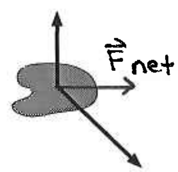
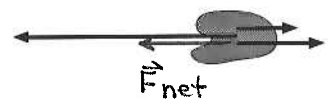
5 Force and Motion

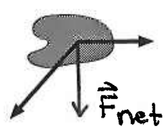
5.1 Force

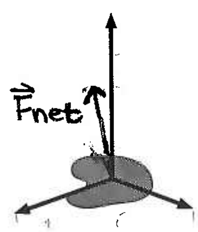
1. Two or more forces are shown on the objects below. Draw and label the net force $\vec{F}_{net}$.





2. Two or more forces are shown on the objects below. Draw and label the net force $\vec{F}_{net}$.





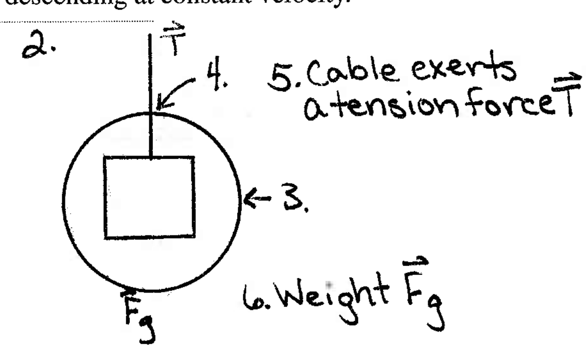
5.2 A Short Catalog of Forces

5.3 Identifying Forces

Exercises 3–8: Follow the six-step procedure of Tactics Box 5.2 to identify and name all the forces acting on the object.

3. An elevator suspended by a cable is descending at constant velocity.

1. System: elevator
Environment: cable

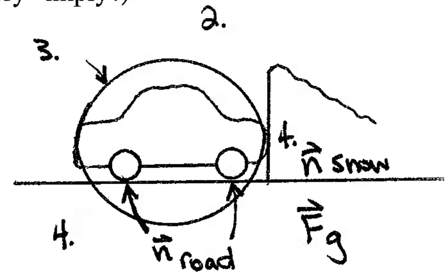


4. A car on a *very* slippery icy road is sliding headfirst into a snowbank, where it gently comes to rest with no one injured. (Question: What does "*very* slippery" imply?)

1. System: Car
Environment: Road, Snowbank

5. The snowbank and road each exert normal forces $\vec{n}_i$.

6. Weight $\vec{F}_g$

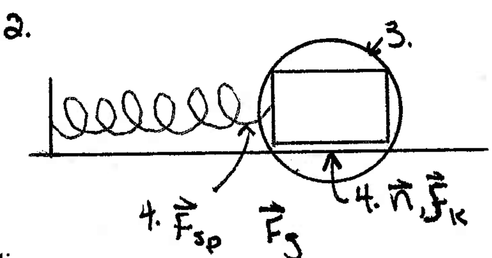


5. A compressed spring is pushing a block across a rough horizontal table.

1. System: Block
Environment: spring, table

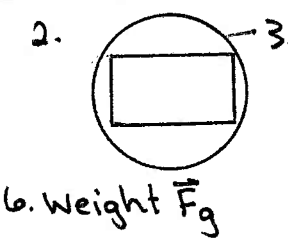
5. Spring exerts F_{sp}.
Table exerts normal force $\vec{n}$ and kinetic friction $\vec{f}_k$

6. weight $\vec{F}_g$

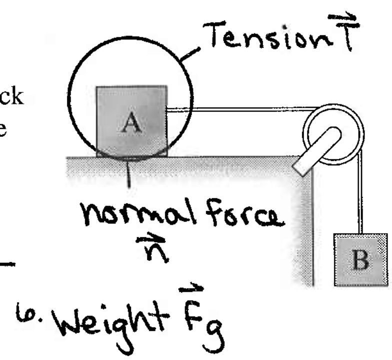


6. A brick is falling from the roof of a three-story building.

1. System: Brick
Environment: none



7. Blocks A and B are connected by a string passing over a pulley. Block B is falling and dragging block A across a frictionless table. Analyze block A.



1. System: Block
Environment: Table, String

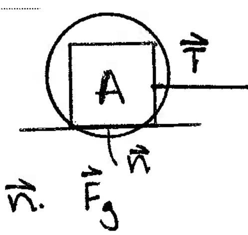
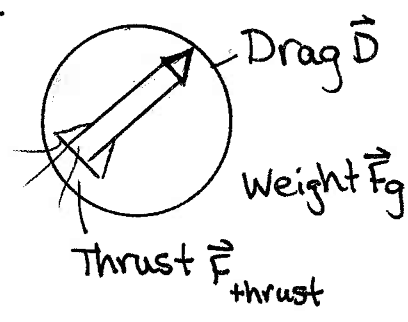


Table exerts normal force $\vec{n}$.
String exerts tension $\vec{T}$.

8. A rocket is launched at a 30° angle. Air resistance is not negligible.

1. System: Rocket
Environment: Air, exhaust



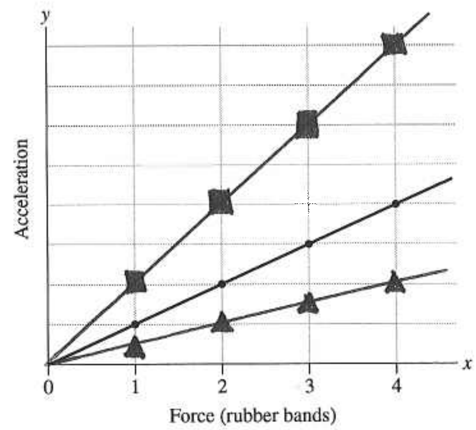
5.4 What Do Forces Do? A Virtual Experiment

9. The figure shows an acceleration-versus-force graph for an object of mass m. Data have been plotted as individual points, and a line has been drawn through the points.

   Draw and label, directly on the figure, the acceleration-versus-force graphs for objects of mass

   a. $2m$ b. $0.5m$

   Use triangles ▲ to show four points for the object of mass $2m$, then draw a line through the points. Use squares ■ for the object of mass $0.5m$.



10. A constant force applied to object A causes A to accelerate at 5 m/s^2. The same force applied to object B causes an acceleration of 3 m/s^2. Applied to object C, it causes an acceleration of 8 m/s^2.

    a. Which object has the largest mass? B
    b. Which object has the smallest mass? C
    c. What is the ratio of mass A to mass B? $(m_A/m_B) =$ 3/5

11. A constant force applied to an object causes the object to accelerate at 10 m/s^2. What will the acceleration of this object be if

    a. The force is doubled? $20\frac{m}{s^2}$ $\left(=\frac{2F}{m}\right)$ b. The mass is doubled? $5\frac{m}{s^2}$ $\left(=\frac{F}{2m}\right)$
    c. The force is doubled *and* the mass is doubled? Same, $10\frac{m}{s^2}$ $\left(=\frac{2F}{2m}\right)$
    d. The force is doubled *and* the mass is halved? $40\,m/s^2$ $\left(=\frac{2F}{m/2}\right)$

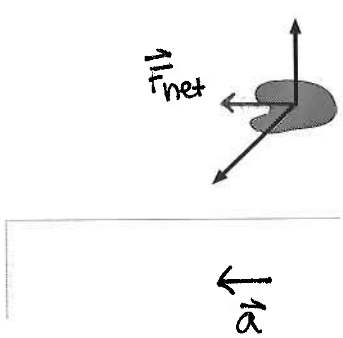
12. A constant force applied to an object causes the object to accelerate at 8 m/s^2. What will the acceleration of this object be if

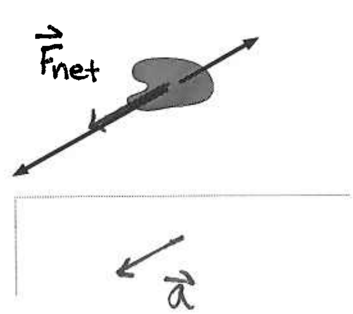
    a. The force is halved? $4\,m/s^2$ b. The mass is halved? $16\,m/s^2$ $\left(=\frac{F}{m/2}\right)$
    c. The force is halved *and* the mass is halved? $8\frac{m}{s^2}$ $\left(=\frac{F/2}{m/2}\right)$
    d. The force is halved *and* the mass is doubled? $2\frac{m}{s^2}$ $\left(=\frac{F/2}{2m}\right)$

5.5 Newton's Second Law

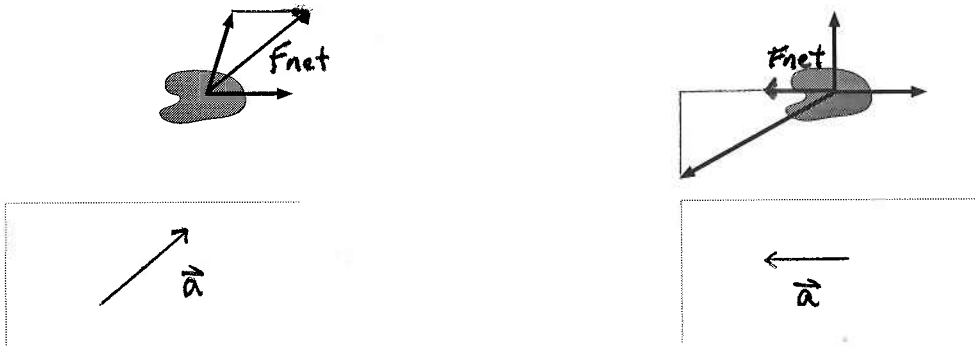
13. Forces are shown on two objects. For each:

    a. Draw and label the net force vector. Do this right on the figure.
    b. Below the figure, draw and label the object's acceleration vector.

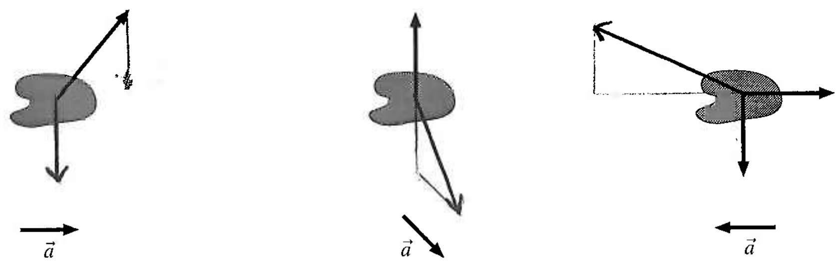




14. Forces are shown on two objects. For each:
    a. Draw and label the net force vector. Do this right on the figure.
    b. Below the figure, draw and label the object's acceleration vector.

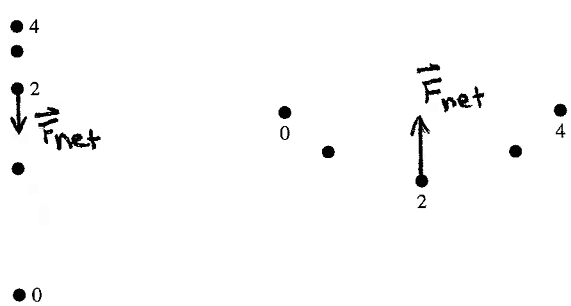


15. In the figures below, one force is missing. Use the given direction of acceleration to determine the missing force and draw it on the object. Do all work directly on the figure.



16. Below are two motion diagrams for a particle. Draw and label the net force vector at point 2.

17. Below are two motion diagrams for a particle. Draw and label the net force vector at point 2.



5.6 Newton's First Law

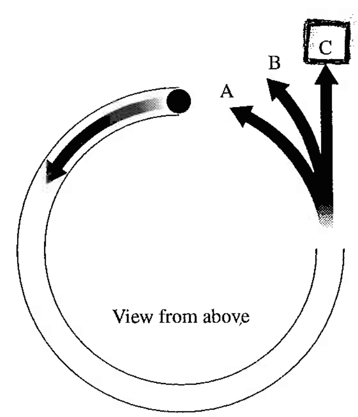
18. If an object is at rest, can you conclude that there are no forces acting on it? Explain.

No. The object's state of rest only tells us about the net force or vector sum of the forces, which must be zero. There may be any number of counter-balancing forces.

19. If a force is exerted on an object, is it possible for that object to be moving with constant velocity? Explain.

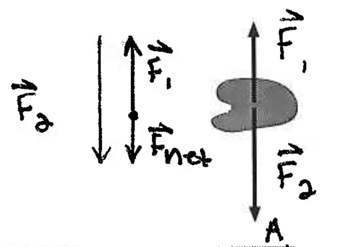
If there is a net force on the object, it must have a changing velocity vector. The object will move at constant velocity if the vector sum of the forces acting on it is zero.

20. A hollow tube forms three-quarters of a circle. It is lying flat on a table. A ball is shot through the tube at high speed. As the ball emerges from the other end, does it follow path A, path B, or path C? Explain your reasoning.

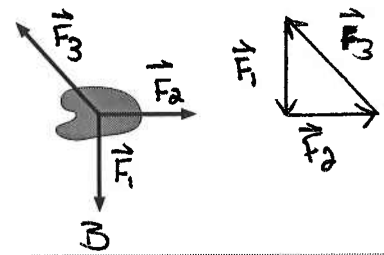


The ball will follow path C. After leaving the tube, the ball no longer is in contact with the wall of the tube and, with no net force, will continue in a straight line.

21. Which, if either, of the objects shown below is in equilibrium? Explain your reasoning.

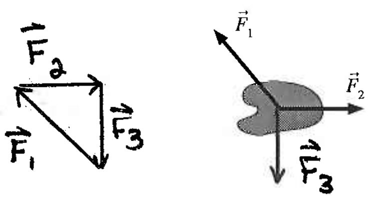


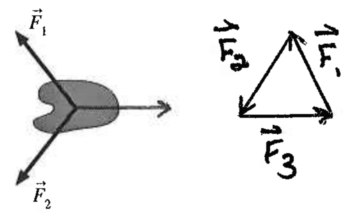
The above object A is not in equilibrium. $|F_2| > |F_1|$ so there is a net downward force on A.



Object B is in equilibrium. The vector sum of forces $\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$

22. Two forces are shown on the objects below. Add a third force $\vec{F}_3$ that will cause the object to be in equilibrium.





23. Are the following inertial reference frames? Answer Yes or No.

a. A car driving at steady speed on a straight and level road. Yes

b. A car driving at steady speed up a 10° incline. Yes

c. A car speeding up after leaving a stop sign. No

d. A car driving at steady speed around a curve. No

e. A hot air balloon rising straight up at steady speed. Yes

f. A skydiver just after leaping out of a plane. No

g. The space shuttle orbiting the earth. No

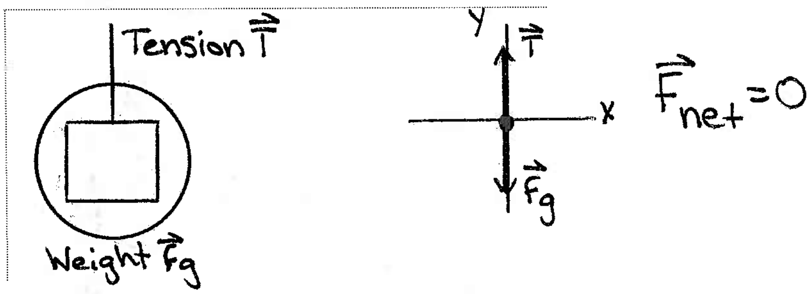
5.7 Free-Body Diagrams

Exercises 24–29:

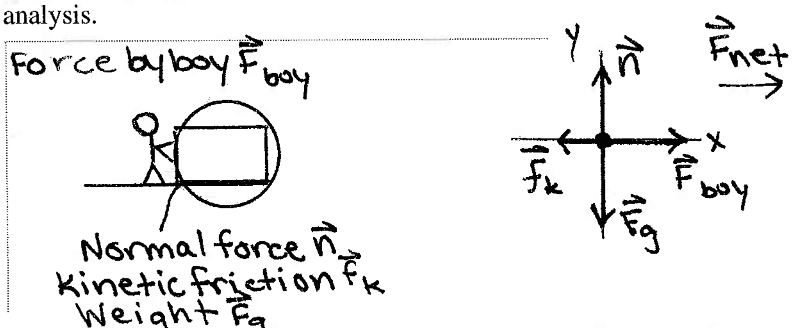
- Draw a picture and identify the forces, then
- Draw a complete free-body diagram for the object, following each of the steps given in Tactics Box 5.3. Be sure to think carefully about the direction of $\vec{F}_{net}$.

Note: Draw individual force vectors with a **black** or **blue** pencil or pen. Draw the *net* force vector $\vec{F}_{net}$ with a **red** pencil or pen.

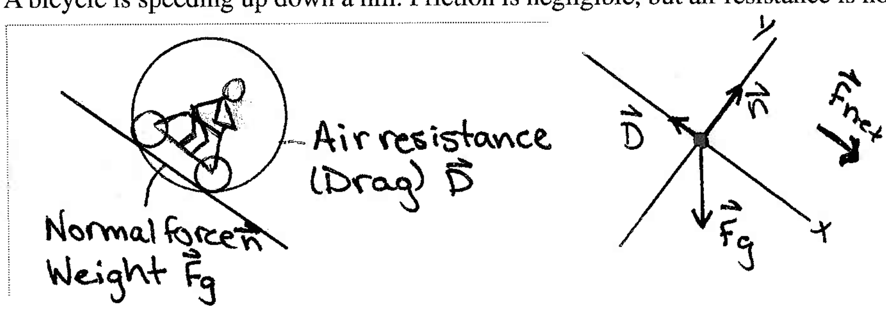
24. A heavy crate is being lowered straight down at a constant speed by a steel cable.



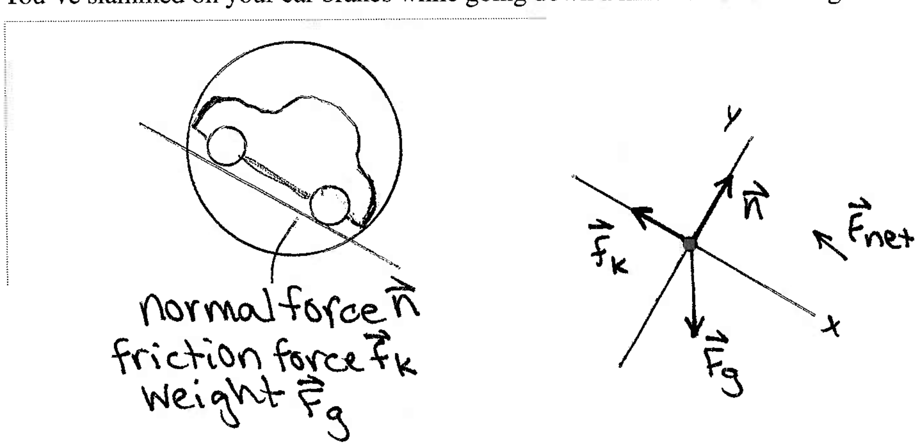
25. A boy is pushing a box across the floor at a steadily increasing speed. Let the box be "the system" for analysis.



26. A bicycle is speeding up down a hill. Friction is negligible, but air resistance is not.

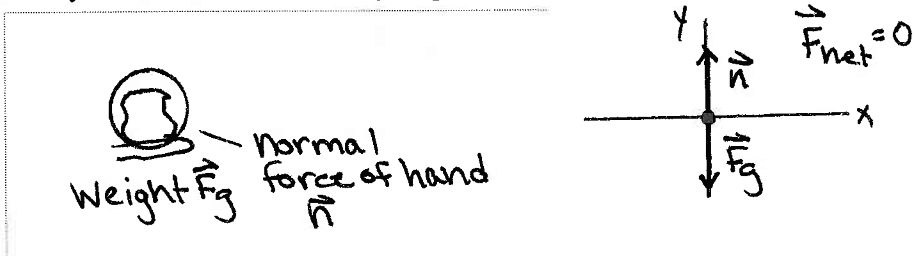


27. You've slammed on your car brakes while going down a hill. You're skidding to a halt.

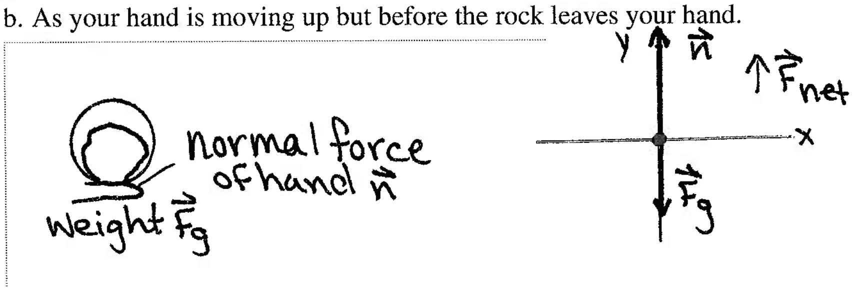


28. You are going to toss a rock *straight up* into the air by placing it on the palm of your hand (you're not gripping it), then pushing your hand up very rapidly. You may want to toss an object into the air this way to help you think about the situation. The rock is "the system" of interest.

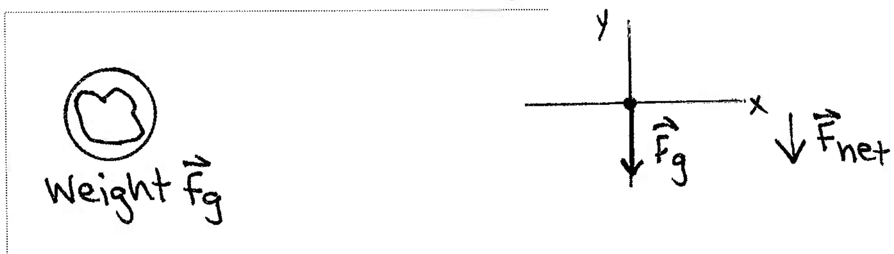
a. As you hold the rock at rest on your palm, before moving your hand.



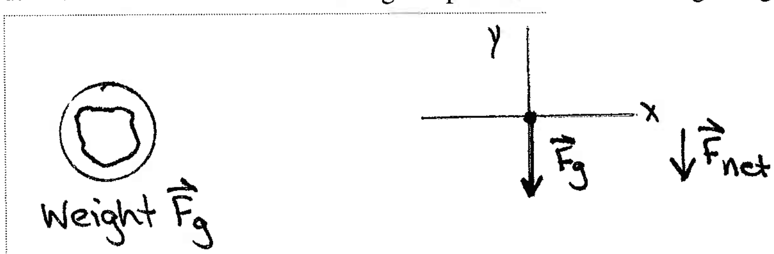
b. As your hand is moving up but before the rock leaves your hand.



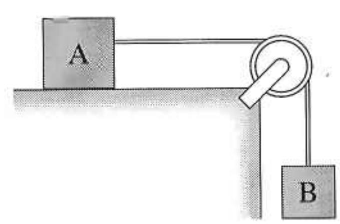
c. One-tenth of a second after the rock leaves your hand.

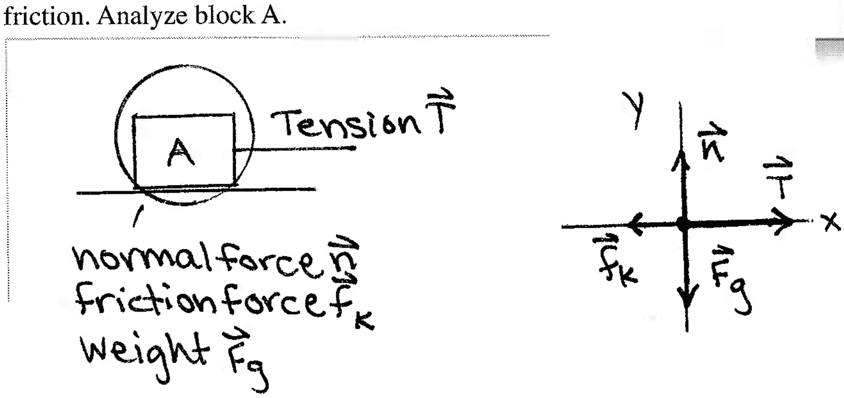


d. After the rock has reached its highest point and is now falling straight down.



29. Block B has just been released and is beginning to fall. The table has friction. Analyze block A.

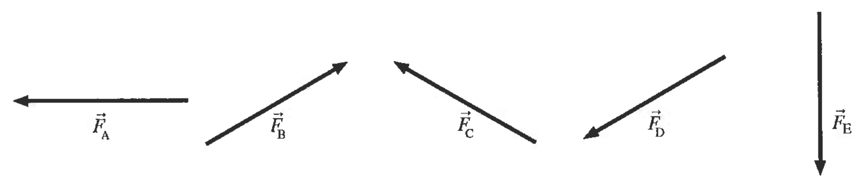




6 Dynamics I: Motion Along a Line

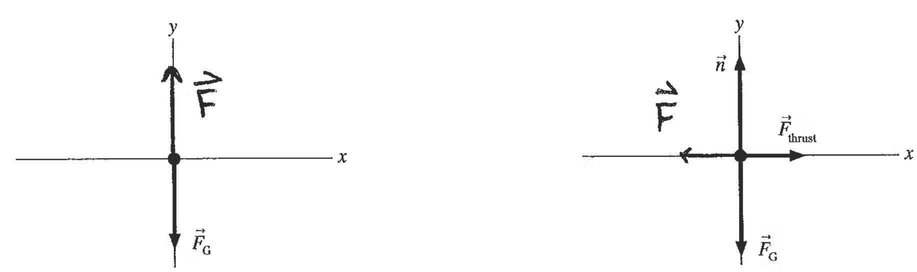
6.1 Equilibrium

1. The vectors below show five forces that can be applied individually or in combinations to an object. Which forces or combinations of forces will cause the object to be in equilibrium?



$\vec{F}_B + \vec{F}_D$ or $\vec{F}_B + \vec{F}_C + \vec{F}_E$

2. The free-body diagrams show a force or forces acting on an object. Draw and label one more force (one that is appropriate to the situation) that will cause the object to be in equilibrium.



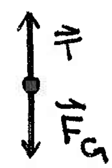
3. If you know all of the forces acting on a moving object, can you tell in which direction the object is moving? If the answer is Yes, explain how. If the answer is No, give an example.

No. If you know all of the forces then you know the direction of the acceleration, not the motion. For example, a car moving forward could have a net force forward if speeding up or backward if slowing down or no net force at all if moving at constant speed.

6.2 Using Newton's Second Law

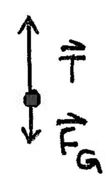
4. a. An elevator travels *upward* at a constant speed. The elevator hangs by a single cable. Friction and air resistance are negligible. Is the tension in the cable greater than, less than, or equal to the weight of the elevator? Explain. Your explanation should include both a free-body diagram and reference to appropriate physical principles.

Because the elevator is not accelerating, the net force on it must be zero. Therefore, the tension and weight must be equal in magnitude and opposite in direction.



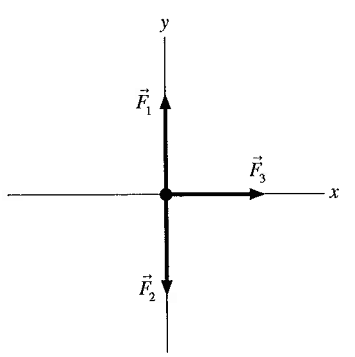
b. The elevator travels *downward* and is slowing down. Is the tension in the cable greater than, less than, or equal to the weight of the elevator? Explain.

Because the elevator is slowing down, its acceleration is in the opposite direction from its motion. Therefore, the net force on the elevator is upward and the tension is greater than the weight.



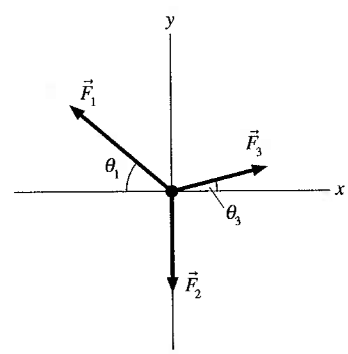
Exercises 5–6: The figures show free-body diagrams for an object of mass m. Write the x- and y-components of Newton's second law. Write your equations in terms of the *magnitudes* of the forces $F_1, F_2, \ldots$ and any *angles* defined in the diagram. One equation is shown to illustrate the procedure.

5.



$ma_x = F_3$

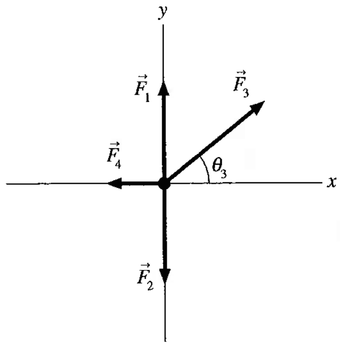
$ma_y = F_1 - F_2$

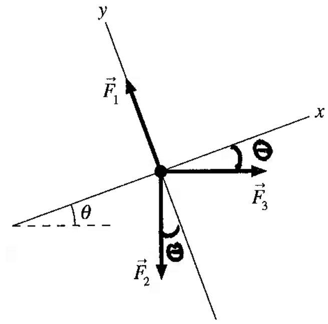


$ma_x = F_3 \cos\theta_3 - F_1 \cos\theta_1$

$ma_y = F_1 \sin\theta_1 + F_3 \sin\theta_3 - F_2$

6.





$ma_x = F_3 \cos \theta_3 - F_4$

$ma_y = F_1 + F_3 \sin\theta_3 - F_2$

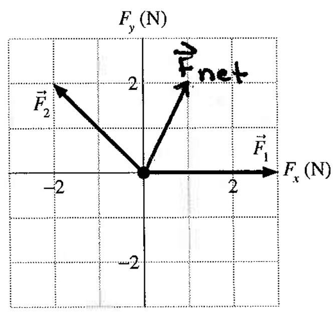
$ma_x = F_3 \cos\theta - F_2 \sin\theta$

$ma_y = F_1 - F_2 \cos\theta$

Exercises 7–9: Two or more forces, shown on a free-body diagram, are exerted on a 2 kg object. The units of the grid are newtons. For each:

- Draw a vector arrow *on the grid,* starting at the origin, to show the net force $\vec{F}_{net}$.
- In the space to the right, determine the numerical values of the components a_x and a_y.

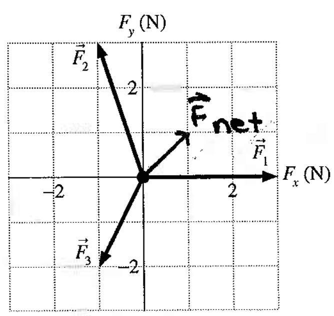
7.



$a_x = \frac{1}{2kg}(3N-2N) = \frac{1}{2} m/s^2 = 0.5 \frac{m}{s^2}$

$a_y = \frac{1}{2kg}(2N) = 1 m/s^2$

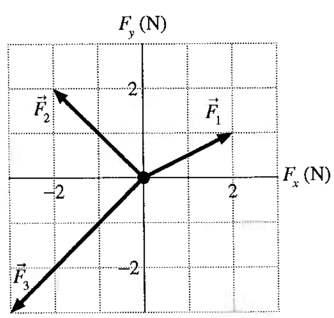
8.



$a_x = \frac{1}{2kg}(3N-1N-1N) = 0.5 m/s^2$

$a_y = \frac{1}{2kg}(3N-2N) = 0.5 m/s^2$

9.

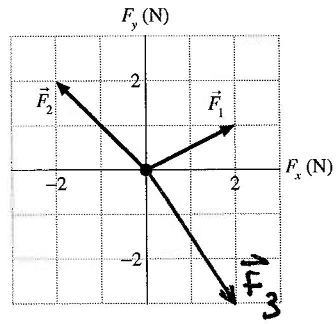


$a_x = \frac{1}{2kg}(2N-2N-3N) = 1.5 m/s^2$

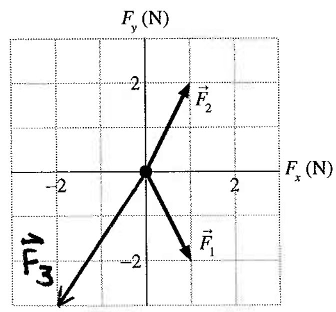
$a_y = \frac{1}{2kg}(1N+2N-3N) = 0 m/s^2$

Exercises 10–12: Three forces $\vec{F}_1$, $\vec{F}_2$, and $\vec{F}_3$ cause a 1 kg object to accelerate with the acceleration given. Two of the forces are shown on the free-body diagrams below, but the third is missing. For each, draw and label *on the grid* the missing third force vector.

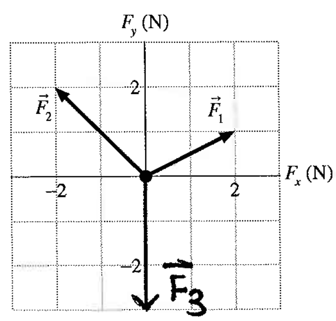
10. $\vec{a} = 2\hat{\imath}\ \text{m/s}^2$



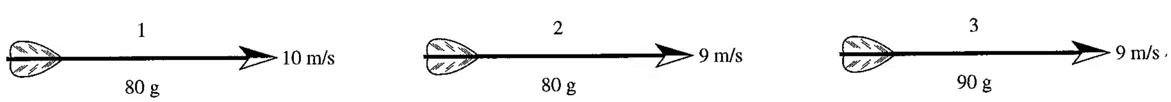
11. $\vec{a} = -3\hat{\jmath}\ \text{m/s}^2$



12. The object moves with constant velocity.



13. Three arrows are shot horizontally. They have left the bow and are traveling parallel to the ground. Air resistance is negligible. Rank in order, from largest to smallest, the magnitudes of the *horizontal* forces F_1, F_2, and F_3 acting on the arrows. Some may be equal. Give your answer in the form A > B = C > D.



Order: 1 = 2 = 3

Explanation: After leaving the bow, there are no horizontal forces on the arrows (neglecting air resistance). The only force on the arrows is the downward force of gravity.

6.3 Mass, Weight, and Gravity

14. An astronaut takes his bathroom scales to the moon and then stands on them. Is the reading of the scales his weight? Explain.

The scales will read his weight on the moon. They will not read the weight that he was on Earth.

15. Suppose you attempt to pour out 100 g of salt, using a pan balance for measurement, while in an elevator that is accelerating upward. Will the quantity of salt be too much, too little, or the correct amount? Explain.

You will still pour the correct amount. Though the apparent weight is increased in the elevator (which would lead to pouring too little on a spring scale), the pan balance compares the mass of the salt poured with the mass of the known 100g object. Both masses are affected by the acceleration in the same way.

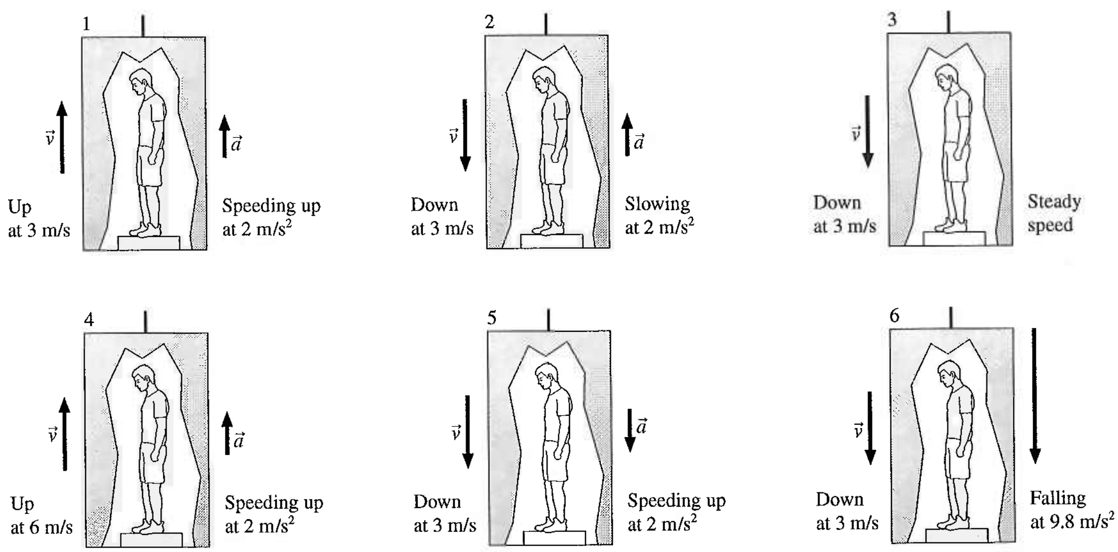
16. An astronaut orbiting the earth is handed two balls that are identical in outward appearance. However, one is hollow while the other is filled with lead. How might the astronaut determine which is which? Cutting them open is not allowed.

The force required to accelerate an object is proportional to its mass. ($\vec{F} = m\vec{a}$). Thus, the astronaut can determine which ball is hollow and which is filled with lead by shaking each or causing each to accelerate with a given force. The force required to accelerate the hollow ball is less due to its lower mass.

17. The terms "vertical" and "horizontal" are frequently used in physics. Give operational definitions for these two terms. An operational definition defines a term by how it is measured or determined. Your definition should apply equally well in a laboratory or on a steep mountainside.

Vertical can be defined by the line a plumb bob makes hanging down due to gravity. Horizontal can be defined by the surface of a liquid far from the edges of its container or by using a bubble level.

18. Suppose you stand on a spring scale in six identical elevators. Each elevator moves as shown below. Let the reading of the scale in elevator n be S_n. Rank in order, from largest to smallest, the six scale readings S_1 to S_6. Some may be equal. Give your answer in the form A > B = C > D.



Order: $S_1 = S_2 = S_4 > S_3 > S_5 > S_6$

Explanation: The scale reading reads your weight, which depends upon the magnitude and direction of your acceleration only, not your speed. Cases 1, 2 and 4 all involve upward acceleration so the scale reads your weight. Case 5 reads less than your weight because your acceleration is downward. For case 6, the scale reading S_6 will be zero.

6.4 Friction

19. A block pushed along the floor with velocity $\vec{v}_0$ slides a distance d after the pushing force is removed.

   a. If the mass of the block is doubled but the initial velocity is not changed, what is the distance the block slides before stopping? Explain.

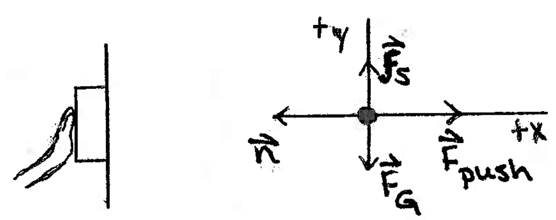
   The block will slide the same distance d. The friction force is proportional to the mass, but blocks response to that force is also proportional to the mass, so the acceleration is the same.

   b. If the initial velocity of the block is doubled to $2\vec{v}_0$ but the mass is not changed, what is the distance the block slides before stopping? Explain.

   The block will slide a distance of 4d. Because the acceleration is unchanged, it will take twice the time to lose twice the velocity. Because the average velocity is also doubled, the block will travel 4x further.

20. Suppose you press a book against the wall with your hand. The book is not moving.

   a. Identify the forces on the book and draw a free-body diagram.



The forces are:

$F_x = F_{push} - n = 0$

$F_y = f_s - F_G = 0$

   b. Now suppose you decrease your push, but not enough for the book to slip. What happens to each of the following forces? Do they increase in magnitude, decrease, or not change?

$\vec{F}_{push}$ decreases

$\vec{F}_G$ same

$\vec{n}$ decreases

$\vec{f}_s$ same

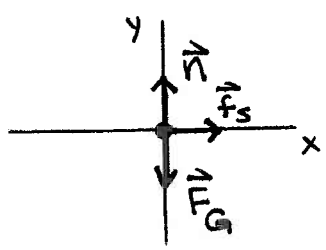
$\vec{f}_{s\,max}$ decreases

6.5 Drag

21. Consider a box in the back of a pickup truck.
   a. If the truck accelerates slowly, the box moves with the truck without slipping. What force or forces act on the box to accelerate it? In what direction do those forces point?

The static friction force accelerates the box. The static friction force points in the same direction as the acceleration of the truck.

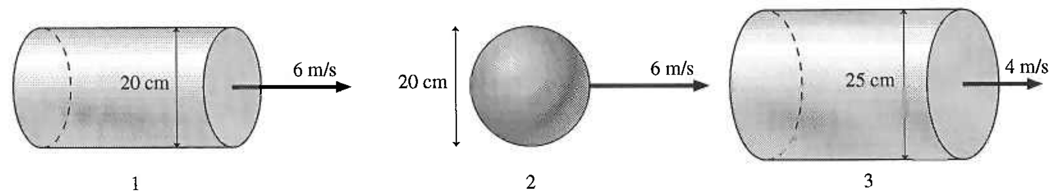
   b. Draw a free-body diagram of the box.



   c. What happens to the box if the truck accelerates too rapidly? Explain why this happens, basing your explanation on physical models and the principles described in this chapter.

If the acceleration is very large then it may require a force on the box in the same direction that exceeds the maximum force that can be provided by static friction, $f_{s_{max}} = \mu_s \vec{n}$. In this case, the block will tend to remain in place while the truck bed accelerates out from underneath it (leaving it to appear to slide backwards).

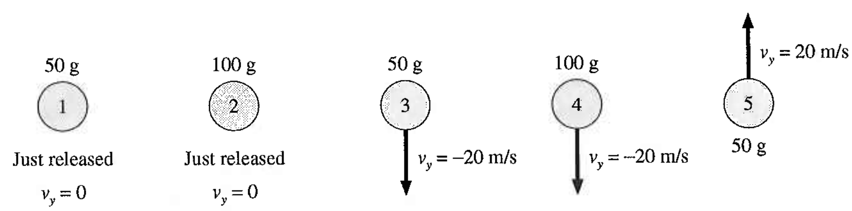
22. Three objects move through the air as shown. Rank in order, from largest to smallest, the three drag forces D_1, D_2, and D_3. Some may be equal. Give your answer in the form A > B = C > D.



Order: $D_1 = D_2 > D_3$

Explanation: Using $D = \frac{Av^2}{4}$ or $D \propto r^2 v^2$, then $D_1 = D_2$ (same r, same v) and $r_3 = \frac{25}{20} r_1 = \frac{5}{4} r_1$; $v_3 = \frac{4}{6} v_1$ so $A_3 v_3^2 = (\frac{5}{4})^2 (\frac{4}{6})^2 A_1 V_1$
$A_3 v_3^2 = (\frac{5}{6})^2 A_1 V_1$ so $D_3 < D_1$

23. Five balls move through the air as shown. All five have the same size and shape. Rank in order, from largest to smallest, the magnitude of their accelerations a_1 to a_5. Some may be equal. Give your answer in the form A > B = C > D.



Order: $a_5 > a_1 = a_2 > a_4 > a_3$

Explanation: a_5 is greatest because both the drag force and gravity are downward. $a_1 = a_2 = -g$ because there is no drag force if $v = 0$. The drag force is not proportional to the mass so the acceleration of ball 4 is greater than that of ball 3 because each experiences the same drag force, but ball 4 experiences a greater gravitational force.

24. A 1 kg wood ball and a 10 kg lead ball have identical shapes and sizes. They are dropped simultaneously from a tall tower.

a. To begin, assume that air resistance is negligible. As the balls fall, are the forces on them equal in magnitude or different? If different, which has the larger force? Explain.

The force on the lead ball is 10 times greater due to its 10 times greater mass. The force of gravity is $-mg$.

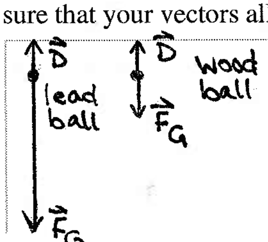
b. Are their accelerations equal or different? If different, which has the larger acceleration? Explain.

Equal. Though the force of gravity is 10 times larger on the 10 kg lead ball, its resistance to acceleration (inertia) is also 10 times greater. ($-mg = ma$ or $a = -g$ for both)

c. Which ball hits the ground first? Or do they hit simultaneously? Explain.

Simultaneously. The balls are dropped at the same time from the same height with the same acceleration. Therefore, they land at the same time.

d. If air resistance is present, each ball will experience the *same* drag force because both have the same shape. Draw free-body diagrams for the two balls as they fall in the presence of air resistance. Make sure that your vectors all have the correct *relative* lengths.



(Though the drag forces are equal speeds, the speeds will differ as explained in part e, below.)

e. When air resistance is included, are the accelerations of the balls equal or different? If not, which has the larger acceleration? Explain, using your free-body diagrams and Newton's laws.

The lead ball has a greater acceleration. Because the drag force is independent of the mass, it will have less effect in reducing the acceleration due to gravity of the lead ball. Using Newton's 2nd Law $|a| = |F|/m = |F_G - D|/m = mg - D/m = g - D/m$. Thus, the larger mass of the lead ball leads to a smaller change in the magnitude of acceleration, (absent air resistance).

f. Which ball now hits the ground first? Or do they hit simultaneously? Explain.

The lead ball will hit the ground first because it has a greater magnitude acceleration.

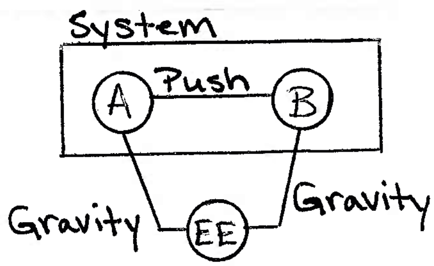
7 Newton's Third Law

7.1 Interacting Objects

7.2 Analyzing Interacting Objects

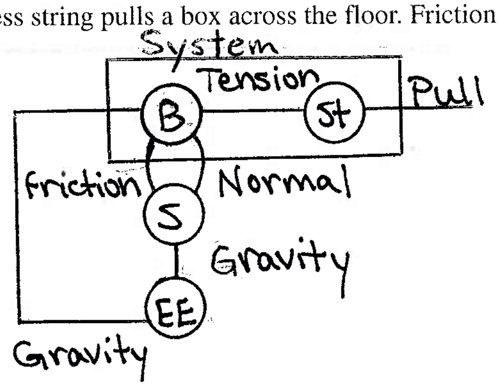
Exercises 1–7: Follow steps 1–3 of Tactics Box 7.1 to draw interaction diagrams describing the following situations. Your diagrams should be similar to Figures 7.6 and 7.10.

1. A bat hits a ball.



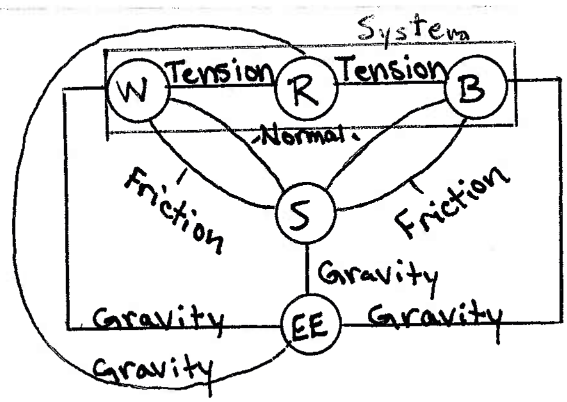
A=Bat
B=Ball
EE=Entire Earth

2. A massless string pulls a box across the floor. Friction is not negligible.



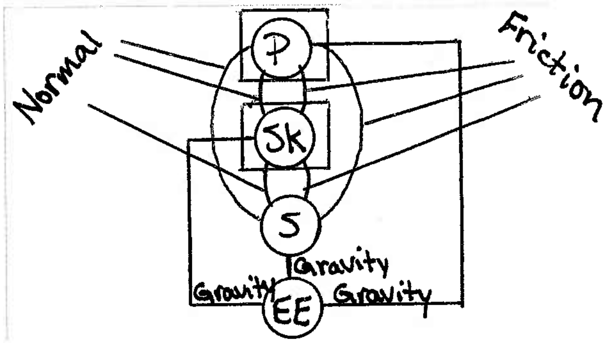
B=Box
S=Surface
St=String
EE=Entire Earth

3. A boy pulls a wagon by a rope attached to the front of the wagon. The rope is not massless, and rolling friction is not negligible.



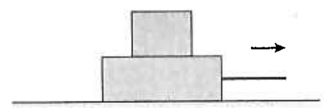
W=Wagon
B=Boy
R=rope
S=surface
EE=Entire Earth

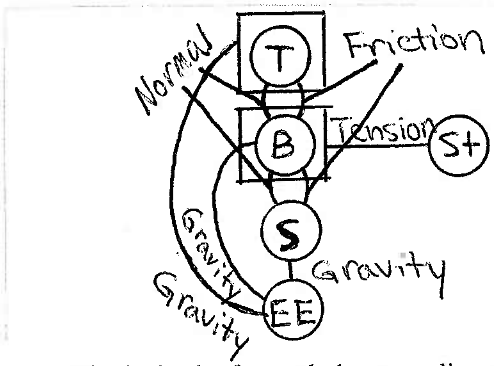
4. A skateboarder is pushing on the ground to speed up. Treat the person and the skateboard as separate objects.



P=Person
Sk=Skateboard
S=Surface
EE=Entire Earth

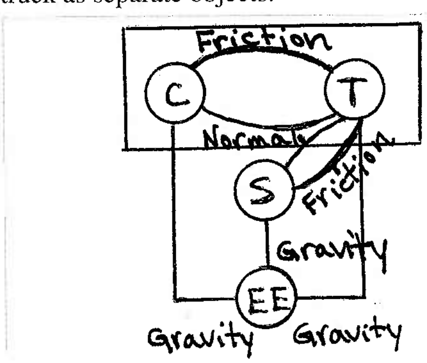
5. The bottom block is pulled by a massless string. Friction is not negligible. Treat the two blocks as separate objects.





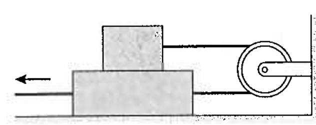
T=top block
B=bottom block
St=string
S=surface
EE=Entire Earth

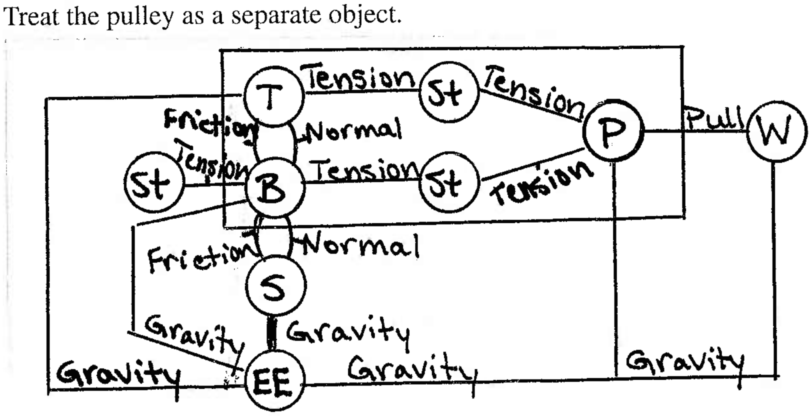
6. A crate in the back of a truck does not slip as the truck accelerates forward. Treat the crate and the truck as separate objects.



C=Crate
T=truck
S=surface (road)
EE=Entire Earth

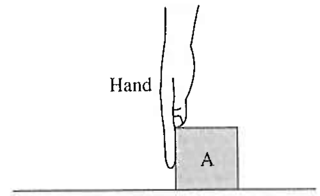
7. The bottom block is pulled by a massless string. Friction is not negligible. Treat the pulley as a separate object.





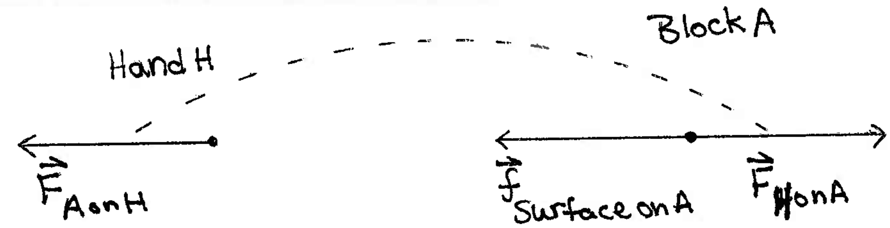
7.3 Newton's Third Law

8. Block A is pushed across a horizontal surface at a *constant* speed by a hand that exerts force $\vec{F}_{\text{H on A}}$. The surface has friction.



a. Draw two free-body diagrams, one for the hand and the other for the block. On these diagrams:

- Show only the *horizontal* forces, such as was done in Figure 7.14 of the text.
- Label force vectors, using the form $\vec{F}_{\text{C on D}}$.
- Connect action/reaction pairs with dotted lines.
- On the hand diagram show only $\vec{F}_{\text{A on H}}$. Don't include $\vec{F}_{\text{body on H}}$.
- Make sure vector lengths correctly portray the relative magnitudes of the forces.



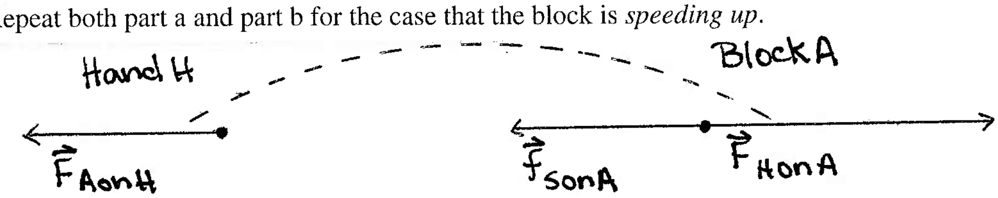
b. Rank in order, from largest to smallest, the magnitudes of *all* of the horizontal forces you showed in part a. For example, if $F_{\text{C on D}}$ is the largest of three forces while $F_{\text{D on C}}$ and $F_{\text{D on E}}$ are smaller but equal, you can record this as $F_{\text{C on D}} > F_{\text{D on C}} = F_{\text{D on E}}$.

Order: $F_{\text{H on A}} = F_{\text{A on H}} = f_{\text{surface on A}}$

Explanation:

$\vec{F}_{\text{H on A}} = -\vec{F}_{\text{A on H}}$ due to Newton's Third Law. These are an action-reaction pair. $\vec{F}_{\text{H on A}} = -\vec{f}_{\text{surface on A}}$ because the block is moving at constant speed. Because these are the only two forces on the block (horizontally) they must be equal and opposite so that $\vec{F}_{net} = 0$.

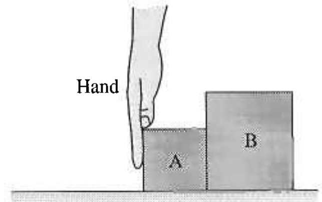
c. Repeat both part a and part b for the case that the block is *speeding up*.



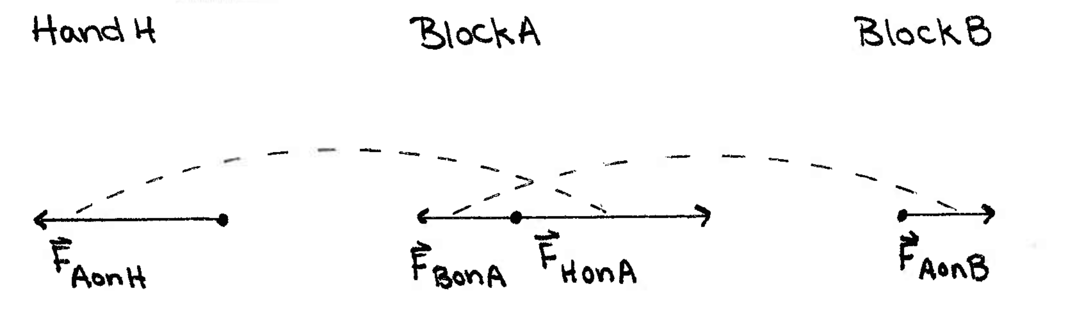
$F_{\text{H on A}} = F_{\text{A on H}} > f_{\text{S on A}}$

The force of the hand on block A is equal and opposite to the force of block A on the hand due to Newton's third Law. They are an action-reaction pair. $F_{\text{H on A}}$ is larger than the force of friction because the block is speeding up. It must have a net force in the direction of its acceleration.

9. A second block B is placed in front of Block A of question 8. B is more massive than A: $m_B > m_A$. The blocks are speeding up.



a. Consider a *frictionless* surface. Draw *separate* free-body diagrams for A, B, and the hand. Show only the horizontal forces. Label forces in the form $\vec{F}_{C \text{ on } D}$. Use dashed lines to connect action/reaction pairs.



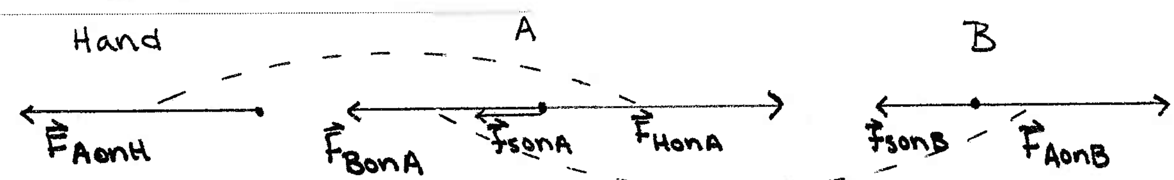
b. By applying the second law to each block and the third law to each action/reaction pair, rank in order *all* of the horizontal forces, from largest to smallest.

Order: $F_{AonH} = F_{HonA} > F_{BonA} = F_{AonB}$

Explanation:

The only horizontal force on B is by Block A. In order for Block A to be also speeding up, the net force on it must be towards B. Thus, F_{HonA} must be greater than F_{BonA} by Newton's second law.

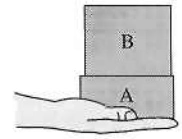
c. Repeat parts a and b if the surface has friction. Assume that A and B have the same coefficient of kinetic friction.



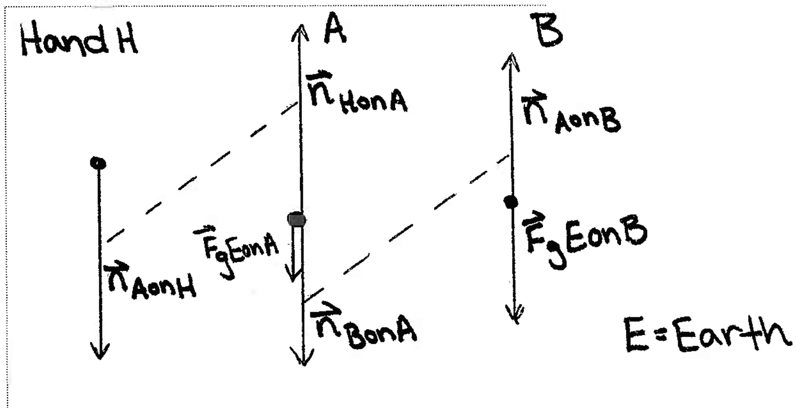
$F_{AonH} = F_{HonA} > F_{AonB} = F_{BonA} > f_{sonB} > F_{sonA}$

If block B is speeding up, then $F_{AonB} > f_{sonB}$ by Newton's second law. Similarly for block A to speed up, $F_{HonA} > F_{BonA} + f_{sonA}$. $f_{sonB} > f_{sonA}$ because Block B is more massive than block A, leading to a greater normal force on B and, thus, a greater frictional force because $f_k = \mu_k n$.

10. Blocks A and B are held on the palm of your outstretched hand as you lift them straight up at *constant speed.* Assume $m_B > m_A$ and that $m_{hand} = 0$.



a. Draw *separate* free-body diagrams for A, B, and your hand.
- Show *all* vertical forces, including the gravitational forces on the blocks.
- Make sure vector lengths indicate the relative sizes of the forces.
- Label forces in the form $\vec{F}_{C \text{ on } D}$
- Connect action/reaction pairs with dashed lines.



b. Rank in order, from largest to smallest, all of the vertical forces. Explain your reasoning.

$n_{AonH} = n_{HonA} > n_{BonA} = n_{AonB} = F_{gEonB} > F_{gEonA}$

Newtons third law Action Reaction Pair — Action Reaction Pair — Block B is more massive

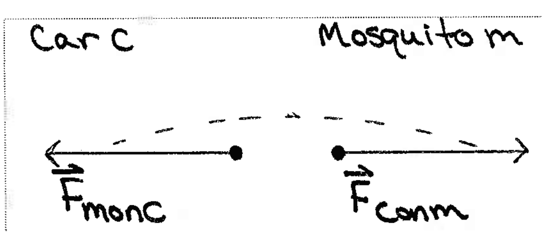
Constant Speed for block A — Constant Speed, $F_{net} = 0$ on B

11. A mosquito collides head-on with a car traveling 60 mph.

a. How do you think the size of the force that the car exerts on the mosquito compares to the size of the force that the mosquito exerts on the car?

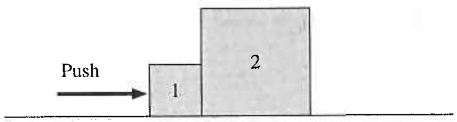
The force of the mosquito on the car is equal to the force of the car on the mosquito. (The mosquito undergoes a much larger acceleration, however, because of its much smaller mass $a = F_{net}/m$.

b. Draw *separate* free-body diagrams of the car and the mosquito at the moment of collision, showing only the horizontal forces. Label forces in the form $\vec{F}_{C \text{ on } D}$. Connect action/reaction pairs with dotted lines.



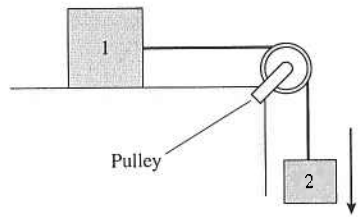
Exercises 12–16: Write the acceleration constraint in terms of *components*. For example, write $(a_1)_x = (a_2)_y$, if that is the appropriate answer, rather than $\vec{a}_1 = \vec{a}_2$.

12.



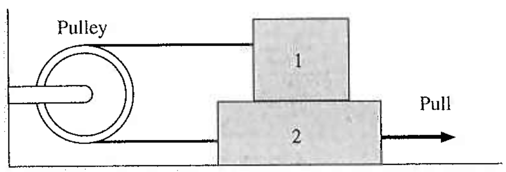
Constraint: $(a_1)_x = (a_2)_x$

13.



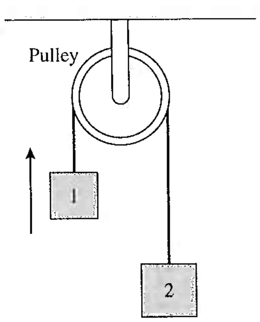
Constraint: $(a_1)_x = -(a_2)_y$

14.



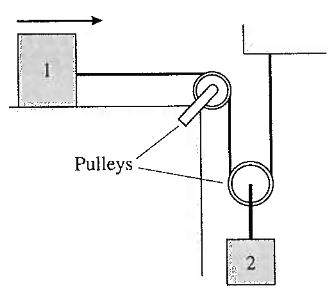
Constraint: $(a_1)_x = -(a_2)_x$

15.



Constraint: $(a_1)_y = -(a_2)_y$

16.



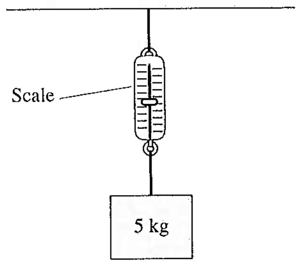
Constraint: $(a_1)_x = -2(a_2)_y$

7.4 Ropes and Pulleys

Exercises 17–22: Determine the reading of the spring scale.

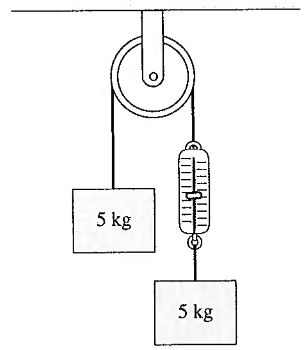
- All the masses are at rest.
- The strings and pulleys are massless, and the pulleys are frictionless.
- The spring scale reads in kg.

17.



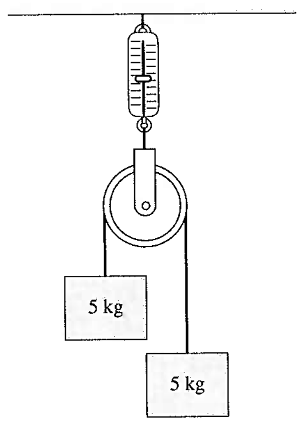
Scale = 5 Kg

18.



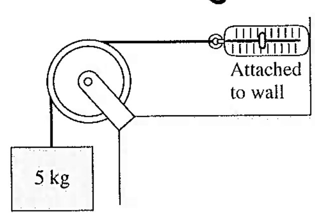
Scale = 5 Kg

19.



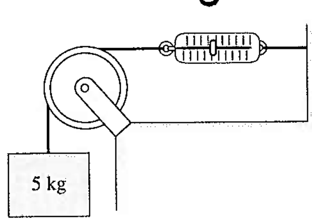
Scale = 10 Kg

20.



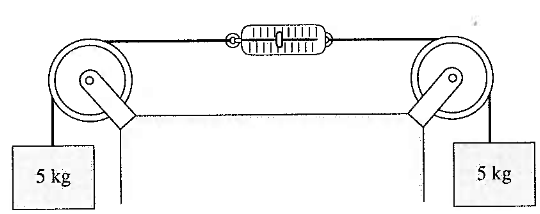
Scale = 5Kg

21.



Scale = 5 Kg

22.

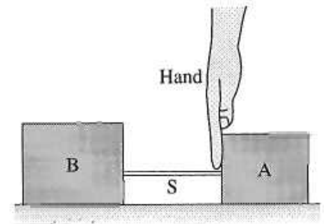


Scale = 5 Kg

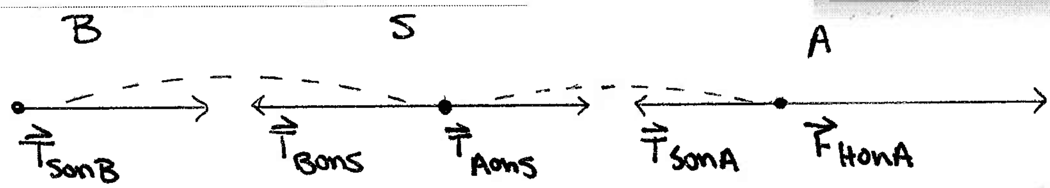
In each case above, the spring scale is held in place by two equal and opposite forces. In # 18 and # 22, the second mass provides the opposite force on the spring scale. In all other cases, the wall or the line attached to the wall provides the force.

7.5 Examples of Interacting-Objects Problems

23. Blocks A and B, with $m_B > m_A$, are connected by a string. A hand pushing on the back of A accelerates them along a frictionless surface. The string (S) is massless.



a. Draw separate free-body diagrams for A, S, and B, showing only horizontal forces. Be sure vector lengths indicate the relative size of the force. Connect any action/reaction pairs with dotted lines.

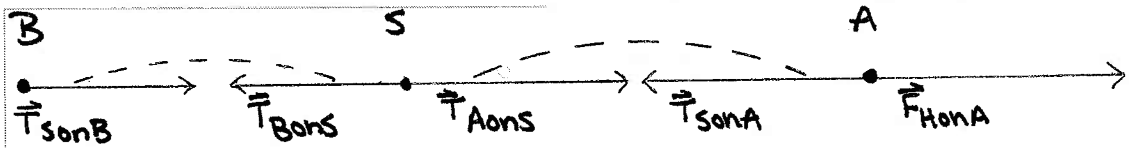


b. Rank in order, from largest to smallest, all of the horizontal forces. Explain.

$F_{HonA} > T_{SonA} = T_{AonS} = T_{BonS} = T_{SonB}$

F_{HonA} must be greater than T_{SonA} to accelerate A by Newton's 2nd law. The string is massless and so there is no net force on the string (or else to accelerate would be infinite). The remaining forces are action-reaction pairs of the forces on the string.

c. Repeat parts a and b if the string has mass.



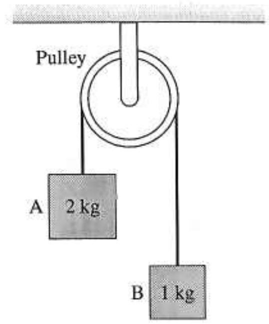
Because the string has mass and is accelerating, $T_{AonS} > T_{BonS}$. Similarly, by Newton's second law, $F_{HonA} > T_{SonA}$.

$$F_{HonA} > \underbrace{T_{SonA} = T_{AonS}}_{\text{Action-Reaction Pair}} > \underbrace{T_{BonS} = T_{SonB}}_{\text{Action-Reaction Pair}}$$

d. You might expect to find $F_{S\text{ on }B} > F_{H\text{ on }A}$ because $m_B > m_A$. Did you? Explain why $F_{S\text{ on }B} > F_{H\text{ on }A}$ is or is not a correct statement.

$F_{SonB} > F_{HonA}$ is not correct. $F_{HonA} > F_{SonB}$. F_{HonA} is partially offset by T_{SonA} so that the net force on A is less than the net force on B. There is no other force on B except T_{SonB}. It may be helpful to think of A, S, and B together so that F_{HonA} acts to accelerate all three. T_{SonB} only accelerates B.

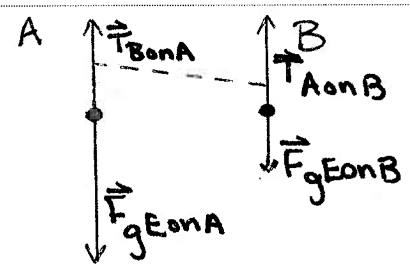
24. Blocks A and B are connected by a massless string over a massless, frictionless pulley. The blocks have just this instant been released from rest.



a. Will the blocks accelerate? If so, in which directions?

A accelerates down, B accelerates up because A is more massive.

b. Draw a separate free-body diagram for each block. Be sure vector lengths indicate the relative size of the force. Connect any action/reaction pairs or "as if" pairs with dashed lines.



c. Rank in order, from largest to smallest, all of the vertical forces. Explain.

$F_{gE on A} > T_{B on A} = T_{A on B} > F_{gE on B}$
Because A is more massive than B, it will accelerate down. Therefore, its weight must be greater than $T_{B on A}$. $T_{A on B} = T_{B on A}$ by Newton's 3rd law. Block B accelerates upward. Therefore, $T_{A on B} > F_{gE on B}$, by Newton's 2nd law.

d. Compare the magnitude of the *net* force on A with the *net* force on B. Are they equal, or is one larger than the other? Explain.

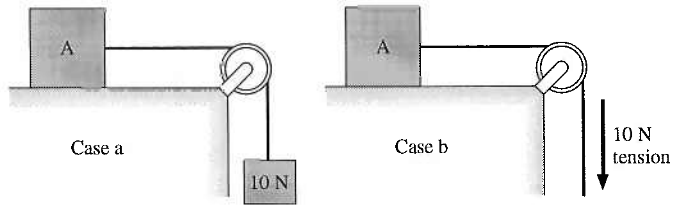
The net force on A is greater than the net force on B. Both blocks have the same magnitude acceleration. The force must be greater on A to produce the same acceleration because it is more massive.

e. Consider the block that falls. Is the magnitude of its acceleration less than, greater than, or equal to g? Explain.

The acceleration is less than "g" because there is the force of the tension $T_{B on A}$ that is in the opposite direction from the weight.

$T_{B on A} - m_A g = m_A a$ so $a_A = -g + \frac{T_{B on A}}{m_A}$

25. In case a, block A is accelerated across a frictionless table by a hanging 10 N weight (1.02 kg). In case b, the same block is accelerated by a steady 10 N tension in the string.



Is block A's acceleration in case b greater than, less than, or equal to its acceleration in case a? Explain.

Block A's acceleration is greater in case b. In case a, the hanging 10N weight must accelerate both the mass of A and its own mass, leading to a smaller acceleration than case b, where the entire 10N force acts only to accelerate Block A.

Case a

$F_g = 10N = (M_A + M_{\text{Hanging Weight}})a$

$a = 10N / (M_A + \frac{10N}{g})$

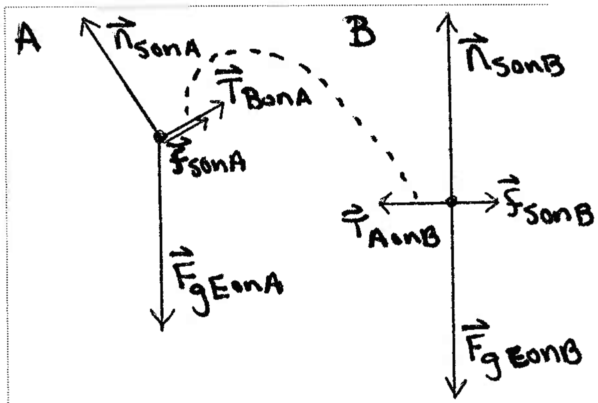
Case b

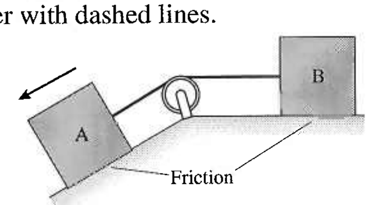
$T = 10N = m_A a$

$a = \frac{10N}{m_A}$

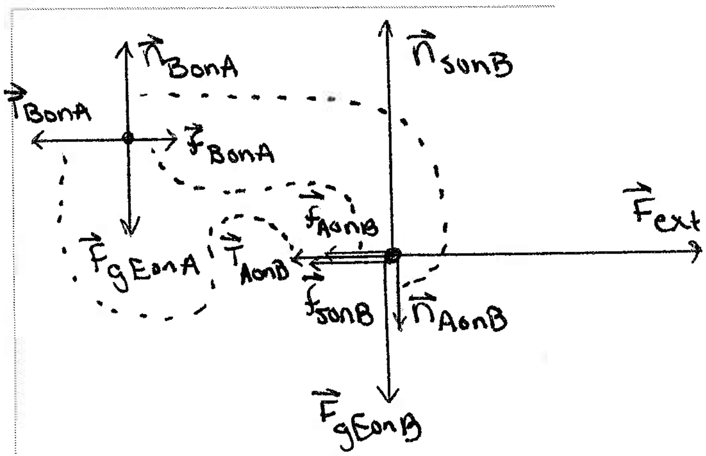
Exercises 26–27: Draw separate free-body diagrams for blocks A and B. Connect any action/reaction pairs (or forces that act *as if* they are action/reaction pairs) together with dashed lines.

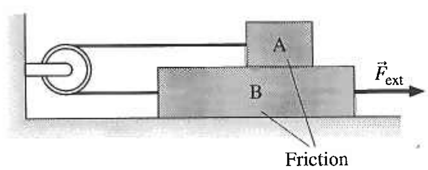
26.





27.

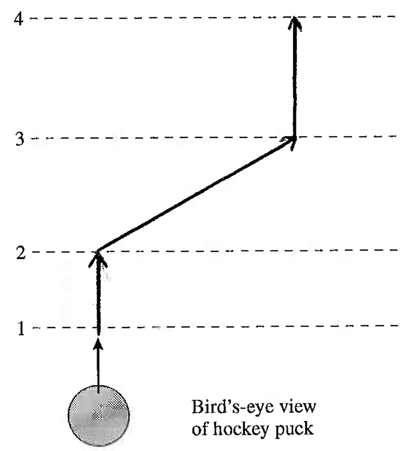




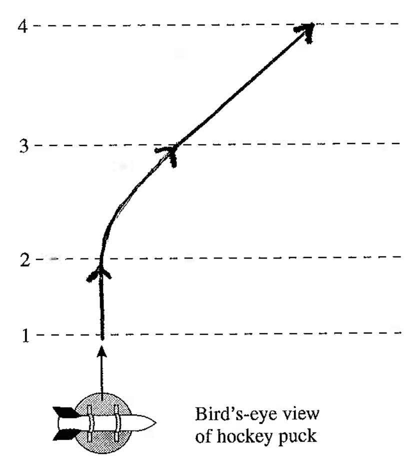
8 Dynamics II: Motion in a Plane

8.1 Dynamics in Two Dimensions

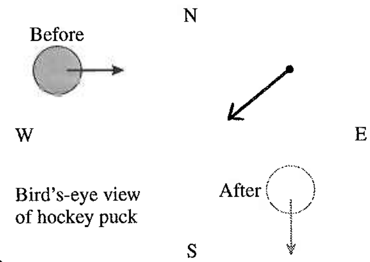
1. An ice hockey puck is pushed across frictionless ice in the direction shown. The puck receives a sharp, very short-duration kick toward the right as it crosses line 2. It receives a second kick, of equal strength and duration but toward the left, as it crosses line 3. Sketch the puck's trajectory from line 1 until it crosses line 4.



2. A rocket motor is taped to an ice hockey puck, oriented so that the thrust is to the left. The puck is given a push across frictionless ice in the direction shown. The rocket will be turned on by remote control as the puck crosses line 2, then turned off as it crosses line 3. Sketch the puck's trajectory from line 1 until it crosses line 4.

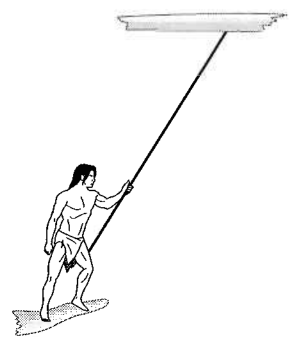


3. An ice hockey puck is sliding from west to east across frictionless ice. When the puck reaches the point marked by the dot, you're going to give it *one* sharp blow with a hammer. After hitting it, you want the puck to move from north to south at a speed similar to its initial west-to-east speed. Draw a force vector with its tail on the dot to show the direction in which you will aim your hammer blow.

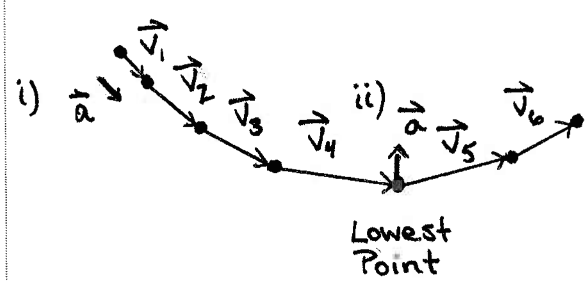


The blow will be at 45° South of West in order to stop the eastward motion and impart an equal southward motion.

4. Tarzan swings through the jungle by hanging from a vine.

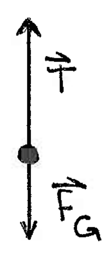


a. Draw a motion diagram of Tarzan, as you learned in Chapter 1. Use it to find the direction of Tarzan's acceleration vector $\vec{a}$:
   i. Immediately after stepping off the branch, and
   ii. At the lowest point in his swing.



b. At the lowest point in the swing, is the tension T in the vine greater than, less than, or equal to Tarzan's weight? Explain, basing your explanation on Newton's laws.

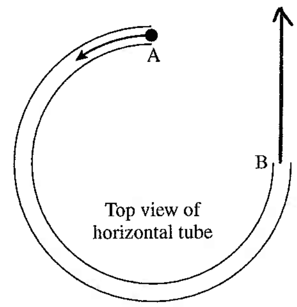
For the acceleration to be upwards, the net force must be upwards. The only two forces are the upward tension and the weight. Therefore, the tension must be greater than the weight.



8.2 Velocity and Acceleration in Uniform Circular Motion

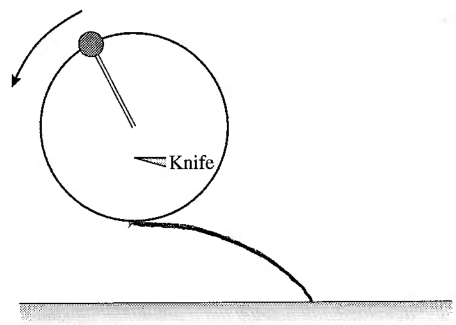
8.3 Dynamics of Uniform Circular Motion

5. The figure shows a *top view* of a plastic tube that is fixed on a horizontal table top. A marble is shot into the tube at A. On the figure, sketch the marble's trajectory after it leaves the tube at B.



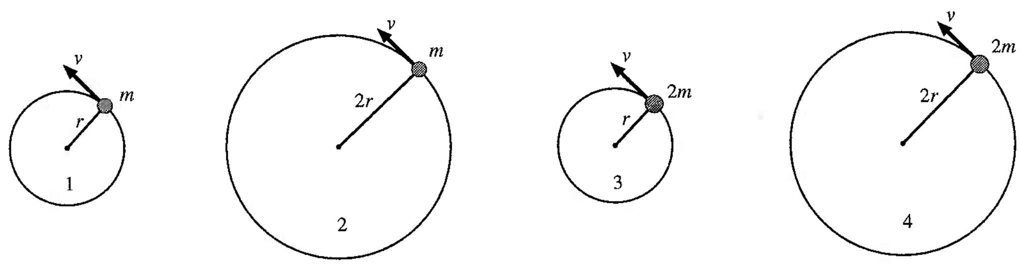
The marble continues in a straight line (towards the top of the page).

6. A ball swings in a *vertical* circle on a string. During one revolution, a very sharp knife is used to cut the string at the instant when the ball is at its lowest point. Sketch the subsequent trajectory of the ball until it hits the ground.



The trajectory is parabolic, like that of a horizontally launched projectile.

7. The figures are a bird's-eye view of particles on a string moving in horizontal circles on a table top. All are moving at the same speed. Rank in order, from largest to smallest, the string tensions T_1 to T_4.



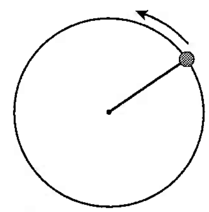
Order: $T_3 > T_1 = T_4 > T_2$

Explanation:

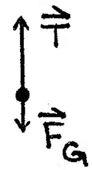
$T = \frac{mv^2}{r}$

Case 3 combines a larger mass and smaller. Case 4 is the same as Case 1 because both the mass and the radius are doubled.

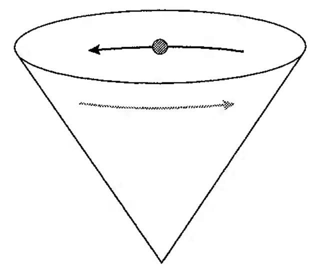
8. A ball on a string moves in a vertical circle. When the ball is at its lowest point, is the tension in the string greater than, less than, or equal to the ball's weight? Explain. (You may want to include a free-body diagram as part of your explanation.)

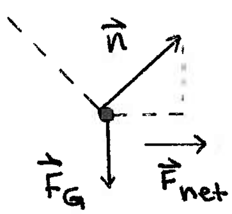


At the lowest point, the acceleration is upward. Thus, the tension must be greater than the weight for the net force to be upward.

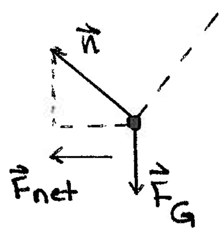


9. A marble rolls around the inside of a cone. Draw a free-body diagram of the marble when it is on the left side of the cone and a free-body diagram of the marble when it is on the right side of the cone.





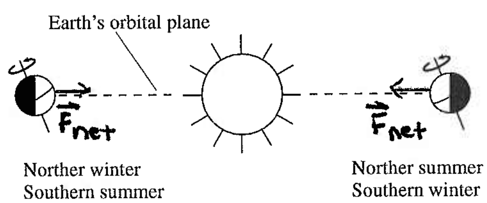
On left side



On right side

8.4 Circular Orbits

10. The earth has seasons because the axis of the earth's rotation is tilted 23° away from a line perpendicular to the plane of the earth's orbit. You can see this in the figure, which shows an edge view of the earth's orbit around the sun. For both positions of the earth, draw a force vector to show the net force acting on the earth or, if appropriate, write $\vec{F} = \vec{0}$.



11. A small projectile is launched parallel to the ground at height $h = 1$ m with sufficient speed to orbit a completely smooth, airless planet. A bug rides in a small hole inside the projectile. Is the bug weightless? Explain.

The bug is weightless in the sense that is in free fall with the projectile. The bug still has a weight of $\vec{F}_G = m_{bug} g$.

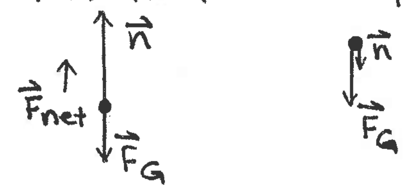
8.5 Fictitious Forces

8.6 Why Does the Water Stay in the Bucket?

12. A stunt plane does a series of vertical loop-the-loops. At what point in the circle does the pilot feel the heaviest? Explain. Include a free-body diagram with your explanation.

The pilot feels heaviest at the bottom of the vertical loop. At that point, the normal force on the pilot is greatest.

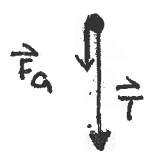
At bottom: At top:



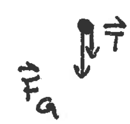
This analysis assumes the pilot is moving at comparable speed throughout.

13. You can swing a ball on a string in a *vertical* circle if you swing it fast enough.

a. Draw two free-body diagrams of the ball at the top of the circle. On the left, show the ball when it is going around the circle very fast. On the right, show the ball as it goes around the circle more slowly.



Very fast



Slower

b. As you continue slowing the swing, there comes a frequency at which the string goes slack and the ball doesn't make it to the top of the circle. What condition must be satisfied for the ball to be able to complete the full circle?

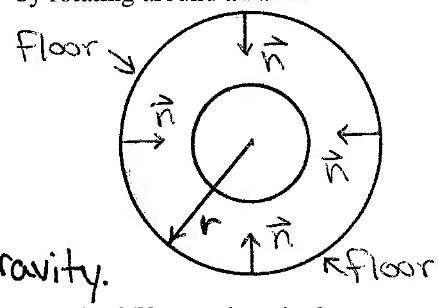
$\vec{F}_{net} = m\frac{v^2}{r} = m\omega^2 r$. The minimum downward force is the weight, so $mg = mr\omega^2_{min}$ or $\omega^2_{min} = g/r$ $\omega_{min} = \sqrt{g/r}$

c. Suppose the ball has the smallest possible frequency that allows it to go all the way around the circle. What is the tension in the string when the ball is at the highest point? Explain.

$\vec{T} = 0$. At the smallest frequency, the only radically inward force is the force of gravity, the weight.

14. It's been proposed that future space stations create "artificial gravity" by rotating around an axis.

a. How would this work? Explain.



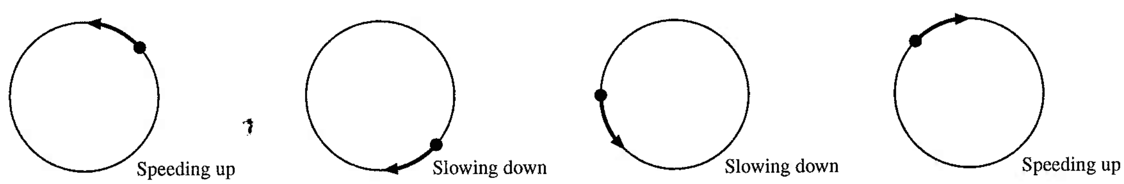
The outside wall of the station would provide the floor and the normal force required to keep the occupants and contents rotating would be the apparent weight of the objects in this artificial gravity.

b. Would the artificial gravity be equally effective throughout the space station? If not, where in the space station would the residents want to live and work?

The apparent weight would be due to an inward normal force provided by the outward wall. As one moves inward, the artificial gravity would become weaker due to the smaller radius. $\vec{n} = m\omega^2 r$

8.7 Nonuniform Circular Motion

15. For each, figure determine the signs (+ or –) of ω and α.

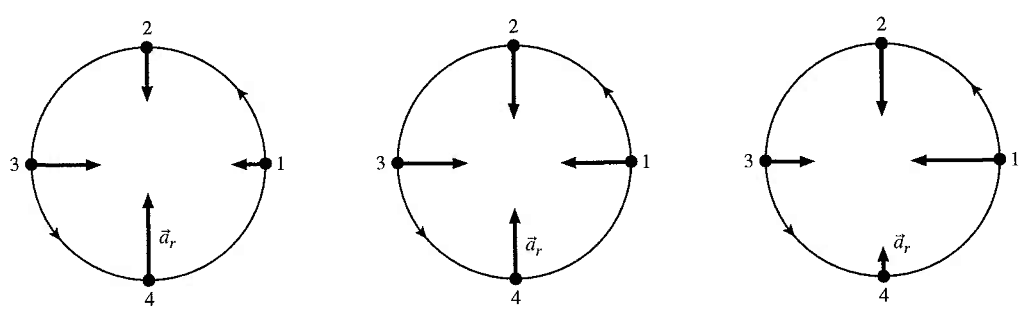


	Speeding up	Slowing down	Slowing down	Speeding up
ω	+	–	+	–
α	+	+	–	–

16. The figures below show the radial acceleration vector $\vec{a}_r$ at four sequential points on the trajectory of a particle moving in a counterclockwise circle.

a. For each, draw the tangential acceleration vector α at points 2 and 3 or, if appropriate, write $\alpha = \vec{0}$.

b. Determine whether α is positive (+), negative (–), or zero (0).



$\alpha =$ (+) $\alpha =$ (0) $\alpha =$ (–)