncertainty, we note that when two quantities, each having uncertainty limits, are divided (or multiplied), the percentage uncertainty of the quotient (or product) is simply equal to sum of the percentage uncertainties. For example, if $z = x / y,$ where x and y are have measured uncertainties of Δx and Δy, respectively, then

$$\frac{\Delta z}{z} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$$

Now the value 100 N could have 1, 2 or 3 significant digits. For simplicity, let's assume that both F and a have two significant digits, so that they can be written as $F = (1.0 \pm 0.1) \times 10^2\ \text{N}$ (with 10% uncertainty) and $a = (0.10 \pm 0.01)\ \text{m/s}^2$ (also with 10% uncertainty), then the percent uncertainty in mass would be

$$\frac{\Delta m}{m} = \frac{\Delta F}{F} + \frac{\Delta a}{a} = 0.10 + 0.10 = 0.20 = 20,$$

So, we should quote the result as $m = (1.0 \pm 0.2) \times 10^3\ \text{kg}$.

21. **Sketch and translate** The system consists of the rope, which is being pulled by four external forces, two directed to the right, and another two directed to the left, as shown below.

Represent mathematically The total force to the right is

$$F_{\text{right}} = F_{1\text{ on R}} + F_{2\text{ on R}} = 330\ \text{N} + 380\ \text{N} = 710\ \text{N}$$

and the total force to the left is

$$F_{\text{left}} = F_{3\text{ on R}} + F_{4\text{ on R}} = 300\ \text{N} + 400\ \text{N} = 700\ \text{N}$$

Solve and evaluate The tension in the string is the smaller of the two forces, $T = 700$ N. A net force of $F_{\text{net}} = F_{\text{right}} - F_{\text{left}} = 710\text{ N} - 700\text{ N} = 10\text{ N}$ provides the acceleration of the entire system to the right.

22. Ignoring air resistance and assuming the shot to be a point-like object, we analyze its motion with one-dimensional kinematics. With $v_0 = 0$ and $v = 13\text{ m/s}$, the acceleration of the shot while being pushed a distance $\Delta x = 1.7\text{ m}$ is

$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{(13\text{ m/s})^2 - 0}{2(1.7\text{ m})} = 49.7\text{ m/s}^2$$

The time it takes to accelerate the shot is $t = \dfrac{v - v_0}{a} = \dfrac{13\text{ m/s} - 0}{49.7\text{ m/s}^2} = 0.26\text{ s}$.

Similarly, the net force exerted on the shot by hand is

$$F_{\text{H on S}} = m_s a = (7.0\text{ kg})(49.7\text{ m/s}^2) = 348\text{ N}$$

23. Given the mass m of an object and the total force $\mathtt{a}\ F$ applied during a time interval Δt, the following quantities can be determined:

(a) acceleration: $a = \dfrac{\mathtt{a}\ F}{m}$;

(b) velocity attained at the end of acceleration: $v = a\Delta t = \left(\dfrac{\mathtt{a}\ F}{m}\right)\Delta t$

(c) the distance traveled during acceleration: $\Delta x = \dfrac{1}{2}a(\Delta t)^2 = \dfrac{1}{2}\left(\dfrac{\mathtt{a}\ F}{m}\right)(\Delta t)^2$.

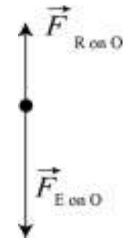
24. (a) For constant acceleration, the distance traveled is proportional to $(\Delta t)^2$. Therefore, if the time interval is doubled, the displacement will increase fourfold.

(b) If air resistance is considered, then the acceleration will no longer be constant. This reduces the travel distance.

25. The equation is of the form $F_{1\text{ on O}} - F_{2\text{ on O}} = m_O a_x$. The problem can be as follows: John pushes a 40 kg crate with 200-N force. The frictional force between the crate and the floor is 40 N. What is the acceleration of the crate?

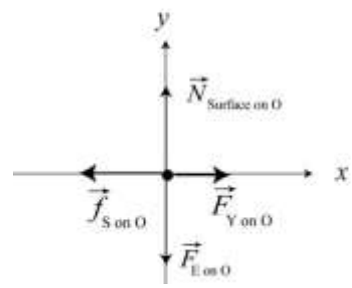
26. Since $29.4\text{ N} = (3.0\text{ kg})(9.8\text{ m/s}^2) = mg,$ the equation is of the form $m_{\text{O}}g - F_{\text{R on O}} = m_{\text{O}}a_x.$ An example of the problem can be as follows:

A block of mass M is placed on a frictionless table. It is connected to a lightweight rope that passes over a frictionless pulley of negligible mass and then fastened to a hanging 3.0-kg object. Upon released, the object begins to accelerate downward at 3.0 m/s^2. What is the tension in the rope?



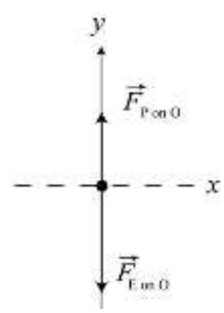
27. An example of the problem can be as follows:

A mover pushes a 30-kg box with a constant force100 N across a smooth floor. He then enters a rough area where the frictional force exerted on the box is $f_{\text{S on O}}$. If the resulting acceleration of the box is -1.0 m/s^2, what is the magnitude of $f_{\text{S on O}}$?

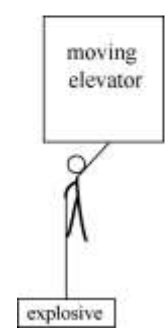


28. Since $196\text{ N} = (20\text{ kg})(9.8\text{ m/s}^2) = mg,$ the equation is of the form $-m_{\text{O}}g + F_{\text{P on O}} = m_{\text{O}}a_x.$ An example of the problem can be as follows:

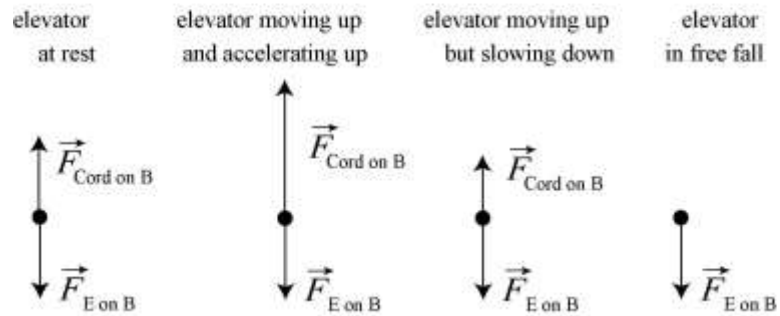
An elevator carrying a 20-kg object placed on a plate is moving upward but slowing down with acceleration -2.0 m/s^2. What is the force exerted by the plate on the object?



29. **Sketch and translate** The situation is sketched on the right. The object of interest is the box of explosives connected to the spider cord.



Simplify and diagram Earth exerts a downward force on the box $F_{\text{E on B}} = mg$, where *m* is the mass of the box, while the cord exerts an upward force $F_{\text{Cord on B}}$. The magnitude of $F_{\text{Cord on B}}$ depends on the acceleration of the elevator. The force diagrams are shown below for various situations.



Solve and evaluate
(a) With $a = 0,$ the force the spider cord exerts on the box is equal to the weight of the box: $F_{\text{Cord on B}} = F_{\text{E on B}} = mg = (50\text{ kg})(9.8\text{ m/s}^2) = 490\text{ N}$.

(b) With the elevator accelerating up, we have $F_{\text{Cord on B}} - F_{\text{E on B}} = ma$, which can be solved to give

$$F_{\text{Cord on B}} = m(g + a) = (50\text{ kg})(9.8\text{ m/s}^2 + 2.0\text{ m/s}^2) = 590\text{ N}$$

(c) With the elevator moving up but slowing down at $a = 2\ 2.0\text{ m/s}^2$, we have $F_{\text{Cord on B}} - F_{\text{E on B}} = ma$, which can be solved to give

$$F_{\text{Cord on B}} = m(g + a) = (50\text{ kg})(9.8\text{ m/s}^2 - 2.0\text{ m/s}^2) = 390\text{ N}$$

(d) If in free fall, $a = 2\ g$, and $F_{\text{Cord on B}} = m(g + a) = 0$.

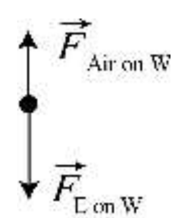
30. (a) We ignore friction and air resistance, and take the wagon to be point-like. Using Newton's second law ($F = ma$), we find the acceleration to be

$$a = \frac{F}{m} = \frac{125\text{ N}}{500\text{ kg}} = 0.25\text{ m/s}^2$$

Including the effects of friction and air resistance would result in a smaller acceleration.

(b) The speed of the wagon after 5.0 s is $v = at = (0.25\text{ m/s}^2)(5.0\text{ s}) = 1.25\text{ m/s}$.

31. **Sketch and translate** The object of interest is the stuntwoman, and the forces exerted on her are the gravitational force exerted by Earth $F_{\text{E on W}} = m_{\text{W}}g$, and the upward resistive drag force $F_{\text{Air on W}}$.



Represent mathematically Applying Newton's second law, we have (taking +*y*-direction to be downward)

$$F_{\text{E on W}} - F_{\text{Air on W}} = m_{\text{W}}a$$

Solve and evaluate Solving for $F_{\text{Air on W}}$, we obtain

$$F_{\text{Air on W}} = F_{\text{E on W}} - m_{\text{W}}a = m_{\text{W}}(g - a) = (60\text{ kg})\left(9.8\text{ m/s}^2 - 7.0\text{ m/s}^2\right) = 168\text{ N}$$

Note that $F_{\text{Air on W}} < F_{\text{E on W}}$. If air resistance were ignored, the stuntwoman would be in free fall, with acceleration $a = 9.8\text{ m/s}^2$ downward.

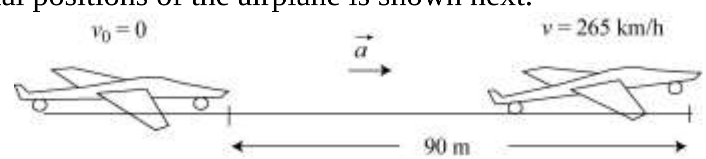
32. We ignore friction and air resistance, and take the ball to be point-like. In addition, we assume that the pitcher accelerates the ball through a distance of 3.0 m, from behind his body to where the ball is released. The acceleration of the baseball is then given by

$$a = \frac{v^2 - v_0^2}{2\Delta x} = \frac{(40\text{ m/s})^2 - 0}{2(3.0\text{ m})} = 267\text{ m/s}^2$$

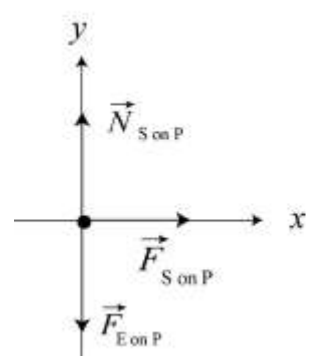
The force exerted by hand on the ball is

$$F_{\text{H on B}} = ma = (0.145\text{ kg})\left(267\text{ m/s}^2\right) = 38.7\text{ N}$$

33. **Sketch and translate** The Super Hornet jet airplane is our object of interest. We assume the motion to be one-dimensional in the horizontal direction. A sketch of the initial and the final positions of the airplane is shown next.



Simplify and diagram We take +*x* to be eastward. The forces exerted on the airplane are (1) $\vec{F}_{\text{E on P}}$: the gravitational force by Earth; (2) $\vec{N}_{\text{S on P}}$, the upward normal force by surface on the plane; and (3) $\vec{F}_{\text{S on P}}$, the frictional force exerted by the surface on the plane tires that is needed for acceleration. We ignore air resistance and other resistive forces that retard the motion of the plane. The force diagram is shown to the right.



Represent mathematically Applying Newton's second law, we have

$$F_{\text{E on P}} - N_{\text{S on P}} = ma_y = 0$$
$$F_{\text{S on P}} = ma_x$$

where $m = 2.1\times10^4$ kg is the mass of the plane. We assume the acceleration a_x to be constant. The speed attained at the end of acceleration is $v = 256\text{ km/h} = 73.6\text{ m/s}$, and the distance traveled while accelerating is $\Delta x = 90$ m. The relevant kinematics equations are

$$v^2 = v_0^2 + 2a_x(\Delta x), \quad v = a_x(\Delta t)$$

Solve and evaluate Using the formulas above, the following quantities can be determined:

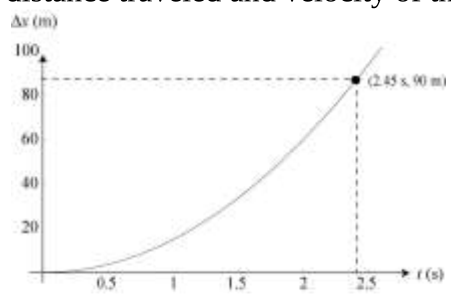
(i) acceleration: $a_x = \dfrac{v^2 - v_0^2}{2\Delta x} = \dfrac{(73.6\text{ m/s})^2 - 0}{2(90\text{ m})} = 30.1\text{ m/s}^2$;

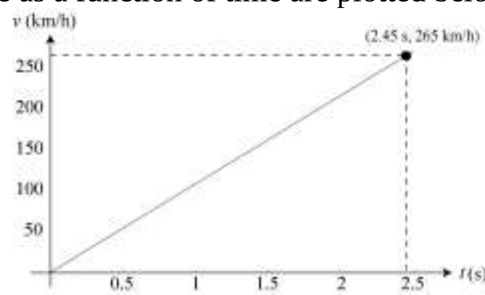
(ii) the acceleration time interval: $\Delta t = \dfrac{v}{a_x} = \dfrac{v}{(v^2/2\Delta x)} = \dfrac{2\Delta x}{v} = \dfrac{2(90\text{ m})}{73.6\text{ m/s}} = 2.45\text{ s}$;

(iii) the force exerted by the surface:

$$F_{\text{S on P}} = ma_x = \frac{mv^2}{2\Delta x} = \frac{(2.1\times10^4\text{ kg})(73.6\text{ m/s})^2}{2(90\text{ m})} = 6.3\times10^5\text{ N}.$$

The distance traveled and velocity of the airplane as a function of time are plotted below.





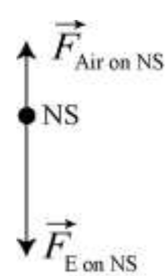
34. The average speed of the Lunar Lander is $v_{\text{avg}} = \dfrac{\Delta y}{\Delta t} = \dfrac{150\text{ m}}{120\text{ s}} = 1.25\text{ m/s}$.

To descend at a constant speed, the required upward lift must balance the downward force of gravity by Moon. Thus,

$$F = ma_{\text{M}} = (2.0\times10^4\text{ kg})(1.633\text{ m/s}^2) = 3.27\times10^4\text{ N}$$

35. **Sketch and translate** The Navy Seal is our object of interest. We assume the motion to be one-dimensional in the vertical direction.

Simplify and diagram We take $+y$-direction to be *downward*. The forces exerted on the Navy Seal are (1) $\vec{F}_{\text{E on NS}}$: the gravitational force by Earth, and (2) $\vec{F}_{\text{Air on NS}}$, the upward resistive, drag force. The force diagram is shown to the right.



Represent mathematically Using Newton's second law, the downward acceleration of the Navy Seal is given by

$$F_{\text{E on NS}} - F_{\text{Air on NS}} = m_{\text{NS}} a_y$$

where $F_{\text{E on NS}} = m_{\text{NS}} g$.

Solve and evaluate Solving for a_y, we obtain

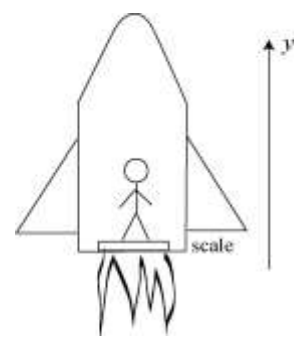
$$a_y = \frac{F_{\text{E on NS}} - F_{\text{Air on NS}}}{m_{\text{NS}}} = \frac{m_{\text{NS}} g - F_{\text{Air on NS}}}{m_{\text{NS}}} = g - \frac{F_{\text{Air on NS}}}{m_{\text{NS}}} = 9.8\ \text{m/s}^2 - \frac{520\ \text{N}}{80\ \text{kg}} = 3.3\ \text{m/s}^2$$

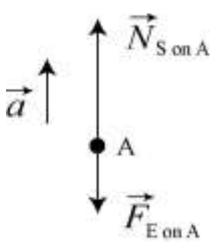
The net force on the Seal is

$$F_{\text{E on NS}} - F_{\text{Air on NS}} = (80\ \text{kg})(9.8\ \text{m/s}^2) - 520\ \text{N} = 264\ \text{N}$$

pointing downward.

36. **Sketch and translate** A sketch of the situation is shown to the right. The astronaut is the system object. We choose +*y*-direction to be upward.





Simplify and diagram The forces exerted on the astronaut are (1) $\vec{F}_{\text{E on A}}$: the gravitational force by Earth, and (2) $\vec{N}_{\text{S on A}}$: the upward normal force by the scale. The force diagram is shown to the left.

Represent mathematically Using Newton's second law, the acceleration of the astronaut is given by

$$N_{\text{S on A}} - F_{\text{E on A}} = m_{\text{A}} a_y$$

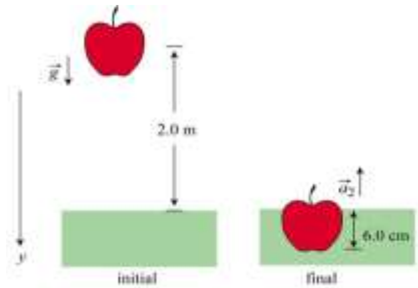
where $F_{\text{E on A}} = m_{\text{A}} g$. By Newton's third law, the magnitude of $\vec{N}_{\text{S on A}}$ is equal to the magnitude of the downward force the astronaut exerts on the scale, $\vec{N}_{\text{A on S}}$, and therefore, the scale reading.

Solve and evaluate Solving for $N_{\text{A on S}}$, we obtain

$$N_{\text{A on S}} = F_{\text{E on A}} + m_{\text{A}} a_y = m_{\text{A}}(g + a) = m_{\text{A}}(g + 3g) = 4 m_{\text{A}} g = 4(60\ \text{kg})(9.8\ \text{m/s}^2) = 2352\ \text{N}$$

or about $2.4 \times 10^3\ \text{N}$.

37. **Sketch and translate** A sketch (not to scale) of the situation is shown below. The apple is the system object. We choose +*y*-direction to be downward.



Simplify and diagram We ignore air resistance and treat the apple as a point-like object. Prior to hitting the grass, the apple is in free fall with acceleration $a_1 = g = 9.8\text{ m/s}^2$ pointing downward. After hitting the ground, the grass exerts an upward force on the apple to slow it down.

Represent mathematically The speed of the apple just before it strikes the ground can be found by using $v_1^2 = v_0^2 + 2a_1(\Delta y_1)$, where $a_1 = g$ and $\Delta y_1 = 2.0\text{ m}$. Substituting the values given, we obtain

$$v_1 = \sqrt{2g(\Delta y_1)} = \sqrt{2(9.8\text{ m/s}^2)(2.0\text{ m})} = 6.26\text{ m/s}$$

After hitting the ground, the apple sinks in $\Delta y_2 = 0.06\text{ m}$ before coming to a complete stop. Using the same equation, $v_2^2 = v_1^2 + 2a_2(\Delta y_2)$, the acceleration of the apple while stopping is

$$a_2 = \frac{v_2^2 - v_1^2}{2(\Delta y_2)} = \frac{0-(6.26\text{ m/s})^2}{2(0.06\text{ m})} = -326.7\text{ m/s}^2$$

The negative sign indicates that the acceleration is upward, in the opposite direction of the velocity.

Solve and evaluate Thus, the force the grass exerts on the apple while stopping it is

$$F_{\text{G on A}} = m|a_2| = (0.10\text{ kg})(326.7\text{ m/s}^2) = 32.7\text{ N.}$$

38. Treating the fireman as a point-like object and applying Newton's second law, the <u>acceleration</u> of the fireman is given by (taking +*y*-direction to be *downward*)

$$F_{\text{E on F}} - F_{\text{P on F}} = m_{\text{F}}a_1$$

where $F_{\text{E on F}} = m_{\text{F}}g$ is the gravitational force exerted by Earth on the fireman, and $F_{\text{P on F}}$ is the upward resistive force on him. Solving for the acceleration a_1, we obtain

$$a_1 = \frac{F_{\text{E on F}} - F_{\text{P on F}}}{m_{\text{F}}} = \frac{m_{\text{F}}g - F_{\text{P on F}}}{m_{\text{F}}} = g - \frac{F_{\text{P on F}}}{m_{\text{F}}} = 9.8\ \text{m/s}^2 - \frac{500\ \text{N}}{80\ \text{kg}} = 3.55\ \text{m/s}^2$$

The acceleration points downward.

The <u>speed</u> of the fireman just before reaching the ground is

$$v_1^2 = v_0^2 + 2a_1(\Delta y_1) \quad \Rightarrow \quad v_1 = \sqrt{2a_1(\Delta y_1)} = \sqrt{2\left(3.55\ \text{m/s}^2\right)(5.0\ \text{m})} = 5.96\ \text{m/s}$$

The <u>time</u> it takes for the fireman to reach the ground is

$$\Delta t_1 = \frac{v_1}{a_1} = \frac{5.96\ \text{m/s}}{3.55\ \text{m/s}^2} = 1.68\ \text{s}$$

After reaching the ground, the fireman bends his knee to lower his body by a vertical distance of $\Delta y_2 = 0.40\ \text{m}$ before stopping. Using the same equation, $v_2^2 = v_1^2 + 2a_2(\Delta y_2)$, the acceleration of the fireman while stopping is

$$a_2 = \frac{v_2^2 - v_1^2}{2(\Delta y_2)} = \frac{0 - (5.96\ \text{m/s})^2}{2(0.40\ \text{m})} = 2\ 44.4\ \text{m/s}^2$$

The negative sign indicates that the acceleration is upward, in the opposite direction of the velocity. The time interval for stopping is

$$\Delta t_2 = \frac{v_2 - v_1}{a_2} = \frac{0 - 5.96\ \text{m/s}}{2\ 44.4\ \text{m/s}^2} = 0.134\ \text{s}$$

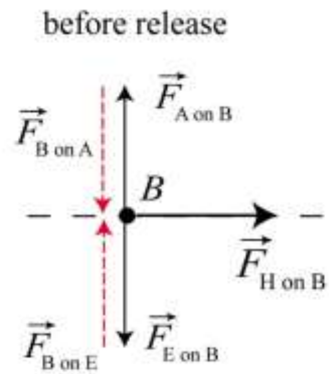
39. (a) By Newton’s third law, the apple exerts an equal-magnitude, oppositely directed force on the Earth. So, $|\vec{F}_{\text{A on E}}| = |\vec{F}_{\text{E on A}}| = 1.0\ \text{N}$ in the upward direction.

(b) The magnitude of the acceleration of the apple is $a_{\text{A}} = \dfrac{F_{\text{E on A}}}{m_{\text{A}}} = \dfrac{1.0\ \text{N}}{0.10\ \text{kg}} = 10\ \text{m/s}^2$. On the other hand, the magnitude of Earth’s acceleration is

$$a_{\text{E}} = \frac{F_{\text{A on E}}}{m_{\text{E}}} = \frac{1.0\ \text{N}}{6.0 \times 10^{24}\ \text{kg}} = 1.67 \times 10^{2\ 25}\ \text{m/s}^2$$

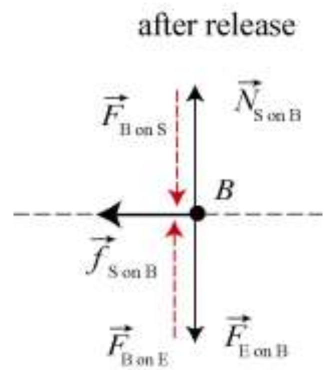
The ratio of the two accelerations is $\dfrac{a_{\text{E}}}{a_{\text{A}}} = \dfrac{m_{\text{A}}}{m_{\text{E}}} = \dfrac{0.10\ \text{kg}}{6.0 \times 10^{24}\ \text{kg}} = 1.67 \times 10^{2\ 26}$.

40. (a) Just before the bowling ball is released, the forces exerted on the ball are (1) $\vec{F}_{\text{E on B}}$: the gravitational force by Earth; (2) $\vec{F}_{\text{H on B}}$, the horizontal force by hand holding the ball; and (3) $\vec{F}_{\text{A on B}}$, the force by arm to support the ball.



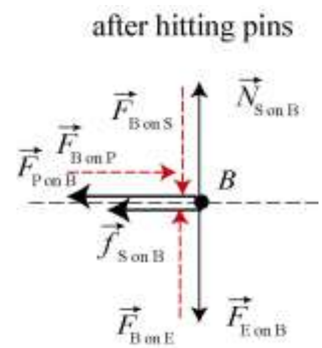
The ball and the arm form an action-reaction pair, with $\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$, where $\vec{F}_{\text{B on A}}$ is the downward force (dashed arrow) exerted on arm by the ball.
The ball and the Earth also form an action-reaction pair, with $\vec{F}_{\text{E on B}} = -\vec{F}_{\text{B on E}}$, where $\vec{F}_{\text{B on E}}$ is the upward force (dashed arrow) exerted on Earth by the ball.

(b) After the ball leaves the hand and starts to roll, the forces exerted on the ball are (1) $\vec{F}_{\text{E on B}}$: the gravitational force by Earth; (2) $\vec{N}_{\text{S on B}}$, the upward normal force by surface on the ball; and (3) $\vec{f}_{\text{S on B}}$, the force of friction on the ball.



The ball and the surface form an action-reaction pair, with $\vec{N}_{\text{S on B}} = -\vec{F}_{\text{B on S}}$, where $\vec{F}_{\text{B on S}}$ is the downward force (dashed arrow) exerted on surface by the ball.
The ball and the Earth also form an action-reaction pair, with $\vec{F}_{\text{E on B}} = -\vec{F}_{\text{B on E}}$, where $\vec{F}_{\text{B on E}}$ is the upward force (dashed arrow) exerted on Earth by the ball.

(c) After the ball hits the pins, the forces acting on the ball are (1) $\vec{F}_{\text{E on B}}$: the gravitational force by Earth; (2) $\vec{N}_{\text{S on B}}$, the upward normal force by surface on the ball; (3) $\vec{f}_{\text{S on B}}$, the force of friction on the ball; and (4) $\vec{F}_{\text{P on B}}$: the force by the pin.



The ball and the surface form an action-reaction pair, with $\vec{N}_{\text{S on B}} = -\vec{F}_{\text{B on S}}$, where $\vec{F}_{\text{B on S}}$ is the downward force (dashed arrow) exerted on surface by the ball.
The ball and the Earth also form an action-reaction pair, with $\vec{F}_{\text{E on B}} = -\vec{F}_{\text{B on E}}$, where $\vec{F}_{\text{B on E}}$ is the upward force (dashed arrow) exerted on Earth by the ball. In addition, the ball and the pin also form an action-reaction pair with $\vec{F}_{\text{P on B}} = -\vec{F}_{\text{B on P}}$, where $\vec{F}_{\text{B on P}}$ is the force (dashed arrow) exerted on the pin by the ball.

41. (a) Assuming the surface to be frictionless, the medicine ball and the skater will travel in opposite directions. Suppose the ball is accelerated through a distance of 2.0 m before leaving your hand at a speed of 6.0 m/s. Its acceleration would be

$$a_{\text{MB}} = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{(6.0\ \text{m/s})^2 - 0}{2(2.0\ \text{m})} = 9.0\ \text{m/s}^2$$

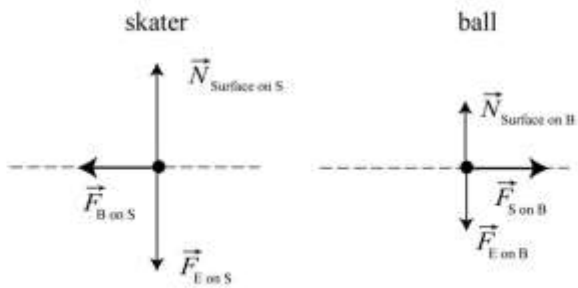
The force exerted by the skater on the medicine ball is

$$F_{\text{S on MB}} = m_{\text{MB}} a_{\text{MB}} = (4.0\ \text{kg})(9.0\ \text{m/s}^2) = 36\ \text{N}$$

or about 8.0 lb of force. With $F_{\text{S on MB}} = F_{\text{MB on S}}$, the acceleration of the skater is

$$a_{\text{S}} = \frac{F_{\text{MB on S}}}{m_{\text{S}}} = \frac{36\ \text{N}}{50\ \text{kg}} = 0.72\ \text{m/s}^2$$

The force diagrams for the skater and the ball are shown below.



42. We ignore air resistance and take the player to be point-like. With an initial speed of v_0, the maximum height attained is $y_{\max} = v_0^2 / 2g$. Given that $y_{\max} = 0.90\ \text{m}$, we find the initial speed to be

$$v_0 = \sqrt{2gy_{\max}} = \sqrt{2(9.8\ \text{m/s}^2)(0.90\ \text{m})} = 4.2\ \text{m/s}$$

Now, let's assume that the jump interval (from lowering the body to his feet taking off) lasts for 0.3 s. The gives

$$a = \frac{\Delta v}{\Delta t} = \frac{4.2\ \text{m/s}}{0.3\ \text{s}} = 14\ \text{m/s}^2$$

for the acceleration. By Newton's second law, the acceleration of the player is (taking +y-direction to be *upward*)

$$N_{\text{S on P}} - F_{\text{E on P}} = m_{\text{P}} a$$

where $F_{\text{E on P}} = m_{\text{P}} g$ is the gravitational force exerted by Earth on the player, and $N_{\text{S on P}}$ is the upward normal force by the surface. Solving for $N_{\text{S on P}}$ assuming $m_{\text{P}} = 200\ \text{lb} = 91\ \text{kg}$, we obtain

$$N_{\text{S on P}} = F_{\text{E on P}} + m_{\text{P}}a = m_{\text{P}}\left(g + a\right) = \left(91\text{ kg}\right)\left(9.8\text{ m/s}^2 + 14\text{ m/s}^2\right) = 2166\text{ N}$$

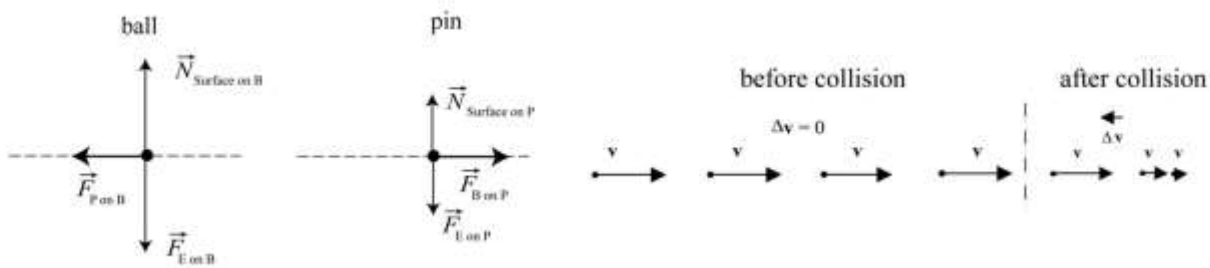
or about 2000 N.

(b) The speed of the player just before landing is the same as his initial speed. If we assume that he bends his knees (for soft landing) and comes to a stop in 0.3 s (same time interval as in jumping), then the force exerted on the player by the floor would be the same, namely, about 2000 N.

If we take air resistance into consideration, then the resulting acceleration would be small, and the normal force by the surface on the player would need to increase in order for him to reach the same height.

43. Assume each player pulls with a 500-N force. Then the total force by each team would be 4000 N. Both teams pull equally as hard, so no one moves. The tension in the rope is also 4000 N. By Newton's third law, this is also the force the rope exerts on each team. Note the distinction between tension and force. The rope is not moving because the net force on it is zero, but its tension is not zero because it's being pulled from both ends.

44. (a) The motion and force diagrams are shown below.



(b) Your friend might think that since the bowling ball has a greater mass compared to the pin, it should hit the pin with a greater force. He might have associated the velocity change (greater for the pin) with the force exerted on the object. The fact is, by Newton's third law, the pin and the ball exert equal but opposite forces on each other.

45. (a) Take the mass of the car to be 800 kg. The magnitude of the force would be

$$F_{\text{on C}} = m_{\text{C}}a = \left(800\text{ kg}\right)\left(300\text{ m/s}^2\right) = 2.4\times10^5\text{ N}$$

(b) Let your reaction time be $t_R = 0.60\text{ s}$. The distance traveled during reaction time is $x_R = v_0 t_R = \left(20\text{ m/s}\right)\left(0.60\text{ s}\right) = 12\text{ m}.$ The distance traveled with $a = 2\ 300\text{ m/s}^2$ before coming to a stop is

$$x_b = 2\ \frac{v_0^2}{2a} = 2\ \frac{\left(20\text{ m/s}\right)^2}{2\left(-300\text{ m/s}^2\right)} = 0.667\text{ m} \approx 0.67\text{ m}$$

So your stopping distance is about $x_R + x_b = 12\text{ m} + 0.67\text{ m} = 12.67\text{ m}$.

(c) In our calculation above, we have ignored friction and air resistance, and assumed point-like object in one-dimensional motion. The answer depends on the reaction time and the magnitude of acceleration to stop the car.

46. The magnitude of <u>acceleration</u> to stop the person is $a = \dfrac{F}{m} = \dfrac{8000\text{ N}}{70\text{ kg}} = 114.3\text{ m/s}^2$.

The <u>speed</u> of the person before the air bag opens up is

$$v_0 = \sqrt{2a(\Delta x)} = \sqrt{2(114.3\text{ m/s}^2)(0.60\text{ m})} = 11.7\text{ m/s}$$

The <u>time interval</u> for the airbag to bring the person to a stop is

$$\Delta t = \frac{\Delta v}{a} = \frac{11.7\text{ m/s}}{114.3} = 0.10\text{ s}$$

47. (a) With an acceleration $a = \dfrac{\Delta v}{t} = \dfrac{2\text{ m/s}}{0.2\text{ s}} = 10\text{ m/s}^2$, the force exerted on the blood by the left ventricle is $F = ma = (88 \times 10^{2\,3}\text{ kg})(10\text{ m/s}^2) = 0.88\text{ N},$ or 0.9 N in 1 significant digit.

(b) To calculate the uncertainty, we note that when two quantities, each having its uncertainty, are divided (or multiplied), the percentage uncertainty of the quotient (or product) is the simply equal to sum of the percentage uncertainties. For example, if $z = x / y,$ where x and y have measured uncertainties of Δx and Δy, respectively, then

$$\frac{\Delta z}{z} = \frac{\Delta x}{x} + \frac{\Delta y}{y}$$

Let the time measurement be $t = (0.20 \pm 0.01)\text{ s}$, with a relative uncertainty of $(0.01\text{ s})/(0.20\text{ s}) = 0.05 = 5.0,$. The speed has greater uncertainty since it is given in only one significant digit. We interpret the speed to be between 1.5 m/s and 2.5 m/s, or $v = (2 \pm 0.5)\text{ m/s},$ with a relative uncertainty of $(0.5\text{ m/s})/(2\text{ m/s}) = 0.25 = 25,$. Thus, the percent uncertainty in our calculation of the force would be

$$\frac{\Delta F}{F} = \frac{\Delta t}{t} + \frac{\Delta v}{v} = 0.05 + 0.25 = 0.30 = 30,$$

So, we should quote the result as $F = (0.9 \pm 0.3)\text{ N}.$

48. Let the mass of the acorn be m = 3.0g. Suppose it drops from a height of 10 m (relative to your head), the speed at which it hits your head is

$$v = \sqrt{2gh} = \sqrt{2\left(9.8\ \text{m/s}^2\right)\left(10\ \text{m}\right)} = 14\ \text{m/s}$$

If we further assume that the acorn sinks in 0.50 cm of your head skin before coming to a stop, then the acceleration is

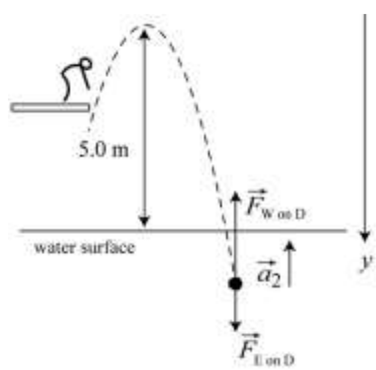
$$a = \frac{v^2 - v_0^2}{2\left(\Delta y\right)} = \frac{0-\left(14\ \text{m/s}\right)^2}{2\left(5.0\times 10^{-3}\ \text{m}\right)} = 1.96\times 10^4\ \text{m/s}^2$$

and the force your head exerts on the acorn is

$$\vec{F}_{\text{H on A}} = m_{\text{A}}a = \left(3.0\times 10^{-3}\ \text{kg}\right)\left(1.96\times 10^4\ \text{m/s}^2\right) = 58.8\ \text{N} \approx 60\ \text{N}$$

This is about 13 lb of force, and will hurt your head a bit.

49. **Sketch and translate** A sketch (not to scale) of the situation is shown below. The diver is the system object. We choose +*y*-direction to be downward.



Simplify and diagram We ignore air resistance and treat the diver as a point-like object. After reaching the maximum height and prior to hitting the water, the diver is in free fall with acceleration $a_1 = g = 9.8\ \text{m/s}^2$ pointing downward. After hitting the water, the water exerts an upward force on the diver to slow her down.

Represent mathematically Using $y(t) = \frac{1}{2}gt^2$, the time taken for the diver to fall a distance y is $t = \sqrt{2y/g}$. With $y = 5.0$ m, we obtain

$$t_1 = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2\left(5.0\ \text{m}\right)}{9.8\ \text{m/s}^2}} = 1.01\ \text{s}$$

Thus, the speed of the diver before entering the water is

$$v_1 = gt_1 = \left(9.8\text{ m/s}^2\right)\left(1.01\text{ s}\right) = 9.9\text{ m/s}$$

The acceleration required to stop her in 0.40 s is

$$a_2 = \frac{\Delta v}{t_2} = \frac{0 - 9.9\text{ m/s}}{0.4\text{ s}} = -24.75\text{ m/s}^2$$

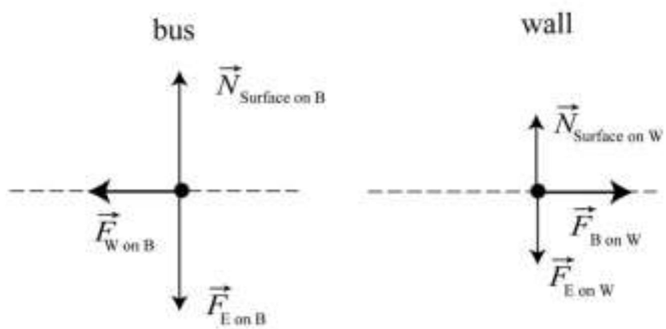
The negative sign implies that the acceleration is in the opposite direction of the velocity.

Solve and evaluate Newton's second law gives $F_{\text{W on D}} - F_{\text{E on D}} = -m_{\text{D}} a_2$, where $F_{\text{E on D}} = m_{\text{D}} g$ is the force exerted by Earth. Assuming the mass of the diver to be 45 kg, we find the resistive force by water to be

$$F_{\text{W on D}} = -m_{\text{D}}\left(a_2 + g\right) = -\left(45\text{ kg}\right)\left(24.75\text{ m/s}^2 + 9.8\text{ m/s}^2\right) = -1.55\times10^3\text{ N}$$

The negative sign means that the force points upward, as it should. Note that in the above calculations, we have ignored air resistance. Taking air resistance into consideration would result in a lower speed for the diver.

50. (a) The force diagrams are shown below.



(b) Assume the bus was going at 40 mph (about 18 m/s) before crashing into the wall, and that it takes 0.1 s for the bus to come to a complete stop. The acceleration required to stop the bus would be

$$a = \frac{\Delta v}{\Delta t} = \frac{0 - 18\text{ m/s}}{0.1\text{ s}} = -180\text{ m/s}^2$$

The negative sign implies that the acceleration is in the opposite direction of the velocity. Assuming the mass of the bus to be 3000 kg, we find the magnitude of the force exerted by the wall to be

$$F_{\text{W on B}} = m_{\text{B}} |a| = \left(3000\text{ kg}\right)\left(180\text{ m/s}^2\right) = 5.4\times10^5\text{ N}$$

51. The bathroom scale reading corresponds to the upward normal force the scale exerts on the person. By Newton's third law, it is equal to your apparent weight. When you stand still on the scale, it reports your true weight (or mass).

Now, to jump up from the scale you need to push down on the scale, and the scale in turns provides the force to propel you upward. The reading would be greater than your weight.

On the other hand, as you land (softly) by bending your knees, the acceleration is upward, so $N = m(g + a)$ and the scale reading again would be greater than your true weight.

52. Let the mass of the runner be 60 kg. If he exerts a force of 800 N on the starting block, by Newton's third law, the block will push back with an equal-magnitude force to propel him forward. Ignoring air resistance, his acceleration would be

$$a_{\text{runner}} = \frac{F_{\text{SB on runner}}}{m_{\text{runner}}} = \frac{800\text{ N}}{60\text{ kg}} = 13.3\text{ m/s}^2$$

If we further assume that the force is exerted on the runner for a duration of 0.3 s, then his speed at the instant when he leaves the starting block would be

$$v_{\text{runner}} = a_{\text{runner}}\Delta t = \left(13.3\text{ m/s}^2\right)\left(0.30\text{ s}\right) = 3.99\text{ m/s}$$

or about 4 m/s.

53. We first analyze the motion of one person, and then apply the result to the entire population. We ignore air resistance and treat the person as point-like. An initial speed v_0 allows a person to reach a maximum height of $h = v_0^2 / 2g$. Let the average height jumped be 0.5 m. His initial speed would be

$$v_0 = \sqrt{2gh} = \sqrt{2\left(9.8\text{ m/s}^2\right)\left(0.50\text{ m}\right)} = 3.13\text{ m/s}$$

Now, let's assume that the jump interval (from lowering the body to the feet taking off) lasts for 0.3 s. The gives an acceleration

$$a = \frac{\Delta v}{\Delta t} = \frac{3.13\text{ m/s}}{0.3\text{ s}} = 10\text{ m/s}^2$$

By Newton's second law, the acceleration of the person is (taking +*y*-direction to be *upward*)

$$N_{\text{S on P}} - F_{\text{E on P}} = m_{\text{P}}a$$

where $F_{\text{E on P}} = m_{\text{P}}g$ is the gravitational force exerted by Earth on the person, and $N_{\text{S on P}}$ is the upward normal force by the surface of Earth. Solving for $N_{\text{S on P}}$ assuming an average mass of $m_{\text{P}} = 50\text{ kg}$, we obtain

$$N_{\text{S on P}} = F_{\text{E on P}} + m_{\text{P}}a = m_{\text{P}}(g+a) = (50\text{ kg})\left(9.8\text{ m/s}^2 + 10\text{ m/s}^2\right) = 990\text{ N}$$

The world has approximately 7 billion people. Assuming that all the people squeeze together at one point on Earth and jump, the total force exerted by the surface would be

$$N_{\text{S on P, total}} = NN_{\text{S on P}} = \left(7\times10^{9}\right)(990\text{ N}) \approx 7\times10^{12}\text{ N}$$

By Newton's third law, this is the force exerted by the entire population on Earth. So the acceleration of Earth $(m_{\text{E}} = 6\times10^{24}\text{ kg})$ would be

$$a_{\text{E}} = \frac{N_{\text{P on S, total}}}{m_{\text{E}}} = \frac{7\times10^{12}\text{ N}}{6\times10^{24}\text{ kg}} = 1\times10^{2\,14}\text{ m/s}^2$$

which is exceedingly small.

54. Using the result from the previous problem, we find that (with a jump interval of 0.3 s) Earth would be a distance

$$d_{\text{E}} = \frac{1}{2}a_{\text{E}}(\Delta t)^2 = \frac{1}{2}\left(1\times10^{2\,14}\text{ m/s}^2\right)(0.3\text{ s})^2 = 5\times10^{2\,16}\text{ m}$$

55. (d) Both the first and second laws are used to explain the outcome. By first law, the passenger dummy has inertia and wants to continue its forward motion. The second law explains how the passenger dummy stopped after skidding down the tracks.

56. (d) Using the conversion factors

$$1\text{ mi} = 5280\text{ ft} = 1.609\text{ km} = 1609\text{ m}$$
$$1\text{ h} = 60\text{ min} = 3600\text{ s},$$

we have

$$67\text{ m/s} = (67\text{ m/s})\left(\frac{1\text{ mi}}{1609\text{ m}}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right) = 150\text{ mph}$$

57. (b) The acceleration required to attain the speed is

$$a_1 = \frac{v_1^2 - v_0^2}{2(\Delta x_1)} = \frac{(67\text{ m/s})^2 - 0}{2(360\text{ m})} = 6.2\text{ m/s}^2$$

or about 6 m/s^2.

58. (d) The acceleration to stop the sled in 6.0 m is

$$a_2 = \frac{v_2^2 - v_1^2}{2(\Delta x_2)} = \frac{0 - (67\text{ m/s})^2}{2(6.0\text{ m})} = 2\ 374\text{ m/s}^2 \approx 2\ 38\ g$$

with a magnitude of 38 *g*.

59. (c) The magnitude of the average force exerted by the restraining system is

$$F = ma_2 = (80\text{ kg})(374\text{ m/s}^2) \approx 3 \times 10^4\text{ N}$$

60. (b) The time interval to stop the sled is

$$t = \frac{v_2 - v_1}{a_2} = \frac{0 - 67\text{ m/s}}{2\ 374\text{ m/s}^2} = 0.18\text{ s}$$

61. (b) With the same acceleration *a*, the distances fallen can be related to the time intervals as

$$a = \frac{2d}{t^2} = \frac{2d'}{t'^2} \quad \Rightarrow \quad d' = \left(\frac{t'}{t}\right)^2 d$$

Thus, if a rocks falls 10 m in 3.5 s, in 5.0 s, the distance it will fall is

$$d' = \left(\frac{t'}{t}\right)^2 d = \left(\frac{5.0\text{ s}}{3.5\text{ s}}\right)^2 (10\text{ m}) = 20.4\text{ m}$$

62. (d) The time interval needed to fall 15 m is

$$t' = t\sqrt{\frac{d'}{d}} = (3.5\text{ s})\sqrt{\frac{15\text{ m}}{10\text{ m}}} = 4.29\text{ s}$$

63. (a) The braking distances traveled for different initial speeds can be related to each other by

$$f_{s\text{ max}} = \frac{m{v_0}^2}{2d} = \frac{m{v'_0}^2}{2d'} \quad \Rightarrow \quad d' = \left(\frac{v'_0}{v_0}\right)^2 d$$

Substituting the values given, we obtain

$$d' = \left(\frac{v'_0}{v_0}\right)^2 d = \left(\frac{27\text{ m/s}}{18\text{ m/s}}\right)^2 (26\text{ m}) = 59\text{ m}$$

64. (d) With $C' = \left(\frac{r'}{r}\right)^2 C$, the size of the pizza is

$$r' = r\sqrt{\frac{C'}{C}} = (7\text{ in.})\sqrt{\frac{\$10}{\$4.5}} = 10\text{ in.}$$

65. (d) The cost of the quilt is

$$C' = \left(\frac{r'}{r}\right)^2 C = \left(\frac{1.6\text{ m}}{1.2\text{ m}}\right)^2 (\$200) = \$356 \approx \$360$$