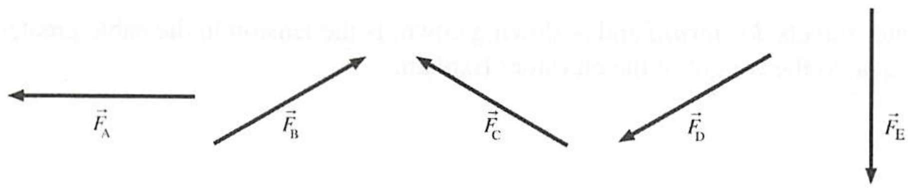
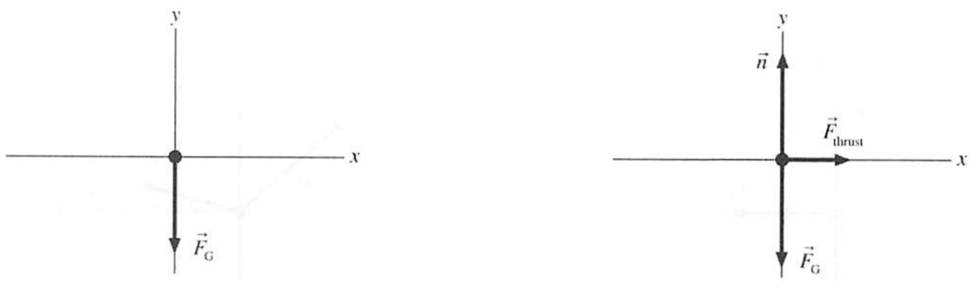
# 6 Dynamics I: Motion Along a Line

## 6.1 The Equilibrium Model

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?




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.

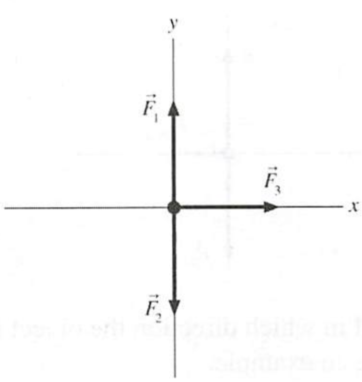
## 6.2 Using Newton's Second Law

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.

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.

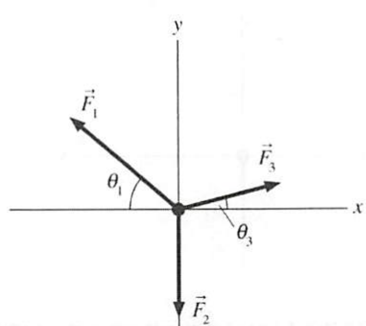
**Exercises 5–6:** The figures show free-body diagrams for an object of mass *m*. Write the *x*- and *y*-components of Newton's second law. Write your equations in terms of the *magnitudes* of the forces $F_1, F_2, \ldots$ and any *angles* defined in the diagram. One equation is shown to illustrate the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

5.




$ma_x =$ ______

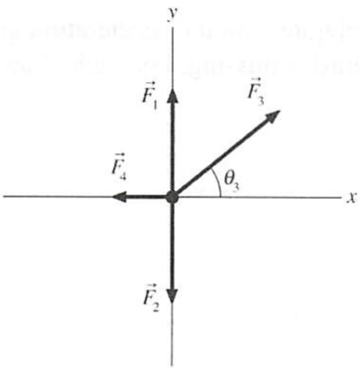
$ma_y = F_1 - F_2$

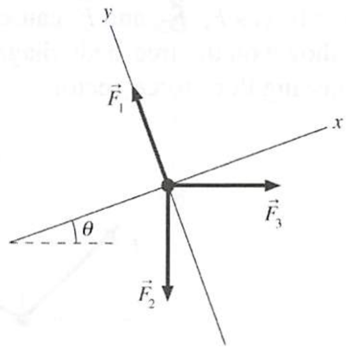



$ma_x =$ ______

$ma_y =$ ______

6.



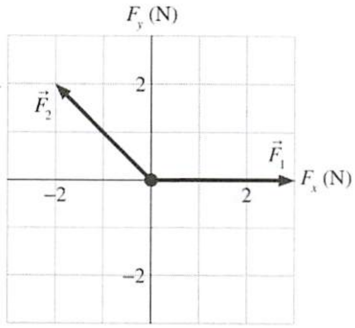

$ma_x = F_3 \cos \theta_3 - F_4$ $\qquad$ $ma_x =$ ______

$ma_y =$ ______ $\qquad$ $ma_y =$ ______

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

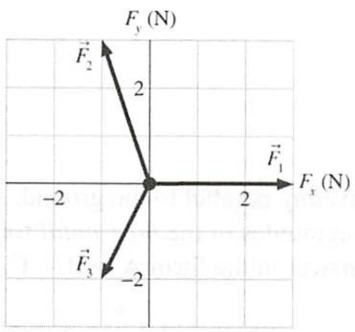
7.




$a_x =$ ______

$a_y =$ ______

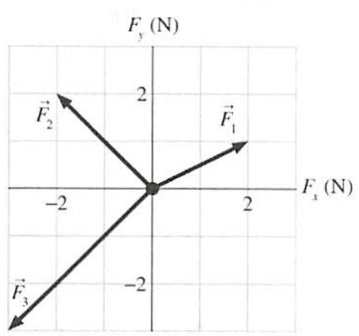
8.




$a_x =$ ______

$a_y =$ ______

9.

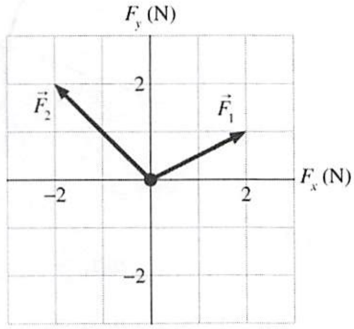



$a_x =$ ______

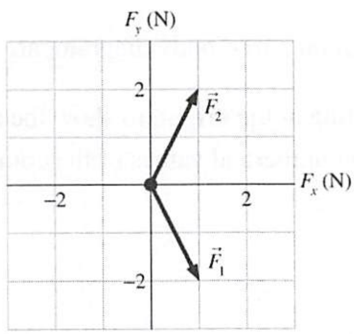
$a_y =$ ______

**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.

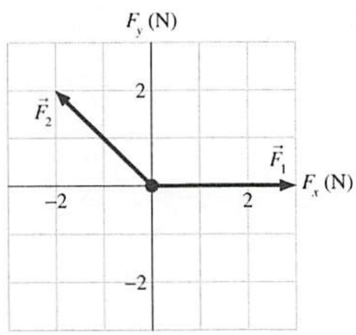
10. $\vec{a} = 2\hat{\imath}$ m/s$^2$



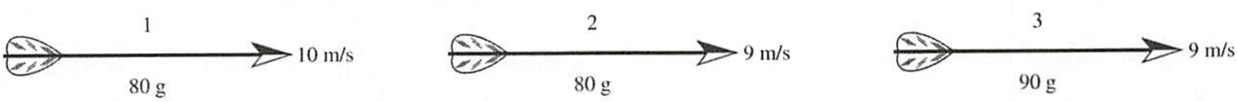

11. $\vec{a} = -3\hat{\jmath}$ m/s$^2$




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 $\vec{F}_1$, $\vec{F}_2$, and $\vec{F}_3$ acting on the arrows. Some may be equal. Give your answer in the form A > B = C > D.




Order:

Explanation:

## 6.3 Mass, Weight, and Gravity

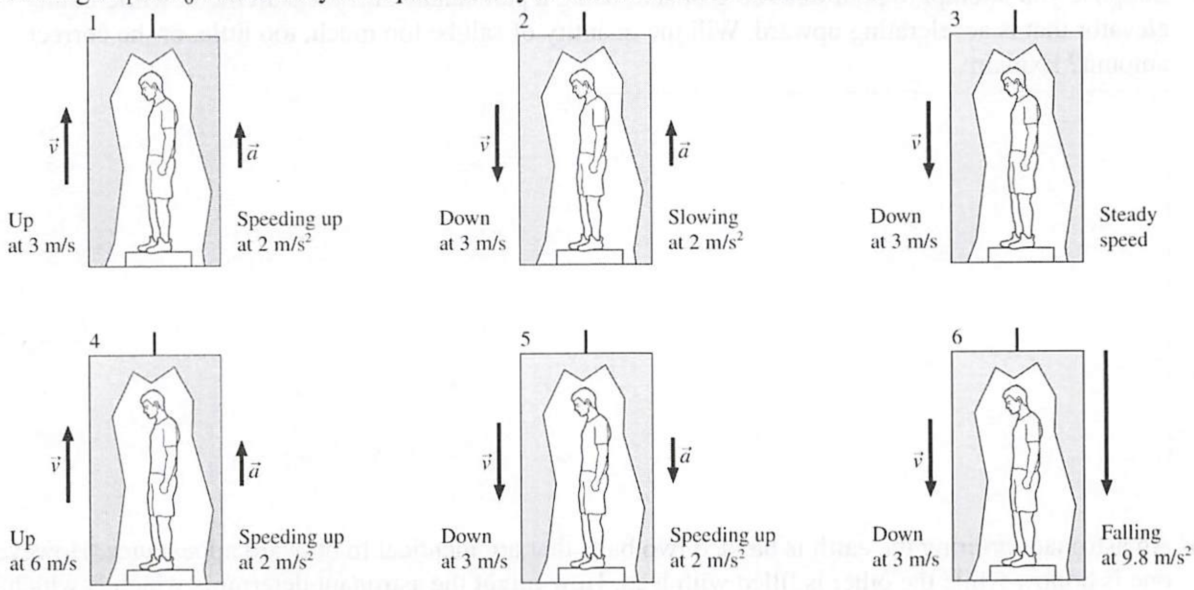
14. An astronaut takes his bathroom scales to the moon and then stands on them. Is the reading of the scales his weight? Explain.

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.

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.

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. 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:

## 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.

    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.

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.

    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?

       $\vec{F}_{\text{push}}$ ____________

       $\vec{F}_{\text{G}}$ ____________

       $\vec{n}$ ____________

       $\vec{f}_{\text{s}}$ ____________

       $\vec{f}_{\text{s max}}$ ____________

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 physical models and the principles described in this chapter.

22. A car is parked on a road that slopes upward at angle $\theta$. The magnitude of the normal force of the road on the car is $mg\cos\theta$. Is the magnitude of the static friction force on the car less than, equal to, or greater than $\mu_s mg\cos\theta$? Explain.

23. PSS 6.1 A small airplane of mass $m$ must take off from a primitive jungle airstrip that slopes upward at a slight angle $\theta$. 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 $\mu_r$. If the plane's take-off speed is $v_{\text{off}}$, 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 1.5. 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. $\vec{F}_{\text{thrust}}$, $m$, $\theta$, $\mu_r$, and $v_{\text{off}}$ 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 $\vec{F}_G$ (see Figure 6.2), and pay close attention to signs. Remember that symbols such as $F_G$ or $f_r$ or 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 $F_G = mg$ 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? ______________

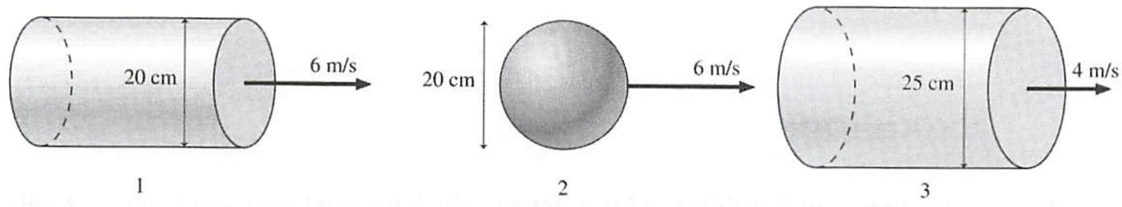
h. Does your expression for acceleration agree with your answer to part g? ______________
Explain how you can tell. If it doesn't, recheck your work.

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 $F_{\text{thrust}}$ or $\theta$ without having to go through the entire solution each time.

## 6.5 Drag

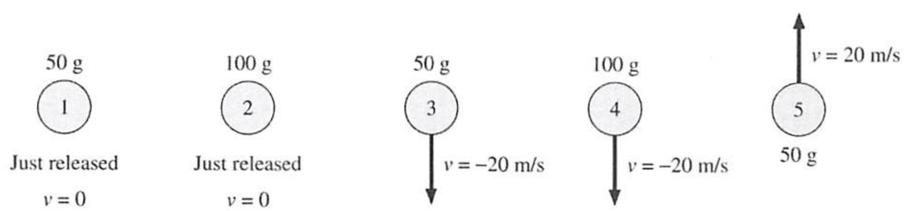
24. Three objects move through the air as shown. Rank in order, from largest to smallest, the three drag forces $F_{drag\ 1}$, $F_{drag\ 2}$, and $F_{drag\ 3}$. Some may be equal. Give your answer in the form A > B = C > D.




Order:

Explanation:

25. 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:

26. 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.

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

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

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.

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.

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