5 Applying Newton's Laws

5.1 Equilibrium

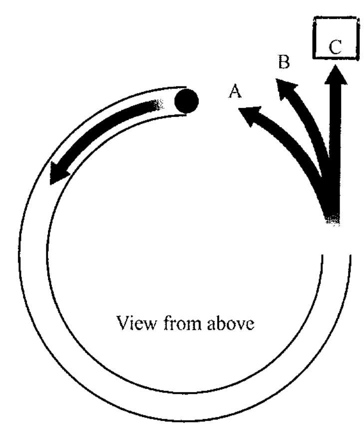
1. If an object is at rest, can you conclude that there are no forces acting on it? Explain.

No. You can only conclude that there is no net force on the object if it remains at rest.

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

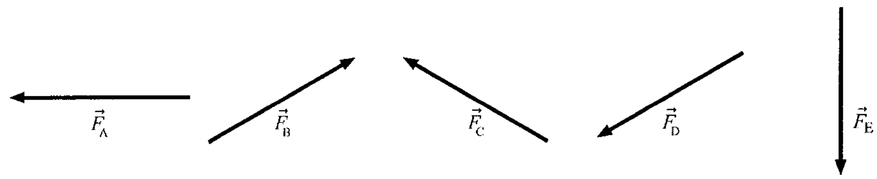
If one nonzero force acts on an object, then it must accelerate (It cannot move at constant velocity). If multiple forces act on the object, it can move at constant velocity if those forces sum to zero net force.

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.



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.

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?

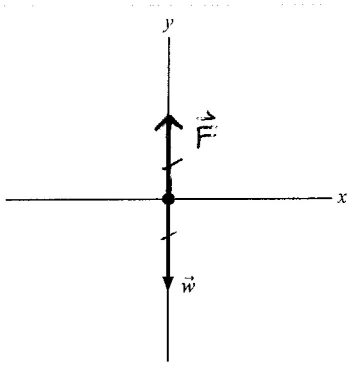


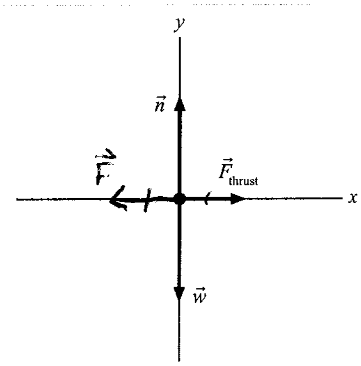
$\vec{F}_B + \vec{F}_D$

OR

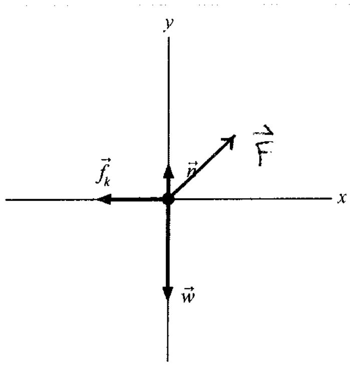
$\vec{F}_B + \vec{F}_C + \vec{F}_E$

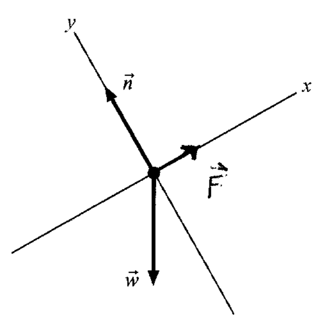
5. The free-body diagrams show a force or forces acting on an object. Draw and label one more force (one that is appropriate to the situation) that will cause the object to be in equilibrium.





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.

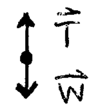




5.2 Dynamics and Newton's Second Law

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 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.

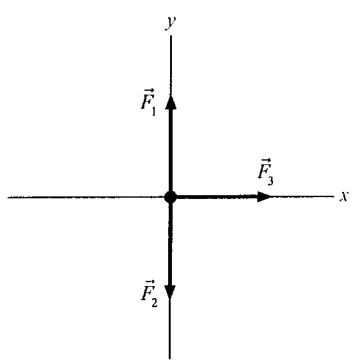


b. The elevator travels *downward* and is slowing down. Is the tension in the cable greater than, less than, or equal to the weight of the elevator? Explain.

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.

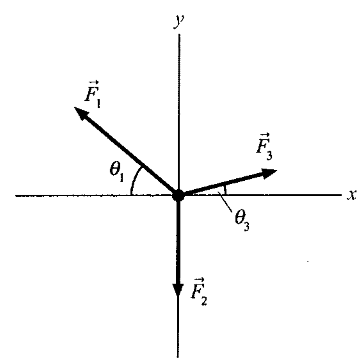
Exercises 8–9: The figures show free-body diagrams for an object of mass m. Write the x- and y-components of Newton's second law. Write your equations in terms of the *magnitudes* of the forces $F_1, F_2, \ldots$ and any *angles* defined in the diagram. One equation is shown to illustrate the procedure.

8.



$ma_x = F_3$

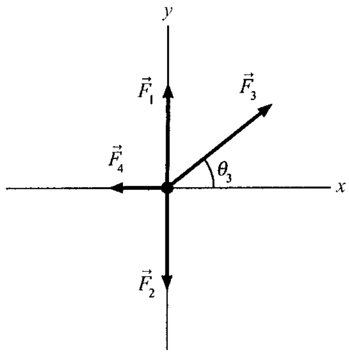
$ma_y = F_1 - F_2$

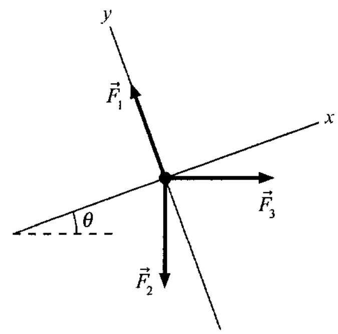


$ma_x = F_3\cos\theta_3 - F_1\cos\theta_1$

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

9.





$ma_x = F_3 \cos\theta_3 - F_4$

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

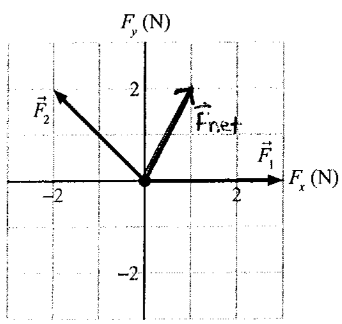
$ma_x = F_3 \cos\theta - F_2 \sin\theta$

$ma_y = F_1 - F_2 \cos\theta$

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

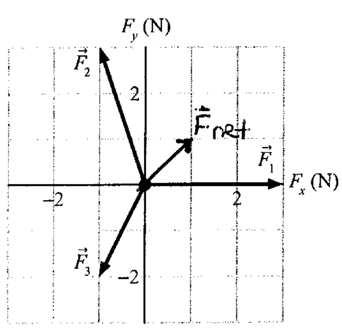
10.



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

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

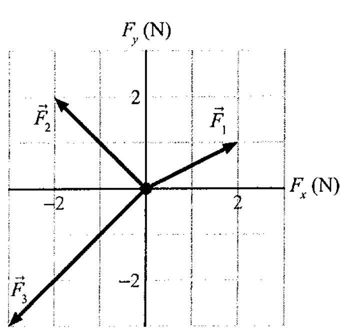
11.



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

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

12.

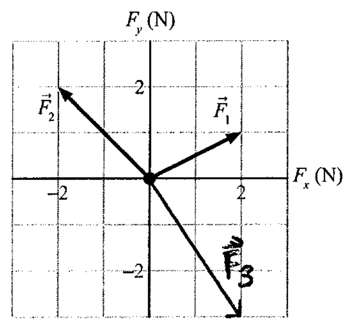


$a_x = \frac{1}{2\,kg}(2N - 2N - 3N) = 1.5\frac{m}{s^2}$

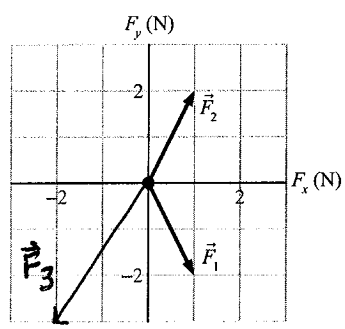
$a_y = \frac{1}{2\,kg}(1N + 2N - 3N) = 0\frac{m}{s^2}$

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.

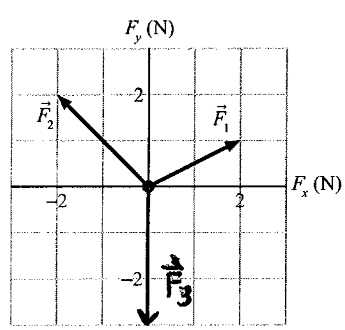
13. $\vec{a} = (2\,\text{m/s}^2)$



14. $\vec{a} = (0, -3\,\text{m/s}^2)$

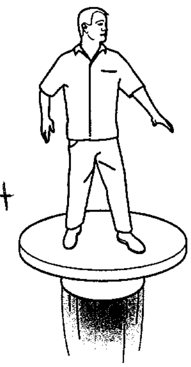


15. The object moves with constant velocity.



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.



W_{app} = apparent weight

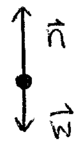
W = true weight

a. You are ascending and speeding up.

$W_{app} > W$

The net force must be upwards.

$\vec{W}_{app} = \vec{n}$ $a_y > 0$



b. You are descending and speeding up.

$W > W_{app}$

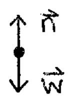
The net force is downwards.

$a_y < 0$

c. You are ascending at a constant speed.

$W = W_{app}$ There is no net force.

$a = 0$



d. You are ascending and slowing down.

$W > W_{app}$

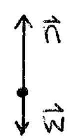
To slow down, the net force must be opposite the motion.

$a_y < 0$

e. You are descending and slowing down.

$W_{app} > W$

The net force must be upwards to slow down while moving downwards. $a_y > 0$



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.

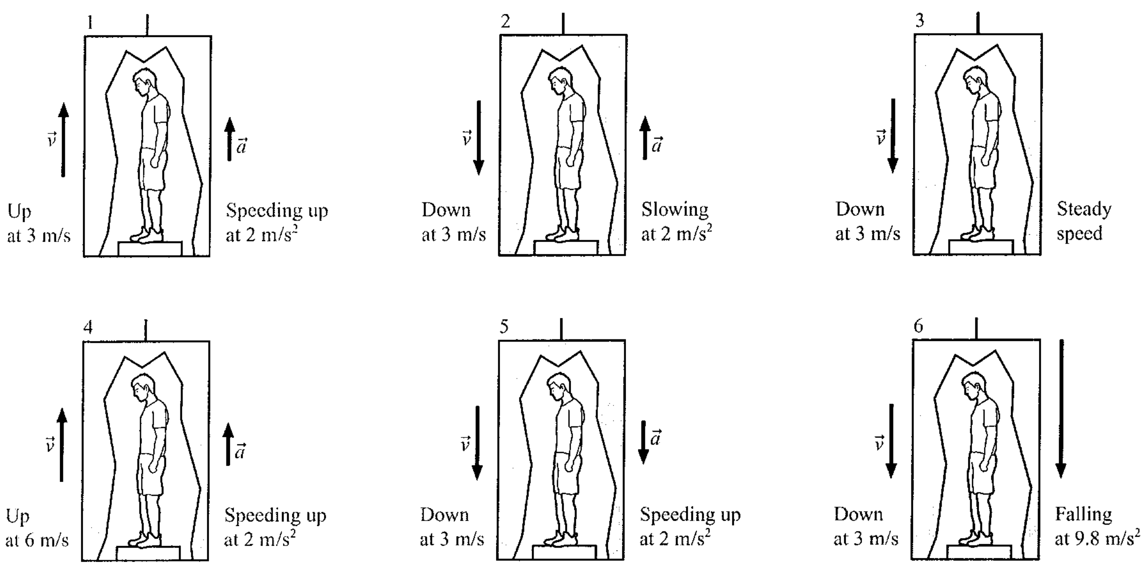
Horizontal can be defined by the surface of a liquid far from the edges of its container or by using a bubble level.

18. 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.

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.

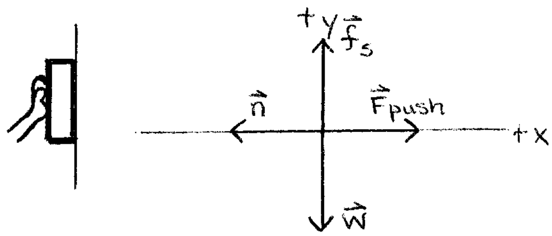


Order: $S_1 = S_2 = S_4 > S_3 > S_5 > S_6$

Explanation: The scale reading reads your apparent weight, which depends upon the magnitude and direction of your acceleration only, not your speed. Cases 1, 2, and 4 all involve equal upward accelerations. Case 3 has no acceleration so the scale reads your true weight. Case 5 reads less than your true weight because your acceleration is downward. For case 6, the scale reading S_6 will be zero.

5.5 Friction

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:
$F_x = F_{push} - n = 0$
$F_y = f_s - w = 0$

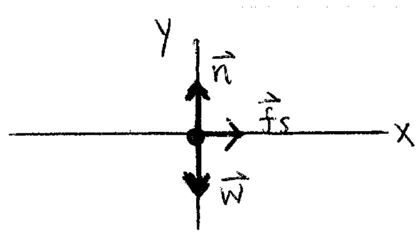
   b. Now suppose you decrease your push, but not enough for the book to slip. What happens to each of the following forces? Do they increase in magnitude, decrease, or not change?

$\vec{F}_{push}$ decreases
$\vec{w}$ Same
$\vec{n}$ decreases
$\vec{f}_s$ Same
$f_{s\,max}$ decreases

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.

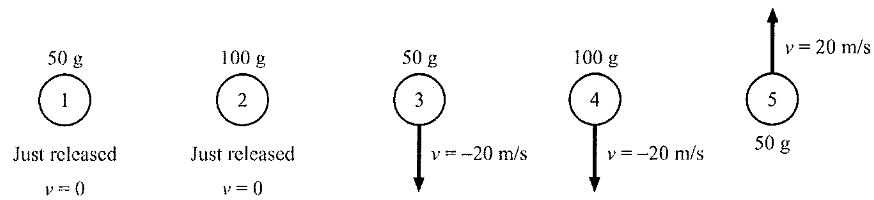


   c. What happens to the box if the truck accelerates too rapidly? *Explain* why this happens, basing your explanation on physical models and the principles described in this chapter.

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; $\vec{f}_{s_{max}} = \mu_s \vec{n}$. 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).

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 size 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 and ball 4 experiences a greater gravitational force.

23. 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? lead ball

b. Are their accelerations equal? 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. When air resistance is included, each ball will experience the *same* drag force when moving at the same speed because both have the same shape. Are the accelerations of the balls now equal or different? If not, which has the larger acceleration? Explain, using your free-body diagrams and Newton's laws.

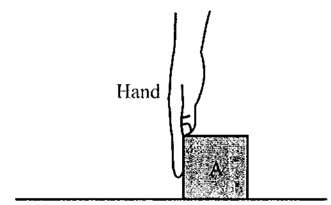
The lead ball has a greater acceleration. Because the drag force is independant of the mass, it will have less effect in reducing the acceleration due to gravity of the lead ball. Using Newton's Second law $|a| = \frac{|F|}{m} = \frac{|w+D|}{m} = \frac{mg-D}{m} = g - \frac{D}{m}$. Thus, the larger mass of the lead ball leads to a smaller change in the magnitude of the acceleration (absent air resistance).

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

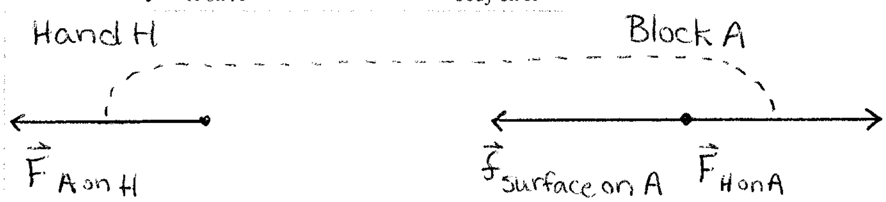
The lead ball will hit the ground first because it has a greater magnitude acceleration.

5.7 Interacting Objects

24. Block A is pushed across a horizontal surface at a *constant* speed by a hand that exerts force $\vec{F}_{H \text{ on } A}$. 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 $\vec{F}_{C \text{ on } D}$. Connect action/reaction pairs with dotted lines. On the hand diagram show only $\vec{F}_{H \text{ on } A}$. Don't include $\vec{F}_{\text{body on } H}$.



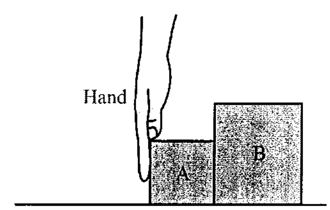
b. Rank in order, from largest to smallest, the magnitudes of *all* of the horizontal forces you showed in part a. For example, if $F_{C \text{ on } D}$ is the largest of three forces while $F_{D \text{ on } C}$ and $F_{D \text{ on } E}$ are smaller but equal, you can record this as $F_{C \text{ on }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

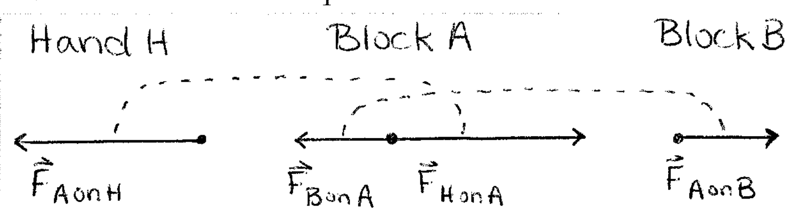
Order: $F_{H on A} = F_{A on H} = f_{surface on A}$

Explanation: $\vec{F}_{H on A} = \vec{F}_{A on H}$ due to Newton's third law. these are an action-reaction pair. $\vec{F}_{H on A} = \vec{f}_{surface on A}$ 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 $\vec{F}_{net} = 0$.

25. A second block B is placed in front of Block A of question 24. 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 dotted lines to connect action/reaction pairs.



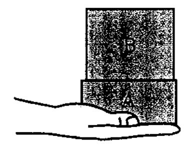


b. By applying the second law to each block and the third law to each action/reaction pair, rank in order *all* of the horizontal forces, from largest to smallest.

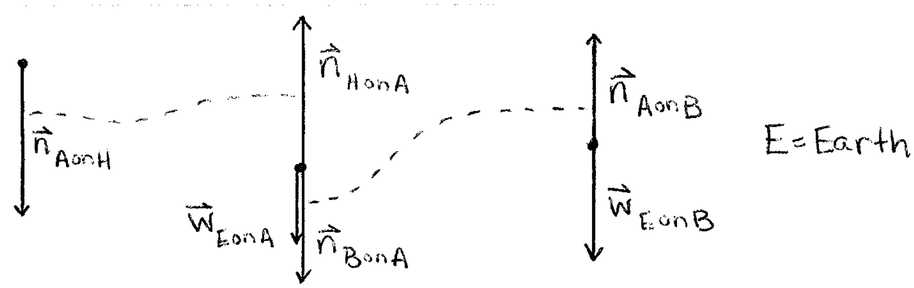
Order: $F_{A on H} = F_{H on A} > F_{B on A} = F_{A on B}$

Explanation: The only horizontal force on B is by block A. In order for block A to be speeding up, the net force on it must be towards B. Thus, $F_{H on A}$ must be greater than $F_{B on A}$ by Newton's Second Law.

26. 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 $\vec{F}_{C \text{ on } D}$. Connect action/reaction pairs with dotted lines.



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

$n_{A on H} = n_{H on A} > n_{B on A} = n_{A on B} = W_{E on B} > W_{E on A}$

Newton's 3rd Law Action-Reaction Pair; Action-Reaction Pair; Block B is more massive

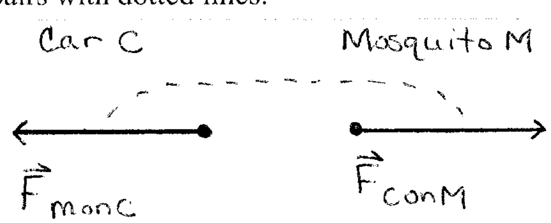
Constant speed for block A; Constant speed $F_{net} = 0$ on B

27. 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.

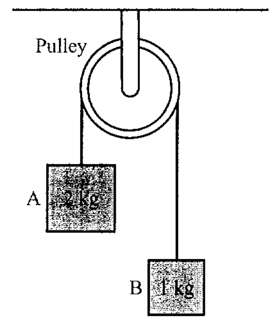


c. Does your answer to part b confirm your answer to part a? Explain why or why not.

Yes, the forces are equal and opposite.

5.8 Ropes and Pulleys

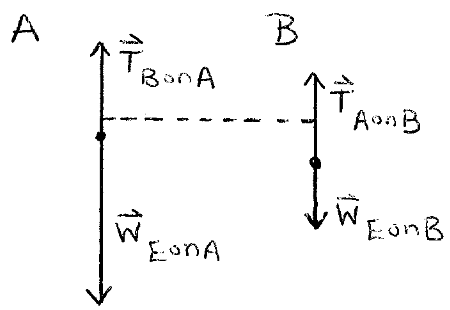
28. Blocks A and B are connected by a massless string over a massless, frictionless pulley. The blocks have just this instant been released from rest.



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 "forces that act *as if* they are action/reaction" pairs with dotted lines.



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

$W_{EonA} > T_{BonA} = T_{AonB} > W_{EonB}$

Because A is more massive than B, it will accelerate down. Therefore, its weight must be greater than T_{BonA}. $T_{AonB} = T_{BonA}$ by Newton's third law. Block B accelerates upward. Therefore, $T_{AonB} > W_{EonB}$, by Newton's second 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.

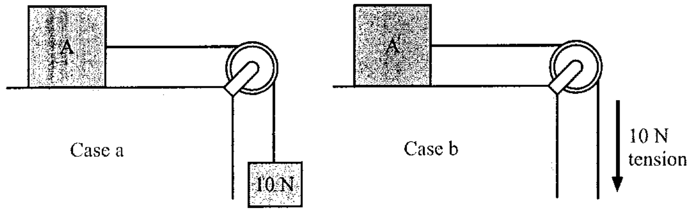
The net force on A is greater than the net force on B. Both blocks have the same magnitude acceleration. The force must be greater on A to produce the same acceleration because it is more massive.

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_{BonA} that is in the opposite direction from the weight.

$$T_{BonA} - m_A g = m_A a \text{ so } a_A = -g + \frac{T_{BonA}}{m_A}$$

29. 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

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

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

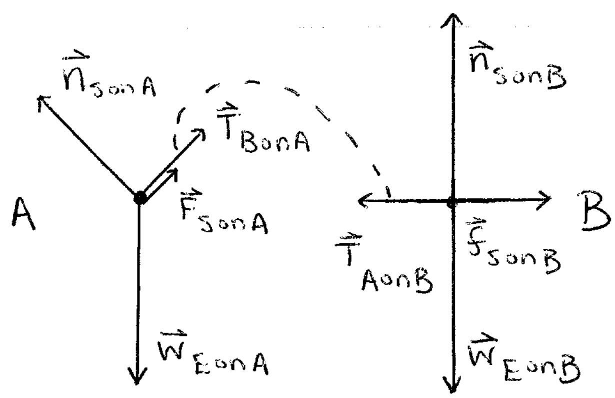
Case b

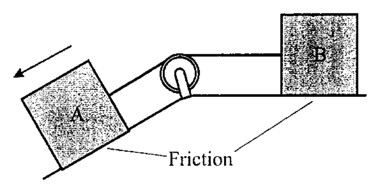
$T = 10N = M_A a$

$a = 10N / M_A$

Exercises 30–31: 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 dotted lines.

30.





31.