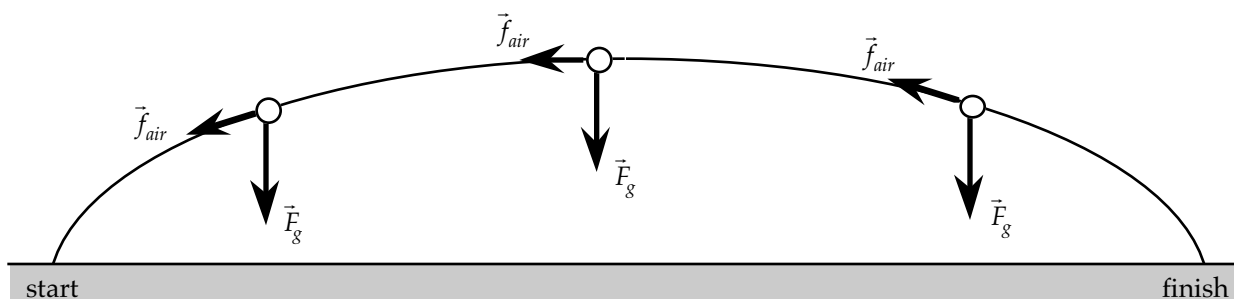


## CHAPTER 4 Newton's Laws

### Answers to Understanding the Concepts Questions

1. After the string has been cut the only force acting on the mass is gravity, and the mass moves as a projectile under its influence. The *only* memory of the fact that the mass was swinging as a pendulum before the string was cut is that the velocity of the mass when the string is cut is the initial velocity of the projectile motion. If the string is cut when the mass is moving horizontally — the bottom of the swing — then the projectile motion is one in which the initial velocity is horizontal, indistinguishable from the motion of a mass pushed off the edge of a flat tabletop with a non-zero initial velocity.

2.



3. One possibility is to hang a bathroom scale on the wall, and have the person push the scale. The reading of the scale then gives the magnitude of the force with which the person is pushing the wall.
4. The net force on you is the vector sum of the force of gravity and the contact force from the elevator floor, and it is the net force that describes your acceleration. If the elevator falls freely, your acceleration is the acceleration of gravity, which implies that the net force on you is just gravity; consequently there is no contact force from the floor. If the elevator accelerates upward, you do too, so that the net force must be upward, and this can only be due to an increased contact force from the elevator floor.
5. The net upward force on you is  $F_N - mg = ma$ , where  $F_N$  is the supporting force from the elevator floor,  $m$  is your mass, and  $a$  is the acceleration of the elevator (with up chosen as positive). As the elevator starts from rest and picks up speed  $a$  is positive (upward), so  $F_N$ , which is what the scale reads, is greater than your weight  $mg$ . As the elevator reaches its cruising speed it is no longer accelerating (i.e.,  $a = 0$ ), so the scale reading equals your weight. As the elevator slows down,  $a$  becomes negative (downward), and the reading is less than your weight. Finally, as the elevator reaches a complete stop  $a = 0$ , so the reading goes back to your weight.
6. Yes, if the astronaut needs to accelerate that piece of equipment. The more massive an object, the more force it would require to change its velocity. This is true whether or not there is apparent weightlessness.
7. False. The spring exerts the same amount of force on each mass (since it is being compressed by the same amount), but the resulting acceleration is not the same --- the more massive object will have less acceleration, so its speed will be slower.

8. A constant speed does not mean a constant velocity! The direction of the velocity of the satellite is changing constantly as it circles Earth, so that by Newton's second law there must be a net force on the satellite, and Newton's first law is not appropriate. The force responsible for the changing velocity (acceleration) is the gravitational force due to Earth.
9. As it is pulled very quickly from rest, the tablecloth is experiencing a large acceleration. To keep up with the tablecloth, the dinner setting must also have a large acceleration, which requires a large friction force between the tablecloth and the dinner setting. Such a large force is usually not available, unless the tablecloth is very sticky. Thus the dinner setting cannot keep up with the tablecloth and is left on the table. Another factor is that the whole thing happens only for a very short period of time, so any acceleration of the dinner setting due to the cloth being pulled does not have enough time to produce any significant speed of the dinner setting, which is often left nearly motionless.
10. A force-free environment is a very elusive idea. As the satellite travels from Earth to the Moon, it is influenced by, among other things, the gravitational force of the Sun, of Earth, and of the Moon. Even at the special point between Earth and the Moon where the vector sum of their gravitational forces on the satellite is zero, the force due to the Sun is still present. This is still true for the spaceship traveling from Earth to Mars. It is true that the forces due to Earth and to Mars will be quite small for much of that journey, but the Sun's force will remain substantial, and affects the spaceship for its entire flight.
11. To balance the weight of the person, the table has to exert an upward normal force on the person. The person, in turn, must exert a downward normal force on the table, thanks to Newton's third law. It is that downward force exerted by the person on the table, not the weight of the person *per se*, that is directly responsible for causing the table to break. One can argue, of course, that this is all caused by the weight of the person — an *indirect* cause.
12. The motion of the bicycles is not governed by gravity alone; there are frictions (between the axles and the wheels, and due to the air, for example) that can differ for different bicycles.
13. In our everyday experience, "touch" is involved with friction, normal forces from the floor, and the rope pulling on an object, whether it is wrapped around a pulley or not. We would classify neither the force of gravity nor forces due to magnets as contact forces.
14. No. The reaction of the weight of the box is the force exerted by the box on Earth, while the reaction of the upward normal force exerted on the box by the table is the downward normal force exerted by the box on the table.
15. We can say that there is no net force on the parachutist if he or she is moving with constant velocity. Thus gravity must be balanced by an equal and opposite force, and for a parachutist that force is the drag force between the air and the parachute. Indeed, a parachute is designed to make the drag force as large as possible!
16. Make an Atwood machine consisting of a light string suspended over a fixed, frictionless pulley. Attach one end of the string to a standard (known) mass,  $m_1$ , and the other end to an unknown mass ( $m_2$ ). If the system is balanced then immediately we have  $m_2 = m_1$ . If not, then the masses will undergo an acceleration. Suppose  $m_1 > m_2$ , then after they are released  $m_1$  will accelerate downward and  $m_2$  upward, with an acceleration of  $a$ :  $(m_1 + m_2)a = (m_1 - m_2)g$ , from which we can solve for  $m_2$ .
17. One way to do it is to exert a known force on the object and measure the resulting acceleration. For example, pull the mass with a spring scale with a constant force  $F$  (which is the case when the scale reading is a constant) over a certain distance  $x$  and clock it. The acceleration can be found from  $x = at^2/2$  and the mass from  $m = F/a$ . Another way would be to attach the mass to a spring, set it into oscillation, and observe the period of the oscillation (the time for one complete cycle of oscillation), which depends on the mass of the object (see Chapter 13 for details.)

18. Newton's remark was more wishful thinking than one based on real knowledge. We know today that the stars are not fixed, and that the mythical inertial frame is an ideal. We can approach this ideal more or less well according to circumstances. We can take the systems mentioned as representing a set of representative circumstances. The physics lab is probably pretty well fixed to Earth, so that we might have to worry only about earthquakes and Earth's rotation. The major effect of Earth's rotation is to modify the acceleration of gravity by a small, fixed amount. The space shuttle in orbit is in free-fall, so that gravity does not appear to be acting. In the sense that contact forces are the most serious consequences of a noninertial frame, the Shuttle is a pretty good platform. A ship at sea, on the other hand, with its pitching and rolling is a poor approximation to an inertial system. But a building on Mars, which is geologically more stable than Earth, would be a good approximation.
19. The greater cross-sectional area of the rubber ball results in a greater amount of air resistance on it.
20. First of all,  $\vec{a}$  is not a force but rather an acceleration. Secondly, even if we were to change  $\vec{a}$  to  $m\vec{a}$ , the diagram would still be incorrect. The two forces ( $\vec{F}_N$  and  $m\vec{g}$ ) exerted on the block sum up as the net force, which is equal to  $m\vec{a}$ . So  $\vec{a}$  does not represent a separate force, but rather the combined effect of the  $\vec{F}_N$  and  $m\vec{g}$ .
21. Taken as a whole, an automobile accelerates because an external force acts on it. This force is one that is exerted on it at the point where the tires touch the road: friction. An automobile is not a point object, and the friction between tire and road is the end result of a number of forces that act inside: the force of hot gases on pistons; the force due to those pistons that turns a crankshaft; the transmission, which in effect allows the crankshaft to act on wheels and make them turn. And when a tire attempts to rotate, the nonzero coefficient of friction between rubber and road introduces the friction force that moves the automobile. Incidentally, there are many other forces of residual friction and drag that tend to slow the car down, so that friction between tire and road is necessary just to keep the automobile moving at a constant speed, at least on a flat or rising road.
22. The rock is in circular motion and must be subject to a centripetal force that is radially inward, along the string. That force is provided by your hand (through the string). Due to Newton's third law, your hand must be subject to its reaction, which is exerted by the rock, radially outward.
23. When she jumps upward the girl has not only a vertical initial velocity but also a horizontal initial velocity which is equal to the tangential velocity  $\vec{v}$  of the merry-go-round at her location. As she is airborne the merry-go-round continues to rotate, while horizontally she moves along a straight line in the tangential direction with velocity  $\vec{v}$ . Depending on her time of flight she may land anywhere on the portion of the merry-go-round that is more than half the radius away from its center, and in fact if she stays airborne long enough she may even land outside the merry-go-round.
24. The forces between ball and bat are, of course, contact forces. The bat and ball are both moving when they meet, but the bat is more massive than the ball, and moreover it has other forces acting on it due to the batter's hands. Thus the forces that act between ball and bat tend to have a greater effect on the ball than on the bat; that is, they accelerate the ball to a greater degree. Neither bat nor ball is rigid, and during the collision the ball compresses and the bat both compresses and bends to some degree. The bat is itself accelerated, but the forces due to the batter's hands tend to resist this acceleration, and the better he or she can do this the more the ball is accelerated. Home run hitters tend to have muscular arms and bodies. Because the bat is not a point object, its response to the forces on it due to the ball are complicated, leading to effects such as the "stinger" that every batter can describe when the ball hits a certain region on the bat.
25. Here are three examples: centrifugal force, the upward force that enables an astronaut to "float" inside a space shuttle, the backward force that keeps you at rest on the driver's seat as you accelerate your car forward.

26. The brick is quite massive so the force of the hammer may not cause a significant downward acceleration on it, reducing the impact on your hand. Plus, the contact area between the brick and your hand is considerably larger than that of the tip of the hammer so the force of the hammer is spread out more evenly.
27. The contact force at the bowl's surface is perpendicular to the motion of the marble, so that it does not itself cause the speed to change. In the absence of friction only gravity would do that. Friction is of course present, and it acts in such a way that the marble slows due to it. In later chapters we shall see that energy is a very efficient way to think about this system, and about why, in the absence of friction, the ball would rise up on the side of the bowl, to the height from which it started.
28. For simplicity, neglect and vertical acceleration of the ship. To measure the acceleration of the ship in the forward or backward direction, place a spring in a smooth, horizontal track parallel to the orientation of the ship, with one end of the spring fixed and the other end attached to an object of mass  $m$ , which can slide frictionlessly along the track. Let's say that the fixed end of the spring is closer to the stern of the ship than the other end. As the ship accelerates forward, the spring gets compressed, and by measuring the amount of compression we can determine the force  $F$  exerted by the spring on the object. Then the acceleration of the object (and that of the ship) is  $a = F/m$ . Similarly, if the ship is decelerating the spring would be stretched, and the amount of stretch again determines the magnitude of the acceleration. Also, by placing the device perpendicular to the ship we can determine any sidewise acceleration.
29. The scale reads the contact force between your feet and the floor. If the elevator were not accelerating, the scale would read the magnitude of the force of gravity on you. But as we described in the answer to Question 4, the contact force between floor and feet would increase if the elevator accelerated upward, and this would give an increased reading on the scale.
30. No. The diver is always subject to the same force of gravity, whether he or she is falling or not. By falling freely, the diver is no longer being supported by the platform or diving board, and that creates the sensation of weightlessness. But this is not to say that gravity is no longer acting on the diver. In fact, quite the contrary, it is the precisely the gravitational force, which is now unbalanced, that causes the diver to accelerate towards the water.
31. Earth always exerts a force on the apple, whether the apple moves or not. Say the weight of the apple is 1 lb. The apple does exert a 1-lb reactionary force that tends to pull Earth towards it. But since the apple is at rest despite its weight, it must also be subject to a 1-lb upward supporting force from the branch which, in turn, gets a 1-lb downward reactionary force from the apple. To keep the branch in balance, Earth has to exert a 1-lb upward force on the branch. The branch then has to exert a 1-lb downward reactionary force on Earth. This force cancels the attractive force from the apple and prevents Earth from being pulled towards the apple.
32. Assuming that the table is horizontal, the magnitude of the normal force on the mass by the table is indeed equal to its mass times the acceleration of gravity ( $mg$ ). Strictly speaking, however, the reaction to this normal force is not the force of gravity on the mass, which also has a magnitude of  $mg$ . Rather, as the force of gravity tries to pull the mass downward it is being balanced by an upward normal force from the table, and in return the table is subject to a downward normal force from the mass. These two forces form a pair of action and reaction, in accordance with Newton's third law.
33. In an inertial frame of reference, an object in mechanical equilibrium (undergoing no acceleration) is subject to zero net force. We can test this by balancing an object so that it does not accelerate, and measuring all the physical forces exerted on it (such as its weight, the tensions in the cables supporting it, etc) and check if these force sum up to zero. If they do, then the reference frame is an inertial one. If not, then it is noninertial.

34. This question is meant to confuse! But you won't be if you keep in mind the fact that the force on one object makes that object accelerate, and that the forces that are equal and opposite in the question act on different objects. If these were the only forces acting the cart would accelerate to the horse as the horse accelerated to the cart. Of course there are many more forces acting, not the least important of which is friction between the horse's hooves and the ground.
35. The engine, through the transmission and axle, forces the driving tires to turn in such a direction that, at their contact points with the ground, the tires have a tendency to move *backward*. Thus the tires exert a backward force of static friction on the road, and, in return, the road exerts a reactionary force of friction that pushes the car *forward*.
36. Either someone has turned on a large magnet or the bus has suddenly started to move forward. In order for you to move along with the bus, a force must then act on you, and this is the force of friction between your feet and the bus floor. If these forces are not strong enough, or if there are effects having to do with your extended size and the point of application of the force, then you will not accelerate forward as much as the bus; in other words, you will be thrown backwards *with respect to the bus*.
37. These forces are indeed equal and opposite, but they do not form a pair of action and reaction. They are both exerted on the same object (the car) to achieve mechanical equilibrium for the car. The reaction to the weight of the car is the upward gravitational pull of the car on Earth, while that to the upward normal force exerted on the car is the downward normal force exerted by the car on the ground.
38. Let's assume that the forces involved are steady. One side being stronger than the other means that the net force on one group is greater than the net force on the other. (Note that these forces involve not only direct forces on the rope but friction between feet and ground.) The motion of both groups is the same because they are connected by the taut rope, and this motion is matched by the motion of the handkerchief. This motion will be steady acceleration towards the winning side.
39. Forces cause acceleration, so they are responsible for the *change* in motion of an object. An object that is already in motion does not need any force to cause it to stay in motion, while a force that is opposite to the direction of motion of an object can actually cause an object to *stop* moving. We can say, however, that a non-zero net force causes an initially stationary object to move.
40. The key to this problem is how we might determine the acceleration of our own reference frame. If it is found to be zero then our frame is inertial, in which an object that undergoes no acceleration must be subject to zero net force, thanks to Newton's first law. To measure the acceleration of the reference frame itself, we can apply a known force  $F$  (by using a pre-calibrated spring scale, for example) on an otherwise "free" object and measure its acceleration  $a$  by kinematic means. If  $F$  is found to be equal to  $ma$  then the frame is inertial. Otherwise, the difference between  $F$  and  $ma$  equals the magnitude of the fictitious force, and dividing that by the mass of the object gives the magnitude of the acceleration of the reference frame.
41. Sounds like a great idea until you think about it a little. If you pull upward on your bootstraps, your bootstraps exert an equal and opposite force downward on your hands. The internal forces — and these are indeed internal forces — cancel, and cannot effect your motion as a whole. If you want to make your bootstraps rise, it is a fine idea to pull on them; if you want to make yourself rise, the only way to make the method work is to annul Newton's third law. Only the Baron was able to do this; of course the Baron was also a notorious liar, so you might draw your own conclusions.

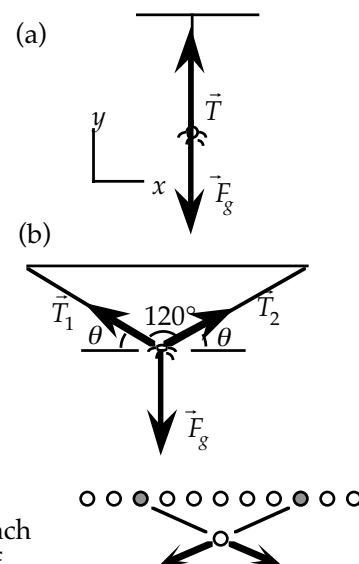
## Solutions to Problems

- The force of gravity (toward Earth);
  - the force of gravity (down), the normal force from the ice (up); and a small friction force from the ice (opposite to the motion);
  - essentially none.
- The skater is subject to the following forces: his weight, down; the supporting force from the ice, up; a force of the wind, and a (very small) friction from the ice exerted on the blades. These forces do not balance, as the horizontal component of the stiff force of the wind is not sufficiently counterbalanced by the negligibly small friction of the ice. The speed of the skater is almost a constant, however, which means that his acceleration is nearly zero, despite the fact that the forces are not quite balanced. (We are assuming here that he does not move in a curve. This is a safe assumption since moving in a curve with near-constant speed would require a variable net force, which is absent here since the wind is steady.) The apparent contradiction of near-zero acceleration under non-zero force can be resolved if we realize that the mass of the skater can be large, so  $a = F_{\text{net}}/m \approx 0$ . Another possibility is that the skater might be thin and small (so a stiff wind does not yield a significant force on him), yet he is "bone heavy" (so  $F_{\text{net}}$  is small but  $m$  is not quite that small).
- Since the velocity is constant,  $\sum \vec{F} = 0$ ; the other team must exert a force of  $600 \text{ N}$  in the  $-y$ -direction.
- Since the velocity is constant,  $\sum \vec{F} = 0$ ; and so the force from the water must be  $3 \times 10^3 \text{ N}$  from the north.
- Because there is no acceleration, the forces provided by the two teams of horses must be equal and opposite. One team could still provide the same force with the opposite force provided by the sturdy tree. The two teams of horses provide a more dramatic demonstration.
- In order to have  $\vec{a} = 0$ ,  $\sum \vec{F} = 0$ . Since the sum of  $\vec{F}_2$  and  $\vec{F}_3$  cannot have a  $z$ -component, it is impossible to balance  $\vec{F}_1$  and make  $\sum F_z = 0$ .
- We choose a coordinate system as shown in the diagram.  
In both parts, the spider is motionless and  $\vec{a} = 0$ , therefore  $\sum \vec{F} = 0$ .
  - $\sum \vec{F} = T\hat{j} - F_g\hat{j} = 0$ , which gives  

$$T = F_g = 3 \times 10^{-4} \text{ N}.$$
  - $\sum \vec{F} = -T_1 \cos \theta \hat{i} + T_1 \sin \theta \hat{j} + T_2 \cos \theta \hat{i} + T_2 \sin \theta \hat{j} - F_g \hat{j} = 0$ .  
 Using the two component equations, we get  

$$T_1 \cos \theta = T_2 \cos \theta, \text{ or } T_1 = T_2; \text{ and}$$

$$T_1 \sin \theta + T_2 \sin \theta = 2T_1 \sin \theta = F_g.$$
 Thus  $T_1 = (3 \times 10^{-4} \text{ N}) / (2 \sin 30^\circ) = 3 \times 10^{-4} \text{ N}.$
- The force from the charge directly above the mass is directed downward. All of the other charges can be treated as a sum of pairs; each pair is symmetrically positioned about the mass and gives two forces of equal magnitude at the same angle below the horizontal, as shown. The sum of these two is a force directed downward. Thus the sum of all of the forces is directed downward.



9. (a) The acceleration opposite to the motion is due to a retarding force, partly from air resistance and partly from other frictional forces.  
 (b) The observer sees the car (initially at rest) move backward with increasing speed until it reaches  $v_0$ . She would say that this is due to a backward force from the wind, etc.

10. The acceleration of the apple will be the acceleration of all freely falling objects:  $g = 10 \text{ m/s}^2$  down.  
 The force of gravity on the automobile is  $mg = (2500 \text{ kg})(10 \text{ m/s}^2) = 2.5 \times 10^3 \text{ N}$ .

11.



12. The net force is the vector sum:

$$\begin{aligned}\Sigma \vec{F} &= \vec{F}_g + \vec{F}_E + \vec{F}_L + \vec{F}_D \\ &= (6 \times 10^5 \text{ N}) \downarrow + (2 \times 10^5 \text{ N}) \rightarrow + (6 \times 10^5 \text{ N}) \uparrow + (1.5 \times 10^4 \text{ N}) \leftarrow = (1.9 \times 10^5 \text{ N}) \rightarrow.\end{aligned}$$

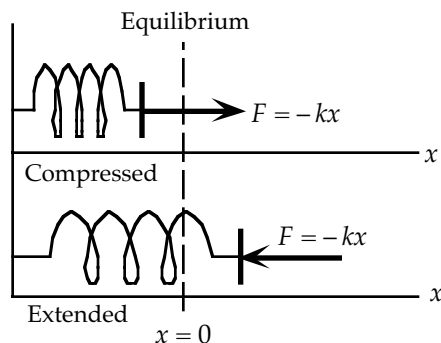
The acceleration is forward.

13. The bullet's speed decreases from  $v_0$  to  $v$  after traveling a distance  $\Delta x$  while undergoing a negative acceleration:  $v^2 - v_0^2 = 2a\Delta x$ , so

$$a = (v^2 - v_0^2) / 2\Delta x = [0^2 - (400 \text{ m/s})^2] / [2(0.14 \text{ m})] = -5.7 \times 10^5 \text{ m/s}^2.$$

The average force on the bullet is  $F = ma = (2 \times 10^{-3} \text{ kg})(-5.7 \times 10^5 \text{ m/s}^2) = -1 \times 10^3 \text{ N}$ .

14.



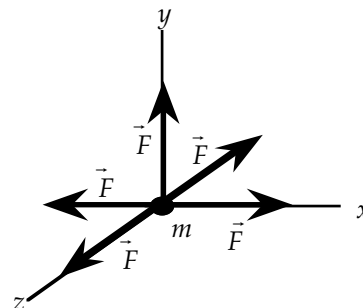
15. The acceleration is produced by the net force.

The pairs of forces along the  $x$ - and  $y$ - axes will add to zero. Thus the net force is the fifth force in the  $z$ -direction. Formally this is

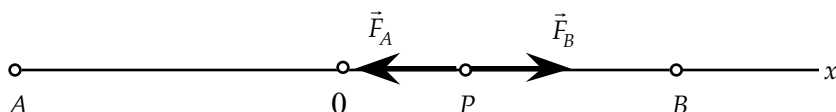
$$\Sigma \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4 + \vec{F}_5 = F\hat{i} - F\hat{i} + F\hat{j} + F\hat{k} - F\hat{k} = F\hat{j}.$$

The acceleration is  $\vec{a} = \Sigma \vec{F} / m = (F/m)\hat{j}$ .

The different order of the forces would not change the answer.



16.



Set up a coordinate system with the origin at the midpoint of the line connecting points A and B. Consider the object (at point P), whose coordinate is  $x$ . It is a distance  $L + x$  from point A and  $L - x$  from point B. The forces exerted on it are  $F_A = -c(L + x)$  and  $F_B = c(L - x)$ ; so the net force is

$$F = F_A + F_B = -c(L + x) + c(L - x) = \boxed{-2cx}.$$

When  $x > 0$ ,  $F < 0$  (to the right); and when  $x < 0$ ,  $F > 0$  (to the left). So  $F$  tends to pull the object back to the origin (the midpoint between A and B), where  $F = 0$ .

17. Let the additional force be  $\vec{F}_3$ . Then  $\sum F_x = F_{x1} + F_{x2} + F_{x3} = ma_x$  and  $\sum F_y = F_{y1} + F_{y2} + F_{y3} = ma_y$ , so
- $$F_{x3} = ma_x - F_{x1} - F_{x2} = (2.5 \text{ kg})(0) - 0.50 \text{ N} - (2.0 \text{ N}) \cos 135^\circ = 0.91 \text{ N}$$
- $$F_{y3} = ma_y - F_{y1} - F_{y2} = (2.5 \text{ kg})(1.5 \text{ m/s}^2) - 0 - (2.0 \text{ N}) \sin 135^\circ = 2.3 \text{ N}.$$
- The additional force is
- $$\vec{F}_3 = \boxed{(0.91\hat{i} + 2.3\hat{j}) \text{ N}}.$$

18. We change the speed units:  $(60 \text{ mi/h})(1.61 \times 10^3 \text{ m/mi})/(3600 \text{ s/h}) = 27 \text{ m/s}$ .

We find the acceleration of the car:  $a_{\text{car}} = \Delta v / \Delta t = (27 \text{ m/s} - 0) / 6.7 \text{ s} = 4.0 \text{ m/s}^2$ .

If we neglect air resistance, this acceleration is produced by the force from the road:

$$\sum F_{\text{car}} = F_{\text{road,car}} = m_{\text{car}} a_{\text{car}} = (720 \text{ kg})(4.0 \text{ m/s}^2) = \boxed{2.9 \times 10^3 \text{ N forward}}.$$

We find the acceleration of the station wagon:  $a_{\text{sw}} = \Delta v / \Delta t = (27 \text{ m/s} - 0) / 9.7 \text{ s} = 2.8 \text{ m/s}^2$ .

$$\text{Thus } F_{\text{road,sw}} = m_{\text{sw}} a_{\text{sw}} = (2400 \text{ kg})(2.8 \text{ m/s}^2) = \boxed{6.7 \times 10^3 \text{ N forward}}.$$

With the same force as on the car, we get

$$a_{\text{sw}} = F_{\text{road,car}} / m_{\text{sw}} = (2.9 \times 10^3 \text{ N}) / 2400 \text{ kg} = \boxed{1.2 \text{ m/s}^2 \text{ forward}}.$$

19. We change the speed units:  $(100 \text{ km/h})(10^3 \text{ m/km}) / (3600 \text{ s/h}) = 27.8 \text{ m/s}$ .

We simplify to two forces: the forward force from the road (assumed constant) and the drag force.

Thus,  $\sum F = F_{\text{road}} - F_{\text{drag}} = ma = m \Delta v / \Delta t$ .

Without streamlining we have

$$F_{\text{road}} - F_{\text{drag1}} = ma_1 = m \Delta v / \Delta t_1 = (1150 \text{ kg})(27.8 \text{ m/s}) / 11 \text{ s} = 2.90 \times 10^3 \text{ N}.$$

With streamlining we have

$$F_{\text{road}} - F_{\text{drag2}} = ma_2 = m \Delta v / \Delta t_2 = (1150 \text{ kg})(27.8 \text{ m/s}) / 9.0 \text{ s} = 3.55 \times 10^3 \text{ N}.$$

If we subtract the two equations, we get  $F_{\text{drag1}} - F_{\text{drag2}} = \boxed{6.5 \times 10^2 \text{ N}}.$

20. The rope can apply a force only away from the body, along the rope.

(a) For the horizontal direction, since the tension is the only force, we have

$$\sum F = T_1 = ma_1 = (25 \text{ kg})(2.4 \text{ m/s}^2) = \boxed{60 \text{ N in the direction of pull}}.$$

$$\sum F = T_2 = ma_2 = (25 \text{ kg})(0.65 \text{ m/s}^2) = \boxed{16 \text{ N in the direction of pull}}.$$

(b) The pulley changes the direction, but not the magnitude of the tension. Then for the cart:

$$\sum F = T_3 = ma_3 = (25 \text{ kg})(1.4 \text{ m/s}^2) = 35 \text{ N, so the force on the pulley is } \boxed{35 \text{ N up}}.$$

For the pulley this upward force is balanced by a downward force at the axle of the pulley.

The horizontal tension is also balanced by a sideways force at the axle of the pulley.



21. We need to look at horizontal forces only.

The tension in the pulled rope must be equal to the force the father exerts:  $T = F$ .

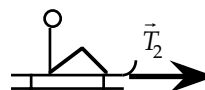
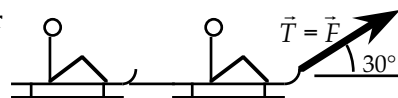
If we take both sleds as the object, we get the force diagram shown. Then for horizontal motion, we have

$$\sum F = T \cos 30^\circ = (m + m)a = 2ma, \text{ so}$$

$$a = T(\cos 30^\circ) / 2m = 0.433T / m.$$

If we take the second sled as the object we get the force diagram shown. Then

$$\sum F = T_2 = ma, \text{ so } T_2 = m(0.433T / m) = \boxed{0.433F}.$$



22. If we assume that the electron starts from rest, the acceleration and resulting motion will be in the direction of the force, so we have a one-dimensional system.

We can find  $a$  from  $\sum F = ma$ :  $5 \times 10^{-14} \text{ N} = (10^{-30} \text{ kg})a$ , which gives  $a = 5 \times 10^{16} \text{ m/s}^2$ .

The speed is found from  $v = v_0 + at = 0 + (5 \times 10^{16} \text{ m/s}^2)t$ :

$$\text{for } t = 10^{-10} \text{ s, } v = \boxed{5 \times 10^6 \text{ m/s}},$$

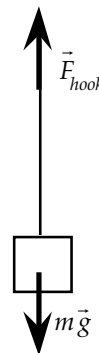
$$\text{for } t = 10^{-9} \text{ s, } v = \boxed{5 \times 10^7 \text{ m/s}}.$$

23. If we take the string and mass as the system, the only forces acting are the downward force of gravity

and the upward force from the hook. Thus

$$\sum \vec{F} = m\vec{a} \text{ becomes } F_{\text{hook}} - mg = 0 \text{ or}$$

$$F_{\text{hook}} = mg = (8 \text{ kg})(9.8 \text{ m/s}^2) = \boxed{78 \text{ N}}.$$



24. If we take the truck and trailer as the system, the road provides the accelerating force.

For the horizontal motion we have

$$F_{\text{road}} = ma = (3000 \text{ kg} + 1200 \text{ kg})(1.2 \text{ m/s}^2) = 5.0 \times 10^3 \text{ N forward}.$$

The reaction to this is the force the truck and trailer exert on the road:  $\boxed{5.0 \times 10^3 \text{ N backward}}.$

25. The force the automobile exerts on Earth is the reaction to the force of gravity on the automobile, so the two forces must have the same magnitude:

$$F_{\text{auto}} = F_{\text{earth}};$$

$$m_{\text{auto}}a_{\text{auto}} = m_{\text{earth}}a_{\text{earth}};$$

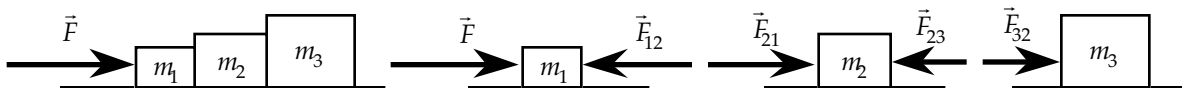
$$(950 \text{ kg})(9.8 \text{ m/s}^2) = (6.0 \times 10^{24} \text{ kg})a_{\text{earth}}, \text{ which gives } a_{\text{earth}} = \boxed{1.6 \times 10^{-21} \text{ m/s}^2}.$$

26. The force exerted by the satellite on the astronaut is the reaction to the force of the astronaut on the satellite:

$$\vec{F}_{\text{astronaut}} = -\vec{F}_{\text{satellite}} = (-6.5\hat{i} - 3.7\hat{j} - 4.7\hat{k}) \text{ N, with magnitude } \boxed{8.8 \text{ N}}.$$

27. (a) The space shuttle attracts Earth;  
(b) the skater exerts forces on the ice and Earth;  
(c) none.

28. In the diagrams for the set and each of the blocks below, only the horizontal forces are shown (as vertical normal forces balance the gravity forces).



- (a) For the set we have  $\sum F_x = ma_x$ :  $8.0 \text{ N} = (2.0 \text{ kg} + 3.0 \text{ kg} + 4.0 \text{ kg}) a$ , which gives  $a = 0.89 \text{ m/s}^2$ .  
 (b) For block 1 we have  $\sum F_x = ma_x$ :  $F - F_{21} = m_1 a$ ;  
 $8.0 \text{ N} - F_{12} = (2.0 \text{ kg})(0.89 \text{ m/s}^2)$ , which gives  $F_{12} = 6.2 \text{ N}$  to the left.  
 The forces are  $F = 8.0 \text{ N}$  to the right,  $F_{12} = 6.2 \text{ N}$  to the left, and  $F_{\text{net}1} = 1.8 \text{ N}$  to the right.  
 (c) For block 2 we have  $\sum F_x = ma_x$ :  $F_{21} - F_{23} = m_2 a$  and  $F_{21} = F_{12}$  (Newton's third law):  
 $6.2 \text{ N} - F_{23} = (3.0 \text{ kg})(0.89 \text{ m/s}^2)$ , which gives  $F_{23} = 3.5 \text{ N}$  to the left.  
 The forces are  $F_{21} = 6.2 \text{ N}$  to the right,  $F_{23} = 3.5 \text{ N}$  to the left, and  $F_{\text{net}2} = 2.7 \text{ N}$  to the right.  
 (d) For block 3 we have  $\sum F_x = ma_x$ :  $F_{32} = m_3 a$ :  
 $F_{32} = (4.0 \text{ kg})(0.89 \text{ m/s}^2)$ , which gives  $F_{32} = 3.6 \text{ N}$  to the right ( $= F_{23}$ , Newton's third law).  
 The forces are  $F_{32} = 3.6 \text{ N}$  to the right, and  $F_{\text{net}3} = 3.6 \text{ N}$  to the right.

29. (a) Each block satisfies  $F = ma$ . Since they are connected by the same spring they are subject to the same magnitude of force. So the block with twice the acceleration must have half of the mass of the other block.  
 (b)  $v = at$ . Since one block has twice as much  $a$  before it the spring is cut, the magnitude of its velocity must also be twice that of the other one at the time the spring is cut.
30. (a) The force acting on the table is the combined weight of the three identical blocks, so the weight of each block must be  $\frac{1}{3}(3 \text{ N}) = 1 \text{ N}$ . The forces exerted on block 3 are: 3N of supporting force from the table, up; 1N of its own weight, down; and 2N of normal force from the other two blocks, down. The net force on block 3 is zero.  
 (b) The forces exerted on block 2 are: 2N of supporting force from block 3, up; 1N of its own weight, down; and 1N of normal force from the block 1, down. The net force on block 2 is zero.  
 (c) The forces exerted on block 1 are: 1N of supporting force from block 2, up; 1N of its own weight, down. The net force on block 1 is zero.

31. (a) If we look at the five cars, the only horizontal force is the force between the engine and the first car.

We have

$$\sum F_x = F = m_{\text{cars}} a_x;$$

$$1.5 \times 10^4 \text{ N} = 5(2.1 \times 10^4 \text{ kg})a, \text{ which gives}$$

$$a = \boxed{0.14 \text{ m/s}^2}.$$

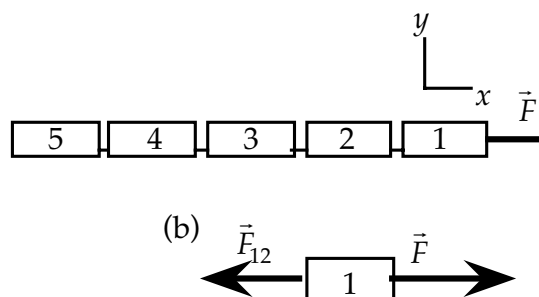
This is the acceleration of the engine and each of the cars.

- (c) If we look at the first car, the horizontal forces are the couplings shown in the diagram.

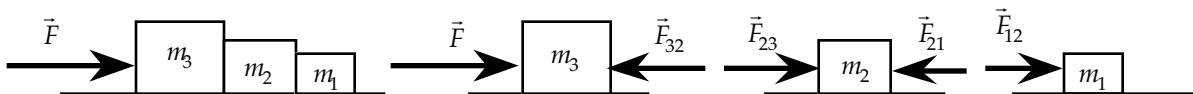
We have  $\sum F_x = ma_x$ , or  $F - F_{12} = m_1 a$ :

$$(1.5 \times 10^4 \text{ N}) - F_{12} = (2.1 \times 10^4 \text{ kg})(0.14 \text{ m/s}^2), \text{ which gives}$$

$$F_{12} = \boxed{1.2 \times 10^4 \text{ N}}, \text{ backward.}$$



32. Since we need only the horizontal forces (vertical normal forces balance the gravity forces), diagrams for the set and each of the blocks are shown.



- (a) For the set we have  $\Sigma F_x = ma_x$ :  $8.0 \text{ N} = (2.0 \text{ kg} + 3.0 \text{ kg} + 4.0 \text{ kg})a$ , which gives  $a = 0.89 \text{ m/s}^2$ .
- (b) For block 1 we have  $\Sigma F_x = ma_x$ :  $F_{12} = m_1 a$ :  
 $F_{12} = (2.0 \text{ kg})(0.89 \text{ m/s}^2)$ , which gives  $F_{12} = 1.8 \text{ N}$  to the right.  
 The forces are  $F_{12} = 1.8 \text{ N}$  to the right, and  $F_{\text{net}1} = 1.8 \text{ N}$  to the right.
- (c) For block 2 we have  $\Sigma F_x = ma_x$ :  $F_{23} - F_{21} = m_2 a$  and  $F_{21} = F_{12}$  (Newton's third law):  
 $F_{23} - 1.8 \text{ N} = (3.0 \text{ kg})(0.89 \text{ m/s}^2)$ , which gives  $F_{23} = 4.5 \text{ N}$  to the right.  
 The forces are  $F_{23} = 4.5 \text{ N}$  to the right,  $F_{21} = 1.8 \text{ N}$  to the left, and  $F_{\text{net}2} = 2.7 \text{ N}$  to the right.
- (d) For block 3 we have  $\Sigma F_x = ma_x$ :  $F - F_{32} = m_3 a$ ;  
 $8.0 \text{ N} - F_{32} = (4.0 \text{ kg})(0.89 \text{ m/s}^2)$ , which gives  $F_{32} = 4.5 \text{ N}$  to the left ( $= F_{23}$ , Newton's third law).  
 The forces are  $F = 8.0 \text{ N}$  to the right,  $F_{32} = 4.5 \text{ N}$  to the left, and  $F_{\text{net}3} = 3.6 \text{ N}$  to the right.
- Note that the acceleration and the net forces are the same as in Problem 28.

33. From Newton's third law, the force that charge 2 exerts on charge 1 is equal and opposite to the force that charge 1 exerts on charge 2:  $\vec{F}_{12} = -\vec{F}_{21}$ . Similarly,  $\vec{F}_{13} = -\vec{F}_{31}$ .

Thus  $\vec{F}_{\text{net}1} = \vec{F}_{12} + \vec{F}_{13} = -\vec{F}_{21} - \vec{F}_{31}$   
 $= (-2\hat{i} + 3\hat{j} - \hat{k}) \text{ N} + (+3\hat{i} - 2\hat{j} + 3\hat{k}) \text{ N}$   
 $= (\hat{i} + \hat{j} + 2\hat{k}) \text{ N}.$

34. If the observer does not realize he is in free fall, he will say that the stationary object must have no net force acting on it. Therefore, there must be an upward force opposing the force of gravity.

35. Professor B will be able to tell that he is accelerating because he will feel the force exerted by the seat back. (At very small accelerations, this may not be evident.) If Professor B simply looks at the change in position of Professor A, he would think that Professor A is accelerating. This apparent acceleration would be  $0.70 \text{ m/s}^2$  in the  $-x$ -direction. This is not a real acceleration, because there is no horizontal force on Professor A.

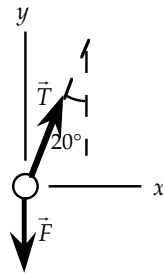
36. The observer will say that there is an outward force away from the center away from the center. Because the observer does not know of another agent, effectively "gravity" is not vertical.

37. (a) While the jet is parked the only force is gravity down, and the chain is parallel to the window edge.  
 (b) While the jet is accelerating there appears to be a force toward the back of the plane, and the chain is angled toward the back of the plane at an angle given by  $\tan \theta = a'/g$ .  
 (c) While the jet is cruising the only force is gravity down and the chain is parallel to the window edge.

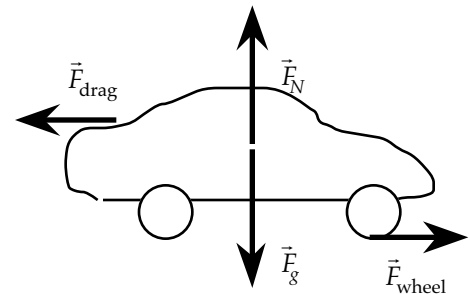
38. From the inertial frame of Earth, for the mass we can write  
 $\sum F_y = ma_y$ :  $T \cos 20^\circ - F = 0$ ;  $T \cos 20^\circ = 6.0 \text{ N}$ , which gives  
 $T = 6.4 \text{ N}$ ; and  
 $\sum F_x = ma_x$ :  $T \sin 20^\circ = ma$ ;  $(6.4 \text{ N}) \sin 20^\circ = (2 \text{ kg})a$ , which gives  
 $a = \boxed{1.1 \text{ m/s}^2}$ .

The observer in the noninertial frame of the truck will say that there are three forces:

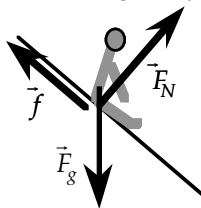
$F = 6.0 \text{ N}$  in  $-y$ -direction,  
 $T$  in the string  $= 6.4 \text{ N}$  at  $20^\circ$  from  $+y$ , and  
 a fictitious force of  $(2 \text{ kg})(1.1 \text{ m/s}^2) = 2.2 \text{ N}$  toward the back of the truck.



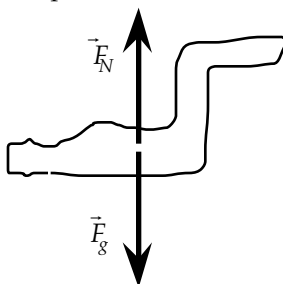
39. We simplify the normal forces from the ground as a single force.



40. The forces are gravity, the normal force from the slide, and a force from the slide opposing the motion.



41. The seat provides a forward normal force.

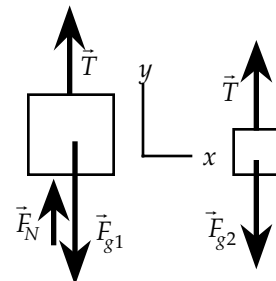


42. The coordinate system and the forces on each mass are shown.  
 Since the system is at rest,  $a = 0$  and we can write:

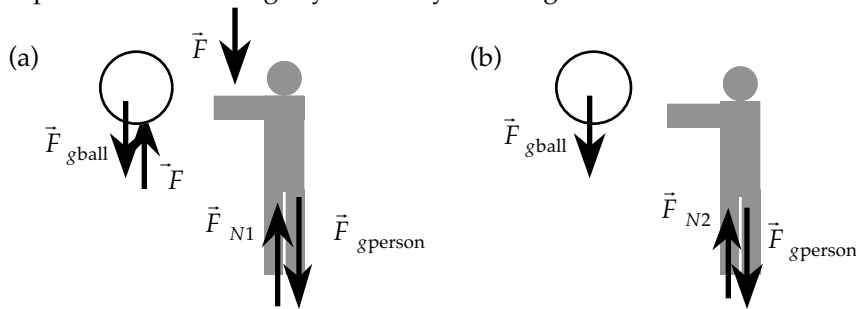
$$\sum F_y = ma_y;$$

$$T + F_N - F_{g1} = 0 \text{ for block } M \text{ and}$$

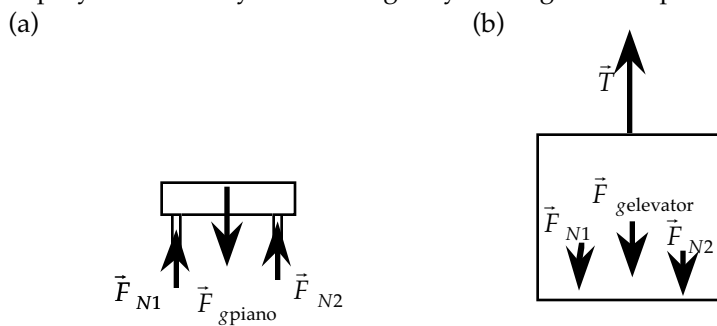
$$T - F_{g2} = 0 \text{ for block } m.$$



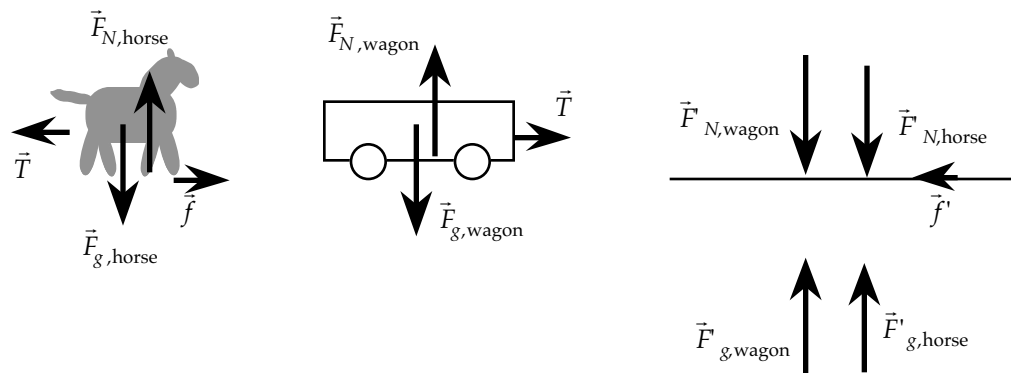
43. We displace the forces slightly to clarify the diagram.



44. We simplify the forces by considering only two legs for the piano.



45. (a) (b) (c)



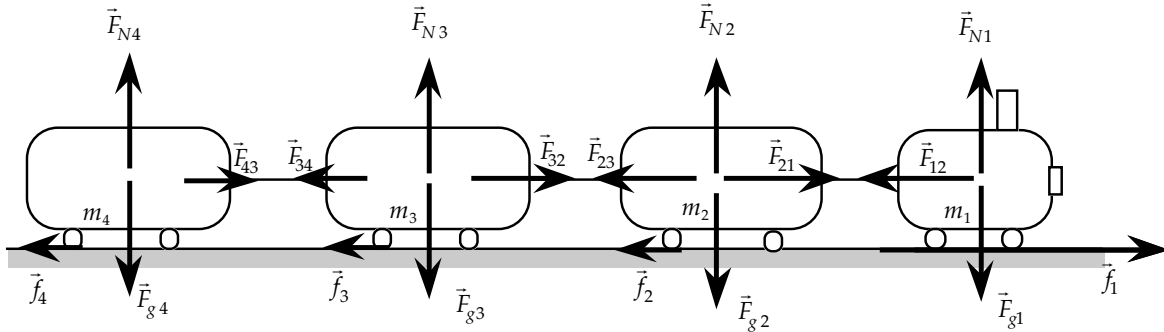
(d) It is the net force that determines the acceleration. In addition to the backward force from the wagon, there is a forward force from Earth on the horse's hooves.

46. (a) A massive rope can never be perfectly horizontal, since there has to be a vertical component of its tension to balance its weight. But in our case the rope is massless, so it can be perfectly horizontal.
- (b) No. The weight of the hanging mass must be balanced by the vertical component of the tension in the rope.
- (c) The answer to (a) was yes.

47. The free-body diagram is shown below. The engine is labeled as 1. Here

$\vec{F}_{12}, \vec{F}_{21}, \vec{F}_{23}, \vec{F}_{32}, \vec{F}_{34},$  and  $\vec{F}_{43}$  are internal forces, all other forces are external. Note that for the entire system

$$\sum F_x = f_1 - f_2 - f_3 - f_4 = (m_1 + m_2 + m_3 + m_4) a.$$



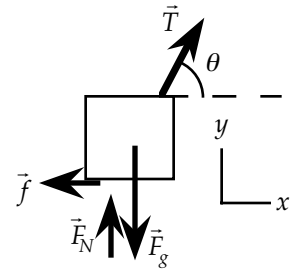
48. The coordinate system and the forces on the block are shown. Since the system is at rest,  $a = 0$  and we can write:

$$\sum F_x = ma_x$$

$$T \cos \theta - f = 0, \text{ which gives } f = \boxed{T \cos \theta}.$$

$$\sum F_y = ma_y$$

$$T \sin \theta + F_N - Mg = 0, \text{ which gives } F_N = \boxed{Mg - T \sin \theta}.$$



49. As shown, the coordinate system has the  $x$ -direction down the plane.

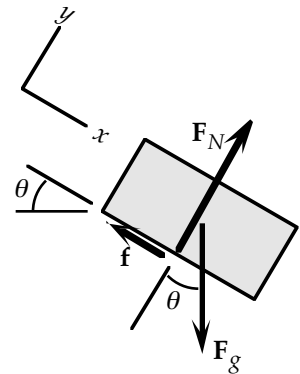
In the  $x$ -direction

$$\sum F_x = F_g \sin 21^\circ - f = ma,$$

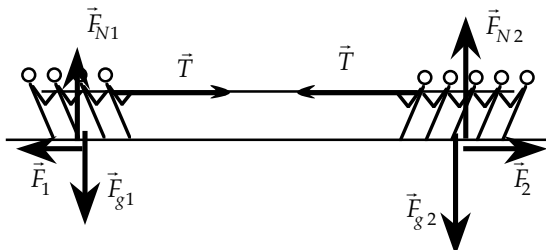
and in the  $y$ -direction

$$\sum F_y = F_N - F_g \cos 21^\circ = 0.$$

Also, note that  $F_g = mg$ ,  $f = \mu F_N$  and  $\vec{f} = -f\hat{i}$ .

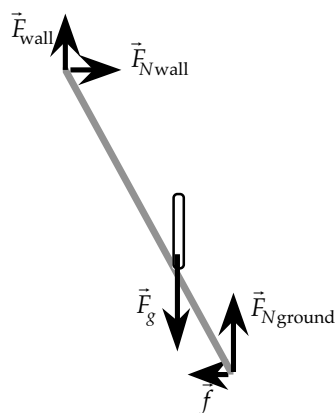


- 50.



Note that even though the sides are unbalanced, the tension in the (massless) rope is the same.

51.



If the ground is smooth, the horizontal force  $f$  at the ground is very small. The ladder might slip because there is a net horizontal force from the wall.

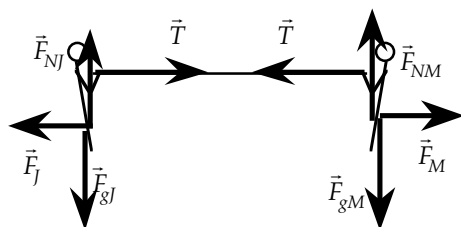
52. (a) Newton's third law requires that  
Force of Joe on Moe = tension =  $-$  Force of Moe on Joe.

- (b) From  $a = \Sigma F/m$ , with the tension in the rope the only force;

$$a_M = T/m_M \quad \text{and} \quad a_J = T/m_J.$$

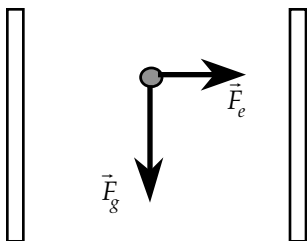
Since  $m_M > m_J$ , we must have  $a_M < a_J$  and consequently  $x_M < x_J$ ; Moe wins.

- (c)

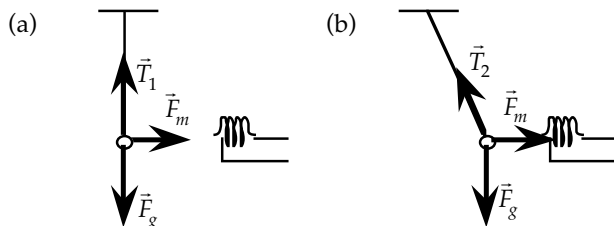


- (d) Joe can exert a larger horizontal force on Earth, and thus, Earth exerts a larger horizontal force on him. His net force will be smaller than the net force on Moe, and thus his acceleration and displacement will be less.

53.



54.



55. (a)  $F_g = \boxed{mg \text{ down}}$  and  $F_N = F_g = \boxed{mg \text{ up}}$ .  
 (b) We choose up as the positive direction. From  $\sum \vec{F} = m\vec{a}$  we can write  
 $F_N - F_g = mg$ , which gives  $F_N = F_g + mg = 2mg$ .  
 The forces are  $\boxed{mg \text{ down}}$  and  $\boxed{2mg \text{ up}}$ .  
 (c) Since the acceleration is now  $g$  down,  $F_N = 0$  and the only force is  $\boxed{mg \text{ down}}$ .

56. (a)  $\vec{F}_1 = (0.071, 0, 0) \text{ N}$ ,  $\vec{F}_2 = (0, 0.081, 0) \text{ N}$

(b)  $\vec{r}_0 = \boxed{(0, 0, 0)}$ ,  $\vec{v}_0 = \boxed{(0, 0, 0)}$ .

The acceleration is found from  $\vec{a} = \sum \vec{F} / m$ . In component form, this becomes

$$a_x = F_1 / m = 0.071 \text{ N} / 0.043 \text{ kg} = 1.7 \text{ m/s}^2 \text{ and}$$

$$a_y = F_2 / m = 0.081 \text{ N} / 0.043 \text{ kg} = 1.9 \text{ m/s}^2.$$

Since the acceleration is constant, we can write

$$\vec{r} = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2} \vec{a} t^2 = (1.7t^2/2, 1.9t^2/2, 0) \text{ and}$$

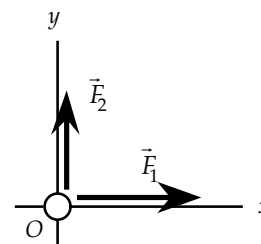
$$\vec{v} = \vec{v}_0 + \vec{a} t = (1.7t, 1.9t, 0).$$

(c) At  $t = 1.200 \text{ s}$  we get

$$\vec{r}_{1.200 \text{ s}} = \boxed{(1.2, 1.4, 0) \text{ m}}, \quad \vec{v}_{1.200 \text{ s}} = \boxed{(2.0, 2.3, 0) \text{ m/s}}.$$

(d) At  $t = 3.600 \text{ s}$  we get

$$\vec{r}_{3.600 \text{ s}} = \boxed{(11, 13, 0) \text{ m}}, \quad \vec{v}_{3.600 \text{ s}} = \boxed{(6.0, 6.9, 0) \text{ m/s}}.$$



57. We can find the components of the acceleration from  $a_x = F_1 / M$  and  $a_y = F_2 / M$ .

Since  $F_1$  and  $F_2$  are constant,  $a_x$  and  $a_y$  are constant, thus  $\vec{a}$  is constant.

The magnitude of  $\vec{a}$  is  $a = (a_x^2 + a_y^2)^{1/2} = \boxed{(1/M)(F_1^2 + F_2^2)^{1/2}}$ .

The direction of  $\vec{a}$  from the  $x$ -axis is found from

$$\tan \theta = a_y / a_x = F_2 / F_1, \quad \text{or} \quad \theta = \boxed{\tan^{-1}(F_2 / F_1)}.$$

58. We are given  $\vec{F}_1 = (1.715, 0, 0) \text{ N}$ ,  $\vec{F}_2 = (0, 1.128, 0) \text{ N}$ , and  $\vec{F}_3 = (F_{3x}, F_{3y}, 0)$ .

(a) If the body does not accelerate, we can write  $\sum \vec{F} = m\vec{a} = 0$ :

For the components we get

$$x: 1.715 \text{ N} + F_{3x} = 0, \text{ which gives } F_{3x} = \boxed{-1.715 \text{ N}};$$

$$y: 1.128 \text{ N} + F_{3y} = 0, \text{ which gives } F_{3y} = \boxed{-1.128 \text{ N}};$$

$$z: 0 = 0.$$

(b) Because the forces are constant, the acceleration will be constant and we can write

$$\vec{r} = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2} \vec{a} t^2, \text{ or}$$

$$(1.000, 1.000, 0) \text{ m} = (0, 0, 0) + (0, 0, 0) + \frac{1}{2} \vec{a} (5.000 \text{ s})^2, \text{ which gives } \vec{a} = (0.08000, 0.08000, 0) \text{ m/s}^2.$$

For  $\sum F_x = ma_x$ , we can write

$$F_1 + F_{3x} = ma_x, \text{ which gives } F_{3x} = (25.43 \text{ kg})(0.08000 \text{ m/s}^2) - 1.715 \text{ N} = \boxed{0.3194 \text{ N}}.$$

For  $\sum F_y = ma_y$ , we can write

$$F_2 + F_{3y} = ma_y, \text{ which gives } F_{3y} = (25.43 \text{ kg})(0.08000 \text{ m/s}^2) - 1.128 \text{ N} = \boxed{0.9064 \text{ N}}.$$

59. We can find the acceleration of the object by differentiating the displacement:

$$v = dx/dt = d(At^{3/4})/dt = \frac{3}{4}At^{-1/4};$$

$$a = dv/dt = d[\frac{3}{4}At^{-1/4}]/dt = (-3/16)At^{-5/4}.$$

We find the net force from

$$F_{\text{net}} = ma = m[(-3/16)At^{-5/4}] = (2.0)[(-3/16)(0.03)t^{-5/4}] = \boxed{(-1.1 \times 10^{-2} t^{-5/4}) \text{ N}}, \text{ where } t \text{ is in seconds.}$$



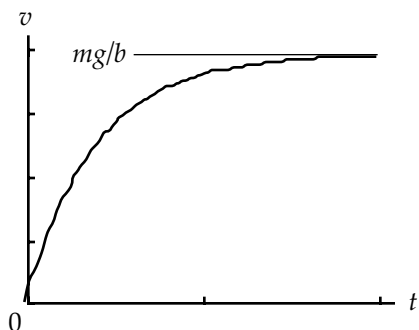
60. (a) To show that  $v(t) = mg(1 - e^{-bt/m})/b$  is a solution we must differentiate;

$$dv/dt = (mg/b)(-b/m)(-e^{-bt/m}) = g e^{-bt/m}.$$

Since we can rewrite the the solution as  $e^{-bt/m} = 1 - bv/mg$ , the differentiation becomes

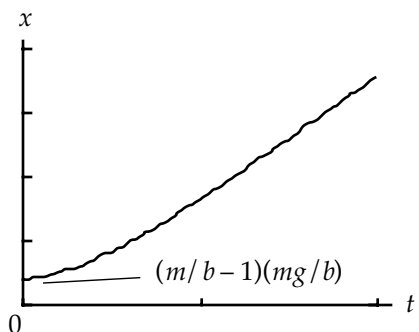
$$dv/dt = g(1 - bv/mg), \text{ or } m(dv/dt) = mg - bv, \text{ which is the given equation of motion.}$$

(b)



- (c) To obtain  $x(t)$ , we integrate:

$$\begin{aligned} x(t) &= \int v \, dt = (mg/b) \left( \int dt - \int e^{-bt/m} dt \right) \\ &= (mg/b) \left[ t + (m/b)(e^{-bt/m} - 1) \right] \\ &= (mg/b) \left[ t + m(e^{-bt/m} - 1)/b \right]. \end{aligned}$$



61. (a) Since the equation of motion is  $-kx = ma$ , we differentiate the proposed solution:

$$x = A \cos(ct) + B \sin(ct),$$

$$v = dx/dt = -Ac \sin(ct) + Bc \cos(ct),$$

$$a = d^2x/dt^2 = dv/dt = -Ac^2 \cos(ct) - Bc^2 \sin(ct) = -c^2x.$$

Since  $a = (-k/m)x$ , this will be a solution if  $c = \sqrt{k/m}$ .

- (b) If we put the initial conditions into the expressions for  $x$  and  $v$ , we get

$$0 = A(1) + B(0), \text{ which gives } A = 0, \text{ and}$$

$$v_0 = -Ac(0) + Bc(1), \text{ which gives } B = +v_0/c = +v_0\sqrt{m/k}.$$

62. The force  $F$  that Earth exerts on the sun is the reaction to the force that the sun exerts on Earth:

$$F = 3.5 \times 10^{22} \text{ N toward Earth.}$$

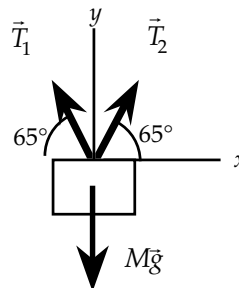
63. (b) From the force diagram we can write

$$\begin{aligned} \sum F_x &= T_2 \cos 65^\circ - T_1 \cos 65^\circ \\ &= (333 \text{ N}) \cos 65^\circ - (333 \text{ N}) \cos 65^\circ = 0, \text{ and} \end{aligned}$$

$$\begin{aligned} \sum F_y &= T_1 \sin 65^\circ + T_2 \sin 65^\circ - mg \\ &= (333 \text{ N}) \sin 65^\circ + (333 \text{ N}) \sin 65^\circ - (53.2 \text{ kg})(9.80 \text{ m/s}^2) \\ &= 82.2 \text{ N up.} \end{aligned}$$

- (c) We find the acceleration from

$$\vec{a} = \vec{F}_{\text{net}}/m = (82.2 \text{ N up})/(53.2 \text{ kg}) = 1.55 \text{ m/s}^2 \text{ up.}$$



64. From the force diagram for the pulley and object we can write

$$\sum F_x = T_2 \cos 35^\circ - T_1 \cos 35^\circ = 0, \text{ which gives } T_1 = T_2.$$

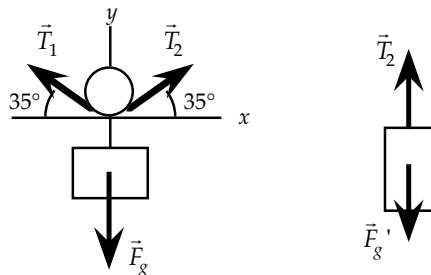
$$\sum F_y = T_1 \sin 35^\circ + T_2 \sin 35^\circ - F_g = 2T_2 \sin 35^\circ - (20 \text{ N}), \text{ which gives}$$

$$T_2 = 17.4 \text{ N}.$$

From the force diagram for the other object we can write

$$\sum F_y = T_2 - F_g' = 0, \text{ which gives}$$

$$F_g' = T_2 = \boxed{17.4 \text{ N}}.$$



65. The board exerts a normal force up on the washer. Since the speed is constant, from the force diagram for the washer we can write

$$\sum F_y = ma_y = 0;$$

$$T_1 + T_2 + F_N - m_W g = 0.$$

The washer exerts a normal force down on the board. Since the speed is constant, from the force diagram for the board we can write

$$\sum F_y = ma_y = 0;$$

$$T_1 + T_2 - F_N - m_B g = 0.$$

If we assume that  $T_1 = T_2 = T$ , when  $F_N$  is eliminated, we find that

$$T = \frac{1}{4} (m_W g + m_B g).$$

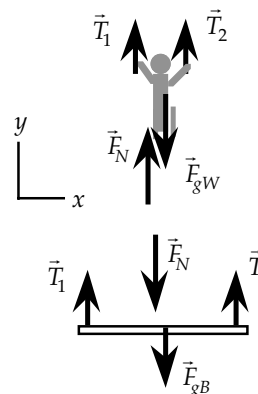
If there is an upward acceleration, the equations become

$$\text{washer: } T_1 + T_2 + F_N - m_W g = m_W a;$$

$$\text{board: } T_1 + T_2 - F_N - m_B g = m_B a.$$

Again, if we assume that  $T_1 = T_2 = T$ , we find that

$$a = \boxed{[4T - (m_W g + m_B g)] / (m_W + m_B)}.$$



66. During the drop, the only force is  $F_g$  (down); during the bounce, the forces are  $F_g$  (down) and  $F_N$  (up) from the slab; during the rise, the only force is  $F_g$  (down).

If we assume a mass of 20 g,

$$F_g = (0.020 \text{ kg})(10 \text{ m/s}^2) = \boxed{0.20 \text{ N down}}.$$

If the ball falls  $h = 1.0 \text{ m}$ , the speed just before it hits is

$$v_1 = (2gh)^{1/2} = [2(10 \text{ m/s}^2)(1.0 \text{ m})]^{1/2} = 4.5 \text{ m/s}.$$

The speed just after it hits is

$$v_2 = [2g(0.80)h]^{1/2} = (0.80)^{1/2} v_1 = 4.0 \text{ m/s}.$$

If we assume the bounce occurs in 0.10 s, we can write

$$F_N - F_g = m \Delta v / \Delta t, \text{ which gives}$$

$$F_N = (0.020 \text{ kg})[4.0 \text{ m/s} - (-4.5 \text{ m/s}) / (0.10 \text{ s})] + 0.20 \text{ N} = \boxed{1.9 \text{ N up}}.$$

67. (a) To accelerate forward, the engine must produce a force which pushes **backwards** on Earth. The reaction to this force on the engine will be  **$3 \times 10^4 \text{ N}$**  (forward).  
 (b) If we look at the entire train, the only horizontal force is the force on the engine.

We have  $\sum F_x = ma_x$ , or  $F = m_{\text{train}}a$ :

$$3 \times 10^4 \text{ N} = (1.7 \times 10^5 \text{ kg})a, \text{ which gives}$$

$$a = \mathbf{0.18 \text{ m/s}^2}.$$

This is the acceleration of the engine and each of the cars.

If we look at the three cars, the only horizontal force is  $F_1$ :

$$F_1 = (m_1 + m_1 + m_1)a = 3(3.0 \times 10^4 \text{ kg})(0.18 \text{ m/s}^2)$$

$$= \mathbf{1.6 \times 10^4 \text{ N forward}}.$$

- (c) If we look at the first car, the horizontal forces are the couplings shown in the diagram. We have

$$\sum F_x = ma_x, \text{ or } F_1 - F_2 = m_1a:$$

$$1.6 \times 10^4 \text{ N} - F_2 = (3.0 \times 10^4 \text{ kg})(0.18 \text{ m/s}^2), \text{ which gives}$$

$$F_2 = 1.1 \times 10^4 \text{ N backward}.$$

If we look at the second car, the horizontal forces are the couplings shown in the diagram.

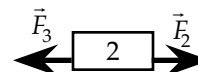
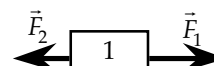
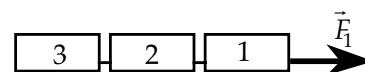
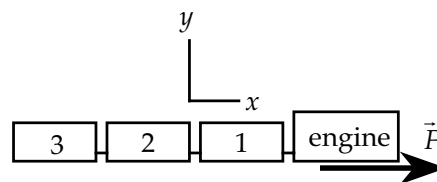
We have  $\sum F_x = ma_x$ , or  $F_2 - F_3 = m_2a$ :

$$1.1 \times 10^4 \text{ N} - F_3 = (3.0 \times 10^4 \text{ kg})(0.18 \text{ m/s}^2), \text{ so}$$

$$F_3 = 5.2 \times 10^3 \text{ N backward}.$$

The forces on the second car are therefore

$$F_2 = \mathbf{1.1 \times 10^4 \text{ N forward}} \text{ and } F_3 = \mathbf{5.2 \times 10^3 \text{ N backward}}; \text{ its acceleration is } \mathbf{0.18 \text{ m/s}^2}.$$



68.

(a)

- (b) We choose the direction of motion as the  $x$ -axis.

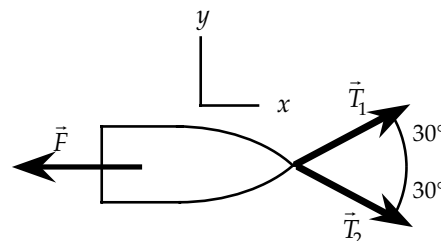
For the  $y$ -direction, we can write  $\sum F_y = ma_y$ :

$$T_1 \sin 30^\circ - T_2 \sin 30^\circ = T \sin 30^\circ - T \sin 30^\circ = 0$$

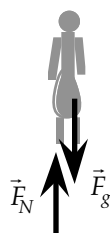
For the  $x$ -direction, we can write  $\sum F_x = ma_x$ :

$$T_1 \cos 30^\circ - T_2 \cos 30^\circ - F_D = 0;$$

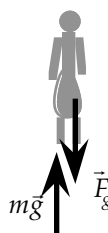
$$F_D = 2(2000 \text{ N}) \cos 30^\circ = \mathbf{3.5 \times 10^3 \text{ N}}.$$



69. (a) The same forces will be acting, since  $a = 0$ .



(b)



- (b) Because the passenger sees no motion with respect to the elevator, she would draw the same forces as in part (a), but the upward force would be a fictitious force  $= mg$ .

70. (a) The forces are the force of gravity and a force due to air resistance.

(b) We do a dimensional analysis of  $\vec{F}_{\text{air}} = -A\vec{v}$ :

$$[F_{\text{air}}] = [A][v],$$

$$[MLT^{-2}] = [A][LT^{-1}], \text{ which gives } [A] = [MT^{-1}].$$

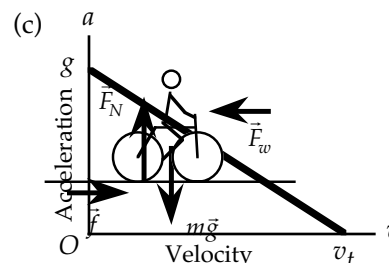
(c) If we take down as positive, we have  $\Sigma F = Ma$ :

$$Mg - Av = Ma, \text{ which gives } a = g - (Av/M).$$

When  $v = Mg/A$ ,  $a = 0$ , after which  $v$  will not change.

(d) From the analysis of part (c):

$$A = Mg/v_t = (1000 \text{ N})/(6.0 \text{ m/s}) = \boxed{1.7 \times 10^2 \text{ kg/s}}.$$



71. We take up as positive, so  $\vec{F}_g = -mg\hat{j}$ ,  $\vec{F}_d = Av^2\hat{j}$ , and  $\vec{v} = -v\hat{j}$ .

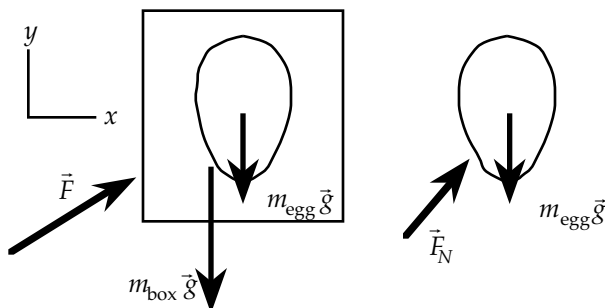
(a) We do a dimensional analysis of  $F_d = Av^2$ :

$$[F_d] = [A][v^2], [MLT^{-2}] = [A][LT^{-1}]^2, \text{ which gives } [A] = [ML^{-1}] \text{ with units of } \text{kg/m}.$$

(b)  $dv/dt = \Sigma F/m = (Av^2 - mg)/m = \boxed{Av^2/m - g}$ .

(c) At constant velocity:  $dv/dt = 0$ ;  $(A/m)v_t^2 - g = 0$ , which gives  $v_t = \boxed{\sqrt{mg/A}}$ .

72. (a)



(b) For the egg + box system we can write  $\Sigma \vec{F} = m\vec{a}$ :

$$\vec{F} - (m_{\text{egg}} + m_{\text{box}})g\hat{j} = (m_{\text{egg}} + m_{\text{box}})\vec{a};$$

For the egg we can write  $\Sigma \vec{F} = m\vec{a}$ :

$$\vec{F}_N - m_{\text{egg}}g\hat{j} = m_{\text{egg}}\vec{a}.$$

(c) From the equation for the egg + box we get

$$(1.2\hat{i} - 0.08\hat{j}) \text{ N} - (0.080 \text{ kg} + 0.200 \text{ kg})(9.8 \text{ m/s}^2)\hat{j} = (0.080 \text{ kg} + 0.200 \text{ kg})\vec{a}, \text{ which gives}$$

$$\vec{a} = \boxed{(4.3\hat{i} - 10\hat{j}) \text{ m/s}^2}.$$

The net force on the egg can be found from  $\Sigma \vec{F} = m\vec{a}$ :

$$\vec{F}_{\text{egg(net)}} = m_{\text{egg}}\vec{a} = (0.080 \text{ kg})[(4.3 \text{ m/s}^2)\hat{i} - (10 \text{ m/s}^2)\hat{j}] = \boxed{(0.34\hat{i} - 0.80\hat{j}) \text{ N}}.$$

73. (a) The forces are

force of gravity:  $mg$  (down),

normal force of ground:  $F_N$  (up),

friction force of ground:  $f$  (forward),

wind resistance:  $F_w$  (backward).

(b) Since the speed is constant:  $\Sigma \vec{F} = \vec{0}$ .

(c) In the bicycle's frame, the speed of the cyclist is

$$v_{cc} = 0; \text{ the speed of the wind is } v_{wc} = \boxed{v_w + v}; \Sigma \vec{F} = \vec{0}.$$

(d) In the frame of the air, the speed of the cyclist is  $v_{cw} = \boxed{v + v_w}$ , that of the wind is  $v_{ww} = \vec{0}$ ,  $\Sigma \vec{F} = \vec{0}$ .

74. Since the initial speed is  $2 \times 10^6$  m/s, the time the electron spends between the plates will be short and we will neglect the vertical acceleration –  $g$  and assume that the vertical motion has constant velocity.

From  $\sum \vec{F} = m\vec{a}$ , we get

$$\sum F_y = ma_y; \sum F_x = ma_x: \quad 0 = a_y; \quad F = ma_x.$$

- (a) For the vertical motion:  $y = v_y t$ ;  $1 \times 10^{-2}$  m =  $(2.0 \times 10^6$  m/s) $t$ , which gives

$$t = \boxed{5 \times 10^{-9} \text{ s}}.$$

- (b) We can find the horizontal acceleration from  $\sum F_x = ma_x$ :

$$a_x = (3.0 \times 10^{-18} \text{ N}) / (9.0 \times 10^{-31} \text{ kg}) = 3.3 \times 10^{12} \text{ m/s}^2.$$

Since the acceleration is constant, the velocity is found from

$$v_x = v_{0x} + a_x t = 0 + (3.3 \times 10^{12} \text{ m/s}^2)(5.0 \times 10^{-9} \text{ s}) = \boxed{1.7 \times 10^4 \text{ m/s}}.$$

75. (a)  $F = ma$ . When  $F$  is doubled so is  $a$ , to  $\boxed{0.4 \text{ m/s}^2}$  for the soda

can and  $\boxed{0.2 \text{ m/s}^2}$  for the box.

- (b) Let the mass of the soda can be  $m$ . Then since the same force produces half of the acceleration on the box the mass of the box must be  $2m$ . The total mass of the box plus the can is then  $3m$ . The same force exerted on this mass will result in  $1/3$  of the acceleration of the soda can (of mass  $m$ ). Thus the acceleration of the box with the can in it is

$$\frac{1}{3}(0.2 \text{ m/s}^2) = \boxed{0.07 \text{ m/s}^2} \text{ for the low setting and}$$

$$\frac{1}{3}(0.4 \text{ m/s}^2) = \boxed{0.1 \text{ m/s}^2} \text{ for the high setting.}$$

- (c) The box has twice the mass of the soda can, or

$$2(4.3 \text{ g}) = \boxed{8.6 \text{ g}}.$$

76. (a) The fictitious force away from the axis is

$$mr\omega^2 = mr(2\pi f)^2 = mr4\pi^2 f^2$$

At the equator, the net force is

$$mg_{\text{eq}} = mg_0 - mR4\pi^2 f^2; \text{ thus}$$

$$\boxed{g_0 - g_{\text{eq}} = 4\pi^2 f^2 R}.$$

- (b)  $9.80 \text{ m/s}^2 - g_{\text{eq}} = 4\pi^2 [1 / (24 \text{ h})(3600 \text{ s/h})]^2 (6.38 \times 10^6 \text{ m}),$

$$g_{\text{eq}} = 9.80 \text{ m/s}^2 - 0.03 \text{ m/s}^2 = \boxed{9.77 \text{ m/s}^2}.$$

- (c) At a latitude angle  $\phi$ , the radius of the circular motion is  $r = R \cos \phi$  and the fictitious force is

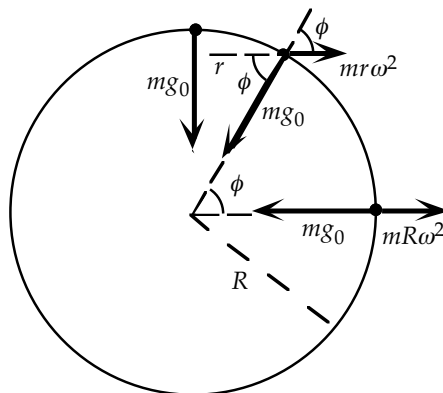
$$m4\pi^2 f^2 R \cos \phi.$$

Since this force is much less than  $mg_0$ , we can

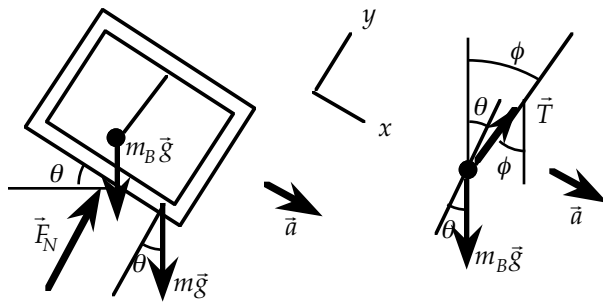
approximate its effect by using the radial component:

$$g = g_0 - 4\pi^2 f^2 R \cos^2 \phi = \boxed{g_0 - 0.034 \cos^2 \phi}.$$

- (d) Some effects are that Earth is not a perfect sphere and  $R$  varies because of an elevation above sea level.



77.



From the force diagram for the system of the frame and plumb bob, we can write

$$\Sigma F_x = ma_x:$$

$$(m_B + m)g \sin \theta = (m_B + m)a; \text{ and}$$

$$\Sigma F_y = ma_y:$$

$$F_N - (m_B + m)g \cos \theta = 0.$$

From the  $x$ -equation we find

$$a = g \sin \theta.$$

From the force diagram for the system of the plumb bob, we can write

$$\Sigma F_x = ma_x:$$

$$m_B g \sin \theta + T \sin (\phi - \theta) = m_B a; \text{ and}$$

$$\Sigma F_y = ma_y:$$

$$T \cos (\phi - \theta) - m_B g = 0.$$

Using  $a = g \sin \theta$  in the  $x$ -equation, we find  $\sin (\phi - \theta) = 0$ , so  $\boxed{\phi = \theta}$ .