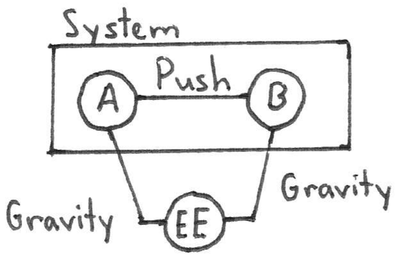
7 Newton's Third Law

7.1 Interacting Objects

7.2 Analyzing Interacting Objects

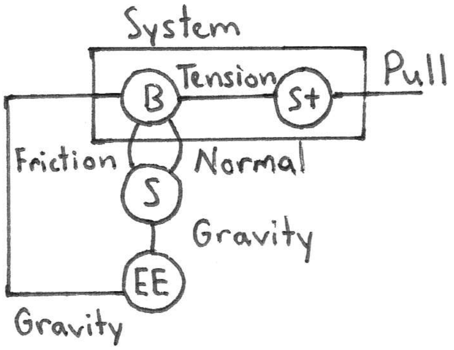
Exercises 1–7: Follow steps 1–3 of Tactics Box 7.1 to draw interaction diagrams describing the following situations. Your diagrams should be similar to Figures 7.6 and 7.10.

1. A bat hits a ball.



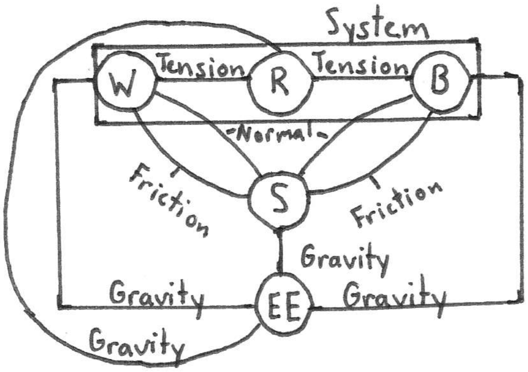
A = Bat
B = Ball
EE = Entire Earth

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



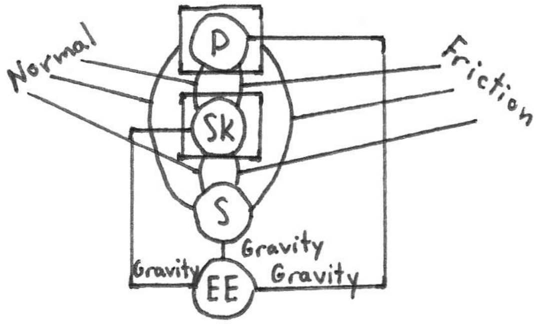
B = Box
S = Surface
St = String
EE = Entire Earth

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.



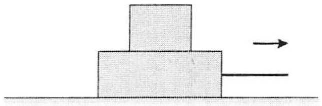
W = Wagon
B = Boy
R = rope
S = surface
EE = Entire Earth

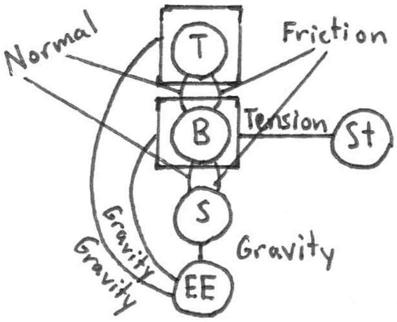
4. A skateboarder is pushing on the ground to speed up. Treat the person and the skateboard as separate objects.



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

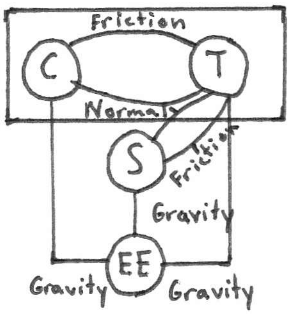
5. The bottom block is pulled by a massless string. Friction is not negligible. Treat the two blocks as separate objects.





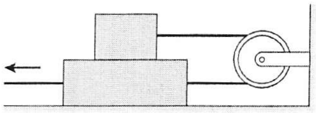
T = top block
B = bottom block
St = string
S = surface
EE = Entire Earth

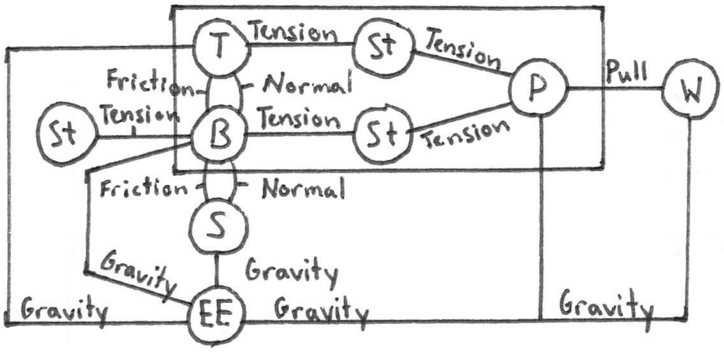
6. A crate in the back of a truck does not slip as the truck accelerates forward. Treat the crate and the truck as separate objects.



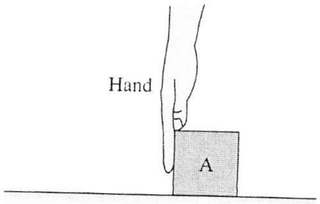
C = Crate
T = truck
S = surface (road)
EE = Entire Earth

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





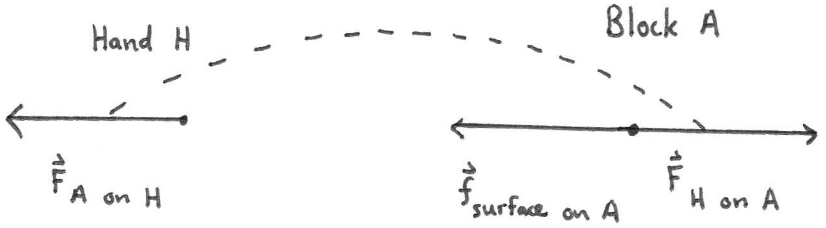
7.3 Newton's Third Law



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.



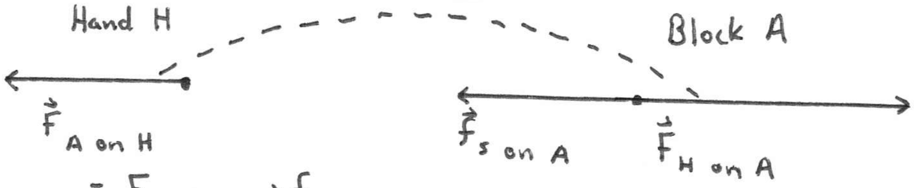
b. Rank in order, from largest to smallest, the magnitudes of *all* of the horizontal forces you showed in part a. For example, if $F_{\text{C on D}}$ is the largest of three forces while $F_{\text{D on C}}$ and $F_{\text{D on E}}$ are smaller but equal, you can record this as $F_{\text{C on D}} > F_{\text{D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

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

Explanation:

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

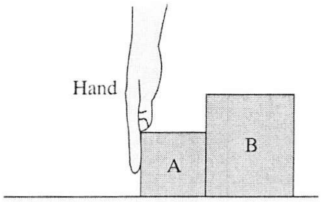
c. Repeat both part a and part b for the case that the block is *speeding up*.



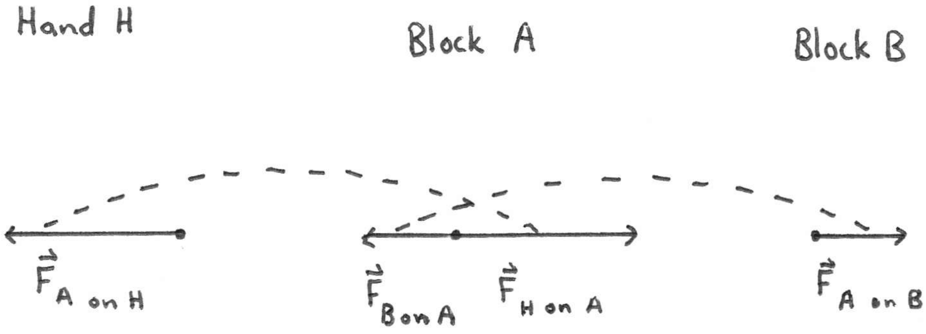
$F_{H \text{ on } A} = F_{A \text{ on } H} > f_{s \text{ on } A}$

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. $\vec{F}_{H \text{ on } A}$ 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.



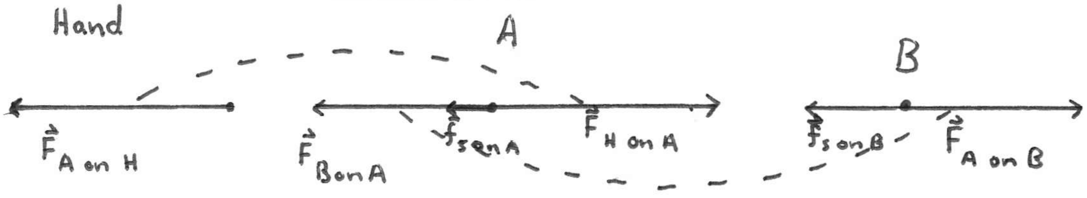
b. By applying the second law to each block and the third law to each action/reaction pair, rank in order *all* of the horizontal forces, from largest to smallest.

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

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, $F_{H \text{ on } A}$ must be greater than $F_{B \text{ on } A}$ by Newton's Second Law.

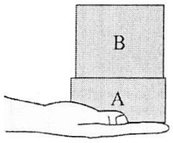
c. Repeat parts a and b if the surface has friction. Assume that A and B have the same coefficient of kinetic friction.



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

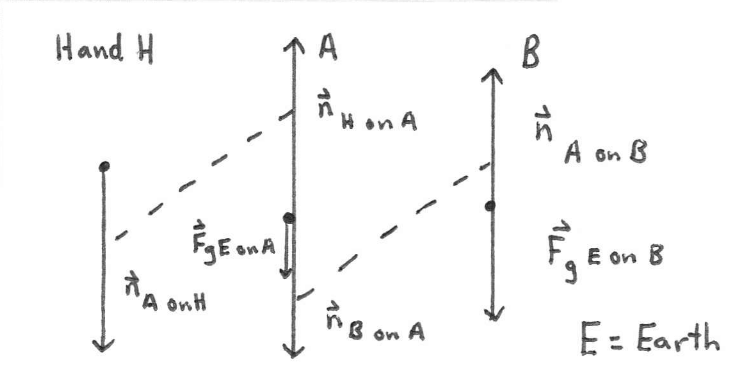
If block B is speeding up, then $F_{A \text{ on } B} > f_{s \text{ on } B}$ by Newton's Second Law. Similarly for block A to speed up, $F_{H \text{ on } A} > F_{B \text{ on } A} + f_{s \text{ on } A}$ Also, $f_{s \text{ on } B} > f_{s \text{ on } A}$ because Block B is more massive than block A, leading 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 $\vec{F}_{C\ on\ D}$.
- Connect action/reaction pairs with dashed lines.



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

$$\underbrace{n_{A\ on\ H} = n_{H\ on\ A}}_{\text{Newton's Third Law Action Reaction Pair}} > \underbrace{n_{B\ on\ A} = n_{A\ on\ B}}_{\text{Action Reaction Pair}} = \underbrace{F_{g\,E\ on\ B} > F_{g\,E\ on\ A}}_{\text{Block B is more massive}}$$

Constant Speed for block A

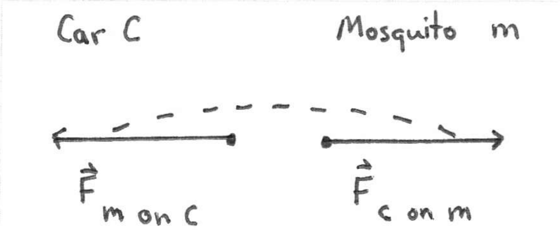
Constant speed, $F_{net} = 0$ on B

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?

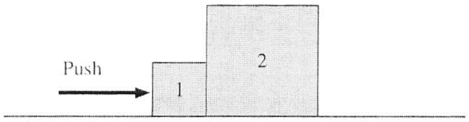
The force of the mosquito on the car is equal to the force of the car on the mosquito. (The mosquito undergoes a much larger acceleration, however, because of its much smaller mass $a = F_{net}/m$.)

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



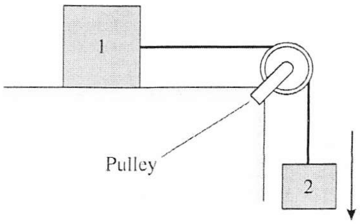
Exercises 12–16: Write the acceleration constraint in terms of *components*. For example, write $(a_1)_x = (a_2)_y$, if that is the appropriate answer, rather than $\vec{a}_1 = \vec{a}_2$.

12.



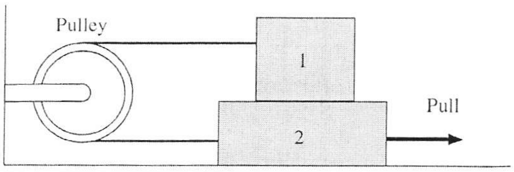
Constraint: $(a_1)_x = (a_2)_x$

13.



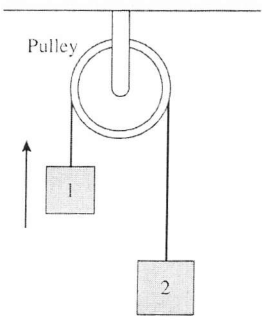
Constraint: $(a_1)_x = -(a_2)_y$

14.



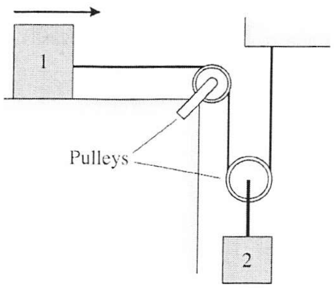
Constraint: $(a_1)_x = -(a_2)_x$

15.



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

16.



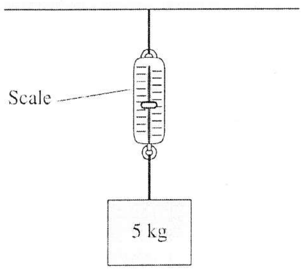
Constraint: $(a_1)_x = -2(a_2)_y$

7.4 Ropes and Pulleys

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

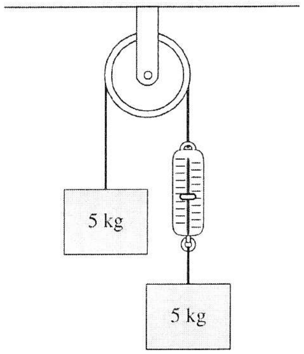
- All the masses are at rest.
- The strings and pulleys are massless, and the pulleys are frictionless.
- The spring scale reads in kg.

17.



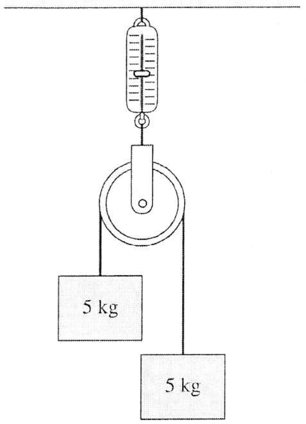
Scale = 5 kg

18.



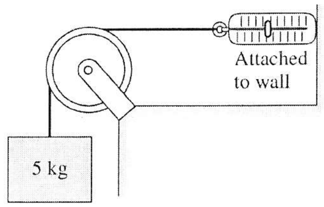
Scale = 5 kg

19.



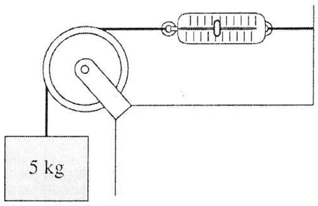
Scale = 10 kg

20.



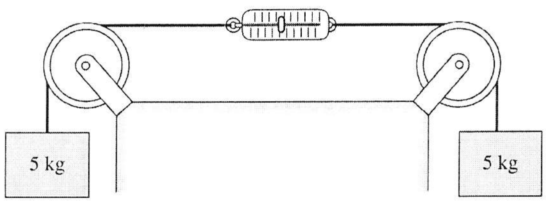
Scale = 5 kg

21.



Scale = 5 kg

22.

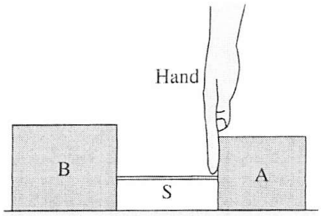


Scale = 5 kg

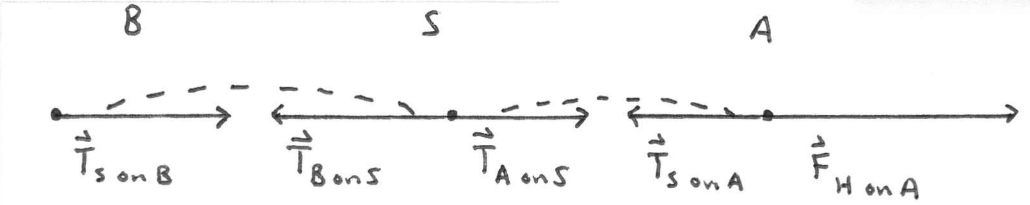
In each case above, the spring scale is held in place by two equal and opposite forces. In #18 and #22, the second mass provides the opposite force on the spring scale. In all other cases, the wall or the line attached to the wall provides the force.

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.

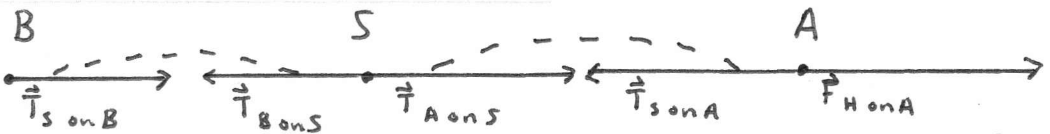


b. Rank in order, from largest to smallest, all of the horizontal forces. Explain.

$F_{H\ on\ A} > T_{S\ on\ A} = T_{A\ on\ S} = T_{B\ on\ S} = T_{S\ on\ B}$

$F_{H\ on\ A}$ must be greater than $T_{S\ on\ A}$ to accelerate A by Newton's Second Law. The string is massless and so there is no net force on the string (or else its acceleration 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.



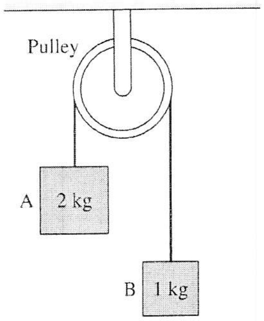
Because the string has mass and is accelerating, $T_{A\ on\ S} > T_{B\ on\ S}$. Similarly, by Newton's Second Law, $F_{H\ on\ A} > T_{S\ on\ A}$.

$$F_{H\ on\ A} > \underbrace{T_{S\ on\ A} = T_{A\ on\ S}}_{\text{Action-Reaction Pair}} > \underbrace{T_{B\ on\ S} = T_{S\ on\ B}}_{\text{Action-Reaction Pair}}$$

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

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

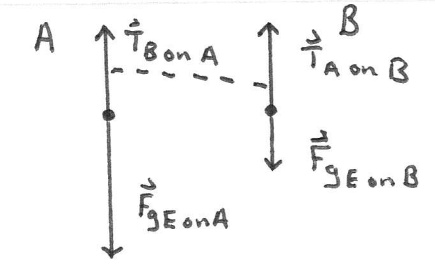
24. Blocks A and B are connected by a massless string over a massless, frictionless pulley. The blocks have just this instant been released from rest.



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.

$F_{g\,E\,on\,A} > T_{B\,on\,A} = T_{A\,on\,B} > F_{g\,E\,on\,B}$

Because A is more massive than B, it will accelerate downward. Therefore its weight must be greater than $T_{S\,on\,A}$. $T_{A\,on\,B} = T_{B\,on\,A}$ by Newton's Third Law. Block B accelerates upward. Therefore, $T_{A\,on\,B} > F_{g\,E\,on\,B}$, 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.

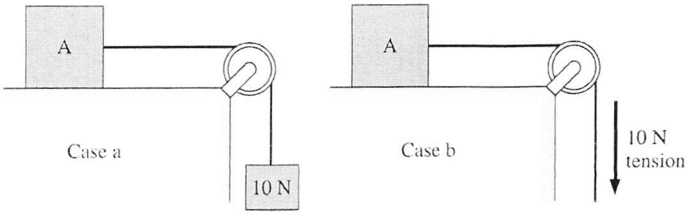
The net force on A is greater than the net force on B. Both blocks have the same magnitude acceleration. The force must be greater on A to produce the same acceleration because it is more massive.

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 $T_{B\,on\,A}$ 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

$F_g = 10N = (m_A + m_{\text{Hanging Weight}})a$

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

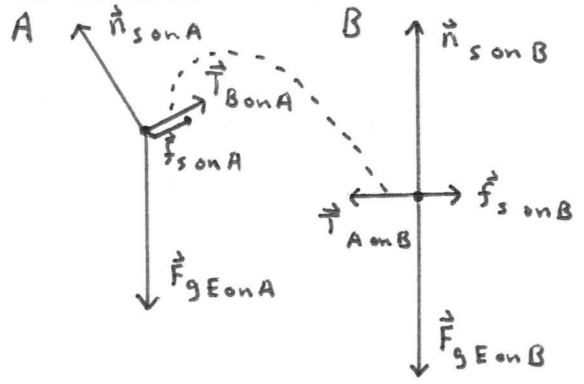
Case b

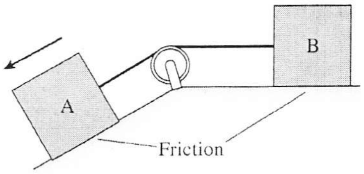
$T = 10N = m_A a$

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

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.