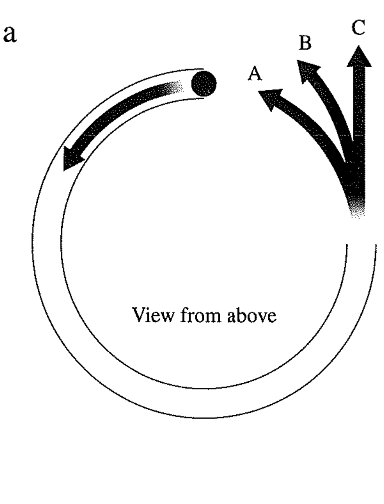
5 Applying Newton's Laws

5.1 Equilibrium

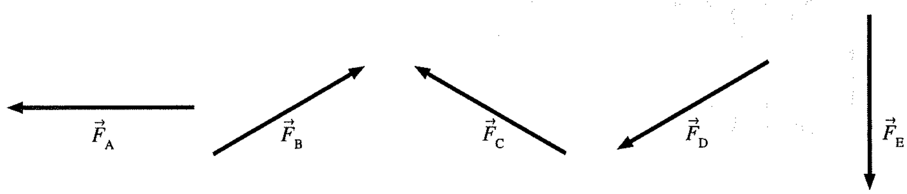
1. If an object is at rest, can you conclude that there are no forces acting on it? Explain.

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

3. 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.

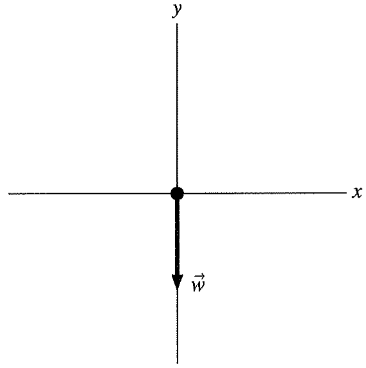


4. The vectors below show five forces that can be applied individually or in combinations to an object. Which forces or combinations of forces will cause the object to be in equilibrium?

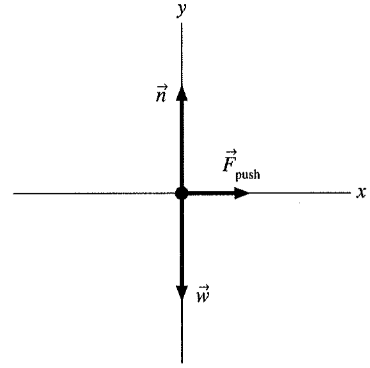


5. The free-body diagrams show a force or forces acting on an object. Draw and label one more force (one that is appropriate to the situation) that will cause the object to be in equilibrium.

a.

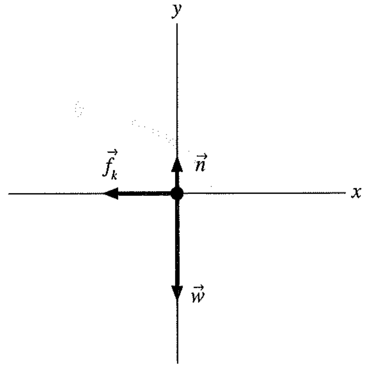


b.

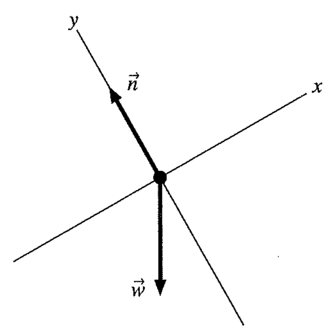


6. The free-body diagrams show a force or forces acting on an object. Draw and label one more force (one that is appropriate to the situation) that will cause the object to be in equilibrium.

a.



b.



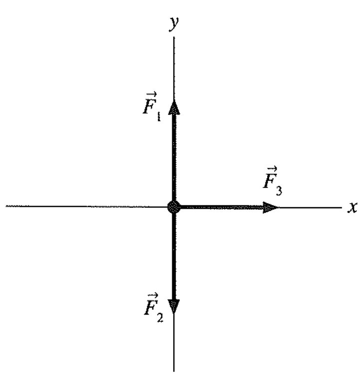
5.2 Dynamics and Newton's Second Law

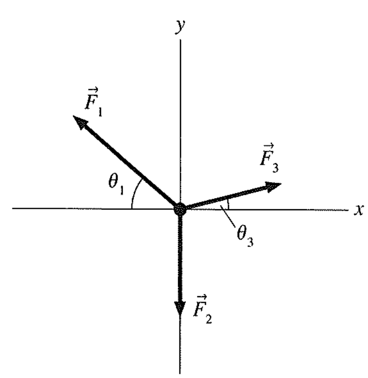
7. a. An elevator travels *upward* at a constant speed. The elevator hangs by a single cable. Friction and air resistance are negligible. Is the tension in the cable greater than, less than, or equal to the weight of the elevator? Explain. Your explanation should include both a free-body diagram and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

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.

Exercises 8–9: 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 in each question to illustrate the procedure.

8.





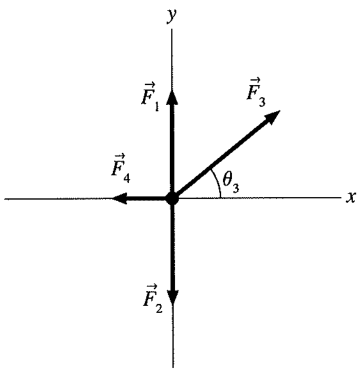
$ma_x =$

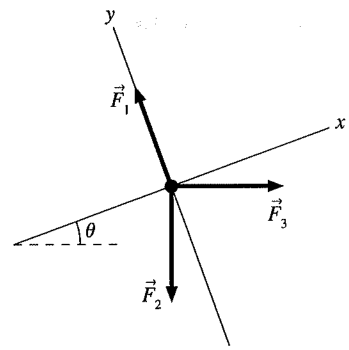
$ma_y = F_1 - F_2$

$ma_x =$

$ma_y =$

9.



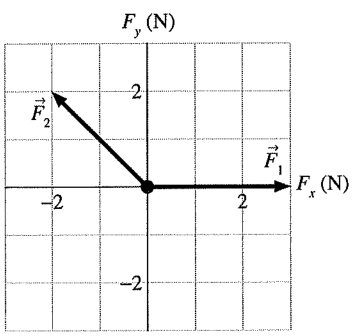


$ma_x = F_3 \cos\theta_3 - F_4$	$ma_x =$
$ma_y =$	$ma_y =$

Exercises 10–12: 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 $\vec{F}_{\text{net}}$.
- In the space to the right, determine the numerical values of the components a_x and a_y.

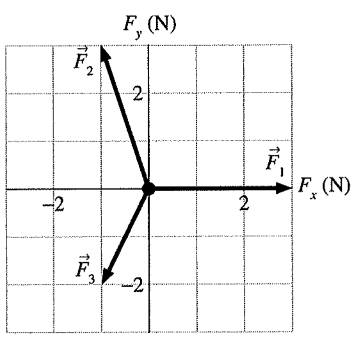
10.



$a_x =$

$a_y =$

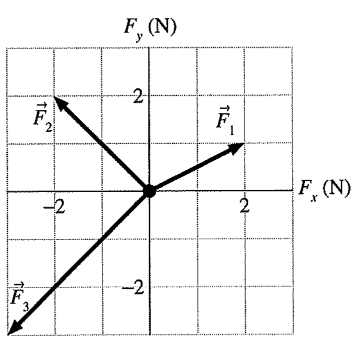
11.



$a_x =$

$a_y =$

12.

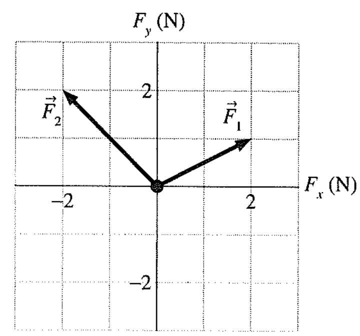


$a_x =$

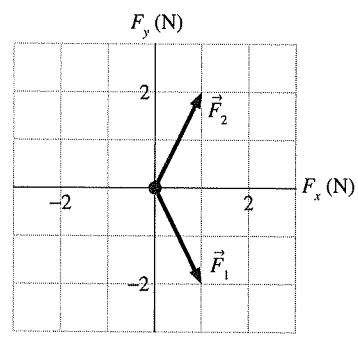
$a_y =$

Exercises 13–15: 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.

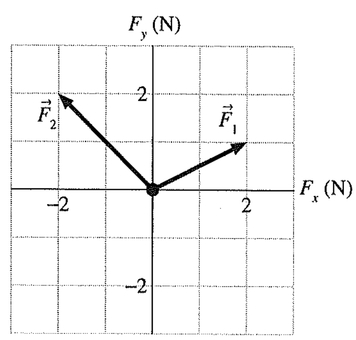
13. $a_x = 2\ \text{m/s}^2$
    $a_y = 0\ \text{m/s}^2$



14. $a_x = 0\ \text{m/s}^2$
    $a_y = -3\ \text{m/s}^2$

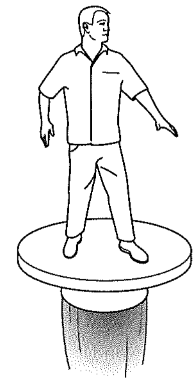


15. The object moves with constant velocity.



5.3 Mass and Weight

16. Suppose you have a jet-powered flying platform that can move straight up and down. For each of the following cases, is your apparent weight equal to, greater than, or less than your true weight? Explain.



a. You are ascending and speeding up.

b. You are descending and speeding up.

c. You are ascending at a constant speed.

d. You are ascending and slowing down.

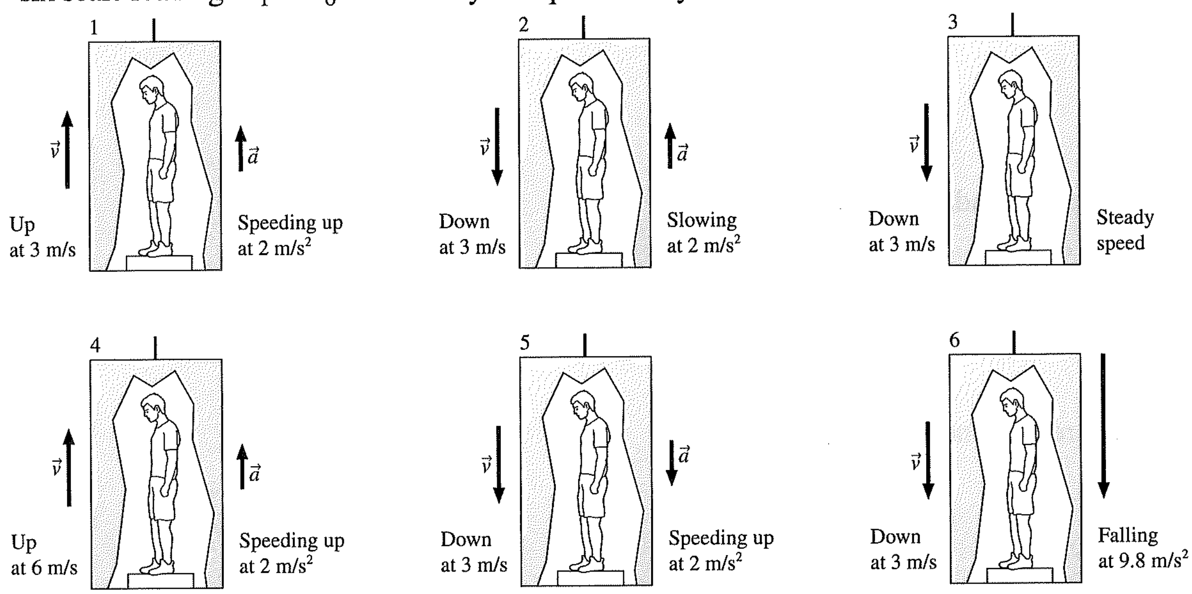
e. You are descending and slowing down.

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.

18. 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.

5.4 Normal Forces

19. 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:

Explanation:

5.5 Friction

20. 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.

   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.

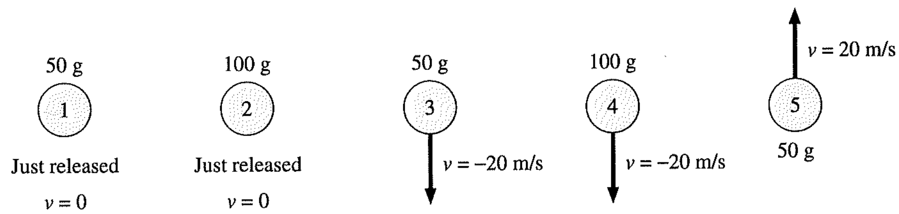
21. Consider a box in the back of a pickup truck.
   a. If the truck accelerates slowly, the box moves with the truck without slipping. What force or forces act on the box to accelerate it? In what direction do those forces point?

   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 the physical laws and models described in this chapter.

5.6 Drag

22. 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:

Explanation:

23. A 1 kg wood ball and a 5 kg metal ball have identical shapes and sizes. They are dropped simultaneously from a tall tower. Each ball experiences the *same* drag force because both have the same shape.

a. Draw free-body diagrams for the two balls as they fall in the presence of air resistance. Make sure your vectors all have the correct *relative* lengths.

b. Both balls have the same acceleration if they fall in a vacuum. The metal ball has a larger gravitational force, but it also has a larger mass and so $a = F/m$ is the same as for the wood ball. But the accelerations are not the same if the balls fall in air. Which now has the larger acceleration? Your explanation should refer explicitly to your free-body diagrams of part a and to Newton's second law.

c. Do the balls hit the ground simultaneously? If not, which hits first? Explain.

24. A small airplane of mass m must take off from a primitive jungle airstrip that slopes upward at
PSS 5.2 a slight angle θ. When the pilot pulls back on the throttle, the plane's engines exert a constant forward force $\vec{F}_{\text{thrust}}$. Rolling friction is not negligible on the dirt airstrip, and the coefficient of rolling resistance is μ_r. If the plane's take-off speed is v_{off}, what minimum length must the airstrip have for the plane to get airborne?

a. Assume the plane takes off uphill to the right. Begin with a pictorial representation, as was described in Tactics Box 2.2. Establish a coordinate system with a tilted x-axis; show the plane at the beginning and end of the motion; define symbols for position, velocity, and time at these two points (six symbols all together); list known information; and state what you wish to find. $\vec{F}_{\text{thrust}}$, m, θ, μ_r, and v_{off} are presumed known, although we have only symbols for them rather than numerical values, and three other quantities are zero.

b. Next, draw a force-identification diagram. Beside it, draw a free-body diagram. Your free-body diagram should use the same coordinate system you established in part a, and it should have 4 forces shown on it.

c. Write Newton's second law as two equations, one for the net force in the x-direction and one for the net force in the y-direction. Be careful finding the components of $\vec{w}$ (see Figure 5.11), and pay close attention to signs. Remember that symbols such as w or f_k represent the *magnitudes* of vectors; you have to supply appropriate signs to indicate which way the vectors point. The right side of these equations have a_x and a_y. The motion is entirely along the x-axis, so what do you know about a_y? Use this information as you write the y-equation.

d. Now write the equation that characterizes the friction force on a rolling tire.

e. Combine your friction equation with the y-equation of Newton's second law to find an expression for the magnitude of the friction force.

f. Finally, substitute your answer to part e into the x-equation of Newton's second law, and then solve for a_x, the x-component of acceleration. Use $w = mg$ if you've not already done so.

g. With friction present, should the *magnitude* of the acceleration be larger or smaller than the acceleration of taking off on a frictionless runway? ________

h. Does your expression for acceleration agree with your answer to part g? ________
Explain how you can tell. If it doesn't, recheck your work.

i. The force analysis is done, but you still have to do the kinematics. This is a situation where we know about velocities, distance, and acceleration but nothing about the time involved. That should suggest the appropriate kinematics equation. Use your acceleration from part f in that kinematics equation, and solve for the unknown quantity you're seeking.

You've found a symbolic answer to the problem, one that you could now evaluate for a range of values of $\vec{F}_{\text{thrust}}$ or θ without having to go through the entire solution each time.

You Write the Problem!

Exercises 25–27: You are given the dynamics equation that is used to solve a problem. For each of these:

a. Write a *realistic* physics problem for which this is the correct equation. Look at worked examples and end-of-chapter problems in the textbook to see what realistic physics problems are like. Be sure that the problem you write, and the answer you ask for, is consistent with the information given in the equation.
b. Draw the free-body diagram and pictorial representation for your problem.
c. Finish the solution of the problem.

25. $-0.80n = (1500\ \text{kg})a_y$

$n - (1500\ \text{kg})(9.8\ \text{m/s}^2) = 0$

26. $T - 0.20n - (20\ \text{kg})(9.8\ \text{m/s}^2)\sin 20° = (20\ \text{kg})(2.0\ \text{m/s}^2)$

$n - (20\ \text{kg})(9.8\ \text{m/s}^2)\cos 20° = 0$

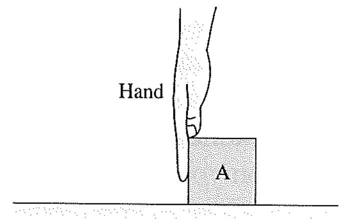
27. $(100\ \text{N})\cos 30° - f_k = (20\ \text{kg})\,a_x$

$n + (100\ \text{N})\sin 30° - (20\ \text{kg})(9.8\ \text{m/s}^2) = 0$

$f_k = 0.20n$

5.7 Interacting Objects

28. 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.



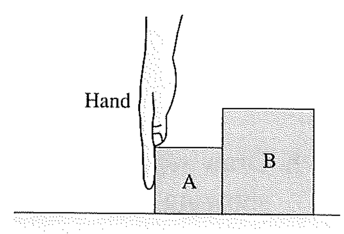
   a. Draw two free-body diagrams, one for the hand and the other for the block. On these diagrams, show only the *horizontal* forces with lengths portraying the relative magnitudes of the forces. Label force vectors, using the form $\vec{F}_{\text{C on D}}$. On the hand diagram, show only $\vec{F}_{\text{H on A}}$. Don't include $\vec{F}_{\text{body on H}}$.

   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:

   Explanation:

29. A second block B is placed in front of Block A of question 28. B is more massive than A: $m_B > m_A$. The blocks are speeding up.



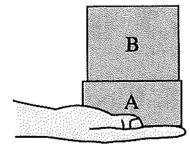
   a. Consider a *frictionless* surface. Draw separate free-body diagrams for A, B, and the hand. Show only the horizontal forces. Label forces in the form $\vec{F}_{\text{C on D}}$.

   b. By applying Newton's 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:

   Explanation:

30. 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 blocks' weights, making sure vector lengths indicate the relative sizes of the forces. For your hand, show only forces exerted by the blocks; neglect the weight of your hand or any forces exerted on your hand by your arm. Label forces in the form $\vec{F}_{C\text{ on }D}$.

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

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

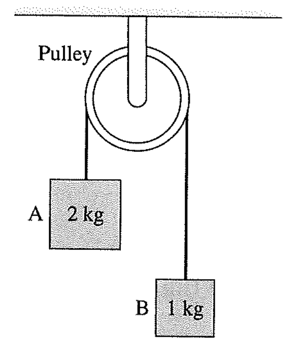
a. How do you think the size of the force that the car exerts on the mosquito compares to the size of the force that the mosquito exerts on the car?

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 $\vec{F}_{C\text{ on }D}$.

c. Does your answer to part b confirm your answer to part a? Explain why or why not.

5.8 Ropes and Pulleys

32. 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.



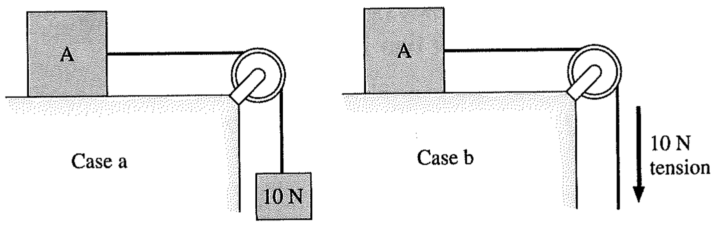
a. Will the blocks accelerate? If so, in which directions?

b. Draw a separate free-body diagram for each block. Be sure vector lengths indicate the relative sizes of the forces.

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

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

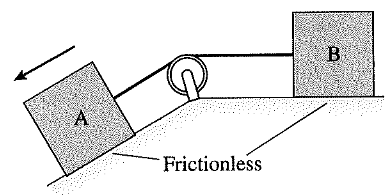
33. In case a, block A is accelerated across a frictionless table by a hanging 10 N weight (1.02 kg). In case b, the same block is accelerated by a steady 10 N tension in the string.



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

Exercises 34–35: Draw separate free-body diagrams for blocks A and B. Indicate any pairs of forces having the same magnitude.

34.



35.