Answers for Unit 1

Lesson 1

Exercise 1.1.1: Displacement and velocity

1. Find the displacement for each of the following.

a) $\vec{d}_1$ = 22 m [E], $\vec{d}_2$ = 36 m [E]

Solution: 14m [E]

b) $\vec{d}_1$ = 32 m [W], $\vec{d}_2$ = 14 m [W]

Solution: -18m [W]

c) $\vec{d}_1$ = 52 m [N], $\vec{d}_2$ = 15 m [S]

Solution: 67m [S]

2. Solve the following problem

A storm is moving at an average velocity of 4.6 km/h [E] toward your town, which is 23 km [E] away. How long will it take the storm to reach the town?

Solution:

Given: $\vec{v}_{avg}$ = 4.6 km/h[E], $\overrightarrow{\Delta d}$ =23km[E]

The equation relating average velocity, displacement and time can be rearranged as follows:

$\vec{v}_{avg} = \frac{\overrightarrow{\Delta d}}{\Delta t}$

Multiply both sides of the equation by Δt to obtain:

$\vec{v}_{avg}\ x\ \Delta t = \overrightarrow{\Delta d}$

Divide both sides of this equation by $\vec{v}_{avg}$ to obtain:

$\Delta t = \overrightarrow{\Delta d} / \vec{v}_{avg}$

Now you can solve for Δt

Δt = 23km [E] / 4.6km/h [E]

Δt = 5.0h

The storm will reach the town in 5.0 h. Notice that since there are two significant digits in the given data, the answer must also have two significant digits.

Velocity is not the same thing as speed, so try not to confuse these terms. Velocity, like displacement, is a vector quantity with direction, while speed, like distance, is a scalar quantity with magnitude and units but no direction. Velocity and speed have the same magnitude when an object is moving in a straight line without changing direction.

To find speed, divide distance by time using an equation very similar to the one you just used. In this course, you will deal mainly with velocity because it provides more information about the movement than speed does. Velocity gives the magnitude and the direction of the motion.

Lesson 2

Exercises 2.3.1

1. The shot put is a track and field sporting event to determine who can throw a heavy ball the farthest. Find the acceleration of a women's shot put (mass of 4.0 kg) when a net force of 640 N [W] acts on it.

Solution:

Step 1

Given: $m = 4.0\text{ kg}$, $\vec{F}_{net} = 640\text{ N [W]}$

Step 2

$\vec{a}$ =?

Step 3

$\vec{F}_{net} = \overrightarrow{ma}$

Step 4

$\vec{a} = \frac{\vec{F}_{net}}{m}$

Step 5

Analysis and solution

$\vec{a} = \frac{\vec{F}_{net}}{m}$

$\vec{a} = 640\text{N [W]}/4.0\text{kg}$

$\vec{a} = 160\text{m/s}^2\text{ [W]}$

Step 6

Paraphrase: The acceleration is $160\text{ m/s}^2\text{ [W]}$.

2. A $1000\ \text{kg}$ car moving at $12\ \text{m/s}$ [S] accelerates for $5.0\ \text{s}$ reaching a final velocity of $26\ \text{m/s}$ [S]. Find the net force acting on the car.

Solution:

Step 1

Given

$m = 1000\ \text{kg}$

$v_i = 12\text{m/s}\ [\text{S}]$

$\Delta t = 5.0\text{s}$

$v_f = 26\text{m/s}\ [\text{S}]$

Step 2

$\vec{F}_{net} = ?$

Step 3

Analysis and Solution

$\vec{F}_{net} = \overrightarrow{ma}$

$\vec{a} = v_f\text{-}v_i/\Delta t$

Step 4

The equations are already in the correct arrangement to solve for acceleration and for net force.

Step 5

$\vec{a} = \frac{26m/s\ [S]\text{-}12m/s[S]}{5.0\ s}$

$\vec{a} = \frac{14\ m/s\ [S]}{5.0s}$

$\vec{a} = 2.8\ \text{m/s}^2\ [\text{S}]$

$\vec{F}_{net} = (1000\text{kg})(28\text{m/s}^2\,[\text{S}])$

$\vec{F}_{net} = 2800\text{N}[\text{S}]$

Step 6

The net force is $2.8 \times 10^3\ \text{N}\ [\text{S}]$

In this question, the data only two significant digits; to report the answer to only two significant digits, you need to use standard form.

Lesson 3

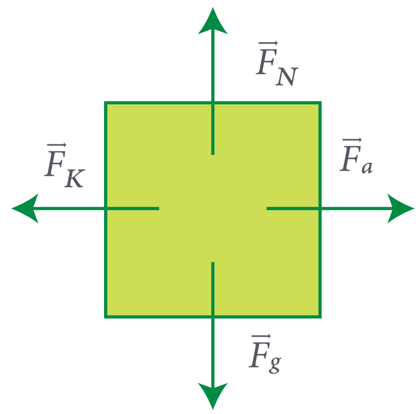
Exercises 3.1.1

Draw the free-body diagrams for:

1. A box pushed forward across a rough floor at a constant speed.

Solution:

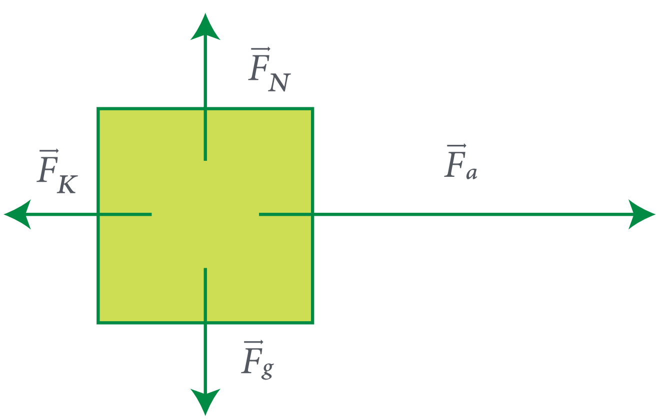
Both gravity and the normal force act on the box, and since these two forces have the same magnitude but are opposite in direction, they balance and cancel one another. Thus the vector arrows in the FBD are shown to be about the same length. In addition, you must also include an applied force to represent the push and kinetic friction due to the floor scraping against the bottom of the box. Because the box is travelling at a constant speed, it has zero acceleration. This is a Newton's first law situation: the forces in the [forward] and [backward] directions also balance and there is no net force on the box.



2. A box pushed across the floor and accelerating forwards

Solution:

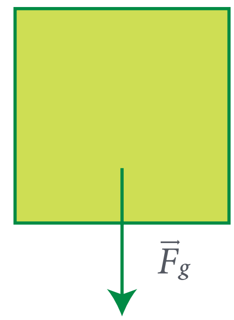
Once again, both gravity and the normal force act on the box, and these two forces balance and cancel one another in the vertical direction. The applied force and the force of kinetic friction act in the horizontal direction, but now the box is accelerating. This is a Newton's second law situation: the forces in the [forward] and [backward] directions are not balanced so that there is a net force on the box. For this reason the vector arrow for the applied pushing force is drawn longer than the vector arrow for kinetic friction.



3. A ball moving through the air because it was hit by a bat (ignore air friction)

Solution:

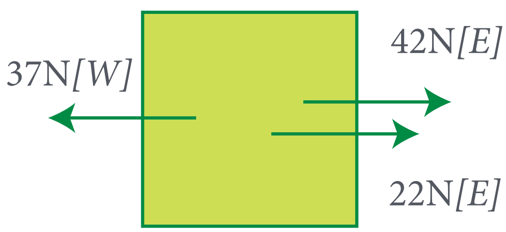
The side view FBD shows only the force of gravity acting on the ball. Consider that the ball is not touching the bat; thus there is no applied force. Nor is the ball touching the ground: thus, there is no normal force. Since the ball is not in contact with any surface, there is no force of friction, and or must ignore air friction, as the question indicates.



Exercises 3.1.2

1. A dog sled dragged over a frozen lake by two dogs (side view)

Solution:



$\vec{F}_{net}$ = 42N[E] + 22N[E] +37N[W]

Rewrite because the directions are not all the same

Convert "+ [W]" to "– [E]"

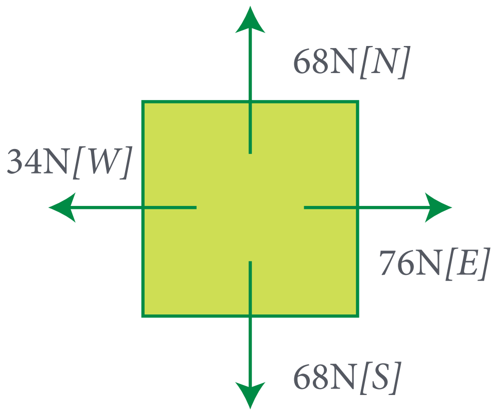
$\vec{F}_{net}$ = 42N[E] + 22N[E] -37N[E]

$\vec{F}_{net}$ = 27N[E]

The net force on the sled is 27 N [E].

2. An inflatable life raft paddled by four people (aerial view)

Solution:



Add the “vertical” or north and south forces.

$\vec{F}_{net} = 68N[N] + 68N[S]$

$\vec{F}_{net} = 68N[N] - 68N[N]$

$\vec{F}_{net} = 0$

Now add the “horizontal” or east and west forces.

$\vec{F}_{net} = 76N[E] + 34N[W]$

$\vec{F}_{net} = 76N[E] - 34N[E]$

$\vec{F}_{net} = 42N[E]$

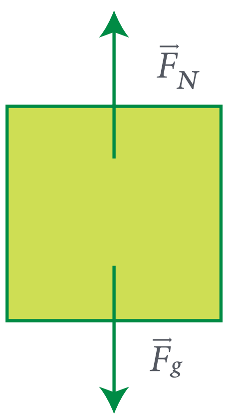
The net force on the life raft is 42 N [E].

Exercises 3.3.1

1. Find the normal force acting on a $3.0\ \text{kg}$ bag of groceries sitting at rest on a counter.

Solution:

First draw the FBD for the bag of groceries.



Now find the force of gravity acting on the bag of groceries.

$\vec{F}_g = mg$

$\vec{F}_g = (3.0\text{kg})(9.8\text{m/s}\ [\text{down}])$

$\vec{F}_g = 29.4\text{N}\ [\text{down}]$

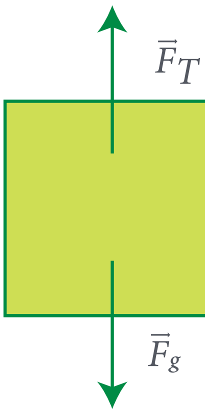
The force of gravity is $29.4\ \text{N}\ [\text{down}]$.

According to Newton's first law, since the bag of groceries is at rest, the net force on the bag is zero. This means the normal force must cancel the force of gravity, or the normal force must be equal in magnitude but opposite in direction to the force of gravity. Therefore, the normal force acting on the bag of groceries is $29.4\ \text{N}\ [\text{up}]$.

2. A cable exerts a force of tension of $1300\ \text{N}\ [\text{up}]$ on a $110\ \text{kg}$ beam to move it to the top of a building.

a) Draw the FBD of the beam as it is moving up.

Solution:



b) Find the force of gravity acting on the beam.

Solution:

$$\vec{F}_g = \overrightarrow{mg}$$

$$\vec{F}_g = (110\text{kg})(9.8\text{m/s}^2[\text{down}])$$

$$\vec{F}_g = 1078\text{N}[\text{down}]$$

The force of gravity acting on the beam is $1.1 \times 10^3\ \text{N}\ [\text{down}]$.

c) Find the net force acting on the beam.

Solution:

$$\vec{F}_{net} = 1300\text{N}[\text{up}] + 1078\text{N}[\text{down}]$$

$$\vec{F}_{net} = 1300\text{N}[\text{up}] - 1078\text{N}[\text{up}]$$

$$\vec{F}_{net} = 222\text{N}[\text{up}]$$

The net force acting on the beam is $2.2 \times 10^2\ \text{N}\ [\text{up}]$.

d) Find the acceleration of the beam.

Solution:

$\vec{F}_g = \overrightarrow{m\vec{a}}$

$\vec{a} = \frac{\vec{F}_{net}}{m}$

$\vec{a} = \frac{222\ \text{N [up]}}{110\ \text{kg}}$

$\vec{a} = 2.0\text{m/s}^2\text{[up]}$

The acceleration of the beam is $2.0\ \text{m/s}^2\ \text{[up]}$.

Lesson 4

Exercises 4.1.1

1. In a sentence, describe the reaction force for each of the following:

a) Your foot pushes backward on the floor when you are walking.

Solution: The floor pushes forward on your foot.

b) Your hand pushes with a force of $30\ \text{N [E]}$ on a door to open it.

Solution: The door pushes with a force of $30\ \text{N [W]}$ on your hand.

c) You push a book with a force of $15\ \text{N [forward]}$.

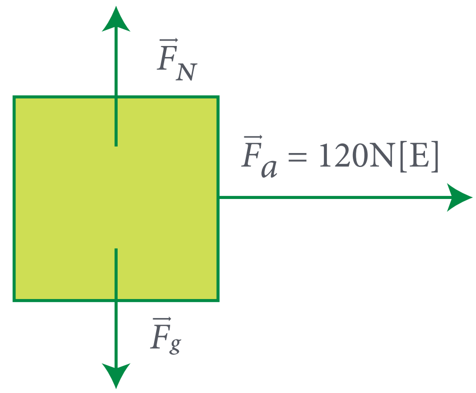
Solution: The book pushes you with a force of $15\ \text{N [backward]}$.

2. A brother and sister, Gianni and Nalini, are playing on the sidewalk in front of their home. Gianni, sitting on a skateboard (total mass of $60.0\ \text{kg}$), pushes on Nalini, also sitting on a skateboard (total mass of $40.0\ \text{kg}$). Gianni pushes on Nalini with a force of $120\ \text{N [E]}$. Assume there is no friction acting on either skateboard.

a) Draw an FBD of each child.

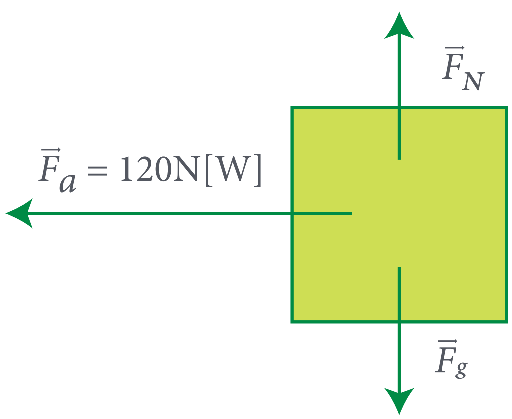
Solution:

FBD of Nalini:



According to Newton's third law, when Gianni pushes on Nalini (action force), the reaction force is Nalini pushing on Gianni with an equal but opposite force of $120\ \text{N}\ [\text{W}]$.

FBD of Gianni:



b) Find the acceleration of Nalini.

Solution:

$\vec{F}_g = m\vec{a}$

$\vec{a} = \frac{\vec{F}_{net}}{m}$

$\vec{a} = \frac{120\ \text{N}\ [\text{E}]}{40.0\ \text{kg}}$

$\vec{a} = 3.0\text{m/s}^2\ [\text{E}]$

The acceleration of Nalini is $3.0\ \text{m/s}^2\ [\text{E}]$.

c) Find the acceleration of Gianni.

Solution:

$\vec{F}_g = m\vec{a}$

$\vec{a} = \frac{\vec{F}_{net}}{m}$

$\vec{a} = \frac{120\ \text{N [W]}}{60.0\ \text{kg}}$

$\vec{a} = 2.0\text{m/s}^2\ [\text{W}]$

The acceleration of Gianni is $2.0\ \text{m/s}^2\ [\text{W}]$.

d) Explain why, although they are opposite in direction, the accelerations are not equal.

Solution:

The accelerations are not equal in magnitude because Gianni has more mass than Nalini. Although the forces in the FBDs are equal $(120\ \text{N})$, the masses of the two children are not. According to Newton's second law, if the net force acting on two bodies is the same in magnitude, then the acceleration of the larger mass will be smaller in magnitude According to Newton's third law, the directions of the forces are opposite; therefore the accelerations are also opposite in direction.

Exercises 4.2.1

1. A squid is a marine animal with long tentacles and an interesting way of swimming. To quickly evade enemies, a squid sucks water into a muscular sack and then shoots it out through a tube located near its mouth, amid its eight arms and two tentacles. Using Newton's third law, explain how a squid can swim by expelling water.

Solution:

The squid exerts an action force on the water backward, in the direction of the trailing arms. According to Newton's third law, the reaction force from the water on the squid is equal in magnitude but opposite in direction. This reaction force accelerates the squid forward, moving it headlong through the water.

2. Explain what a person standing on a skateboard can do to accelerate forward.

Solution:

The person can push with one foot on the ground backward. According to Newton's third law, the reaction force from the ground on the person's foot will be equal in magnitude but opposite in direction. The forward reaction force will accelerate the person and skateboard forward.

3. A toy water rocket accelerates up into the air by expelling water outward.

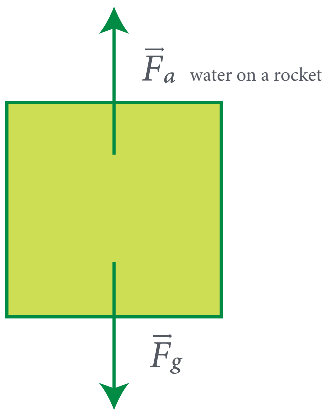
a) Explain how the water rocket can accelerate up into the air.

Solution:

The water rocket exerts an action force on the water, forcing it down. According to Newton's third law, the reaction force from the water on the rocket is equal in magnitude, but directed upwards. If the reaction force is larger than the force of gravity on the water rocket, the water rocket will accelerate up.

b) Draw an FBD of the water rocket.

Solution:



c) The water rocket has a mass of 1.5 kg at one moment while it is in the air and it exerts a force of 20.0 N [down] on the water firing outward. Find the acceleration of the water rocket at this point.

Solution:

$$\vec{F}_g = \overrightarrow{mg}$$

$$\vec{F}_g = (1.5\text{kg})(9.8\text{m/s}^2[\text{down}])$$

$$\vec{F}_g = 14.7\text{N}[\text{down}]$$

The force of gravity is 14.7 N [down].

Since the rocket exerts a force of 20.0 N [down] on the water, the water exerts a reaction force of 20.0 N [up] on the rocket. Now find the net force acting on the rocket.

$\vec{F}_{net}$ = 20.0N [up]+14.7N [down]

$\vec{F}_{net}$ = 20.0N [up]-14.7N [up]

$\vec{F}_{net}$ = 5.3N

The net force acting on the rocket is 5.3 N [up].

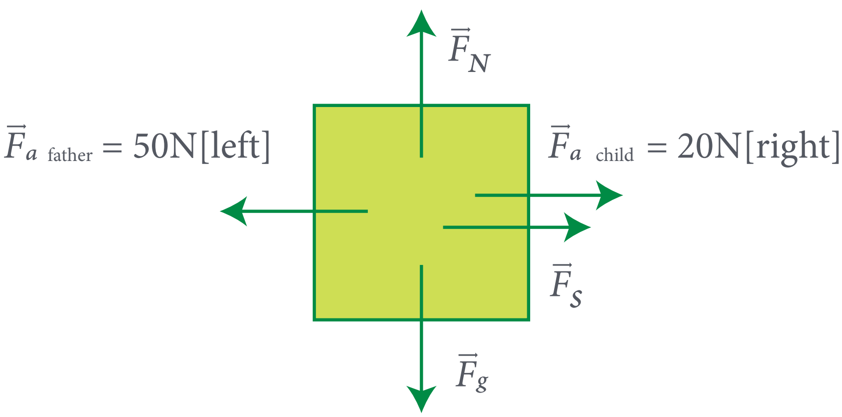
Lesson 5

Exercises 5.1.1

1. Two people pull on a large bin with a mass of 70 kg. The child pulls to the right and the father pulls to the left.

a) Find the force of static friction if the child pulls with 20 N [right] and the father pulls with 50 N [left] and the bin doesn't move.

Solution:



Since the bin doesn't move, this is a Newton's first law situation, and the net force on the bin must be zero.

The forces in the vertical direction are the normal force and the force of gravity, which you know usually balance and cancel.

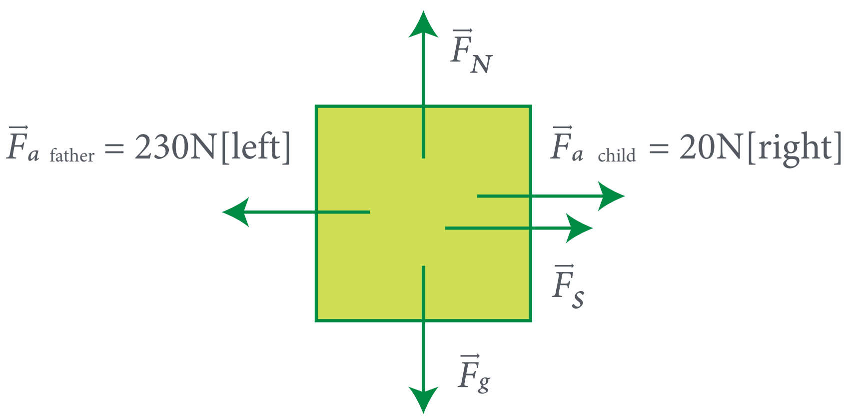
But here the forces in the horizontal direction must also balance and cancel.

$\vec{F}_{net}$ = 50 N [left] + 20 N [right] + $\vec{F}_s$
0 = 50 N [left] - 20 N [left] + $\vec{F}_s$
0 = 30 N [left] + $\vec{F}_s$
-$\vec{F}_s$ = 30 N [left]
$\vec{F}_s$ = 30 N [right]
The force of static friction is 30 N [right].

b) Find the coefficient of static friction if the child pulls with 20 N [right] and the father pulls with 230 N [left] and the bin just starts to move.

Solution:

First draw the FBD of the bin:



Since the bin just starts to move, the net force on the bin is still zero and the static friction is the maximum amount.

The forces in the vertical direction are the normal force and the force of gravity, which you know usually balance and cancel.

But here the forces in the horizontal direction must also balance and cancel.

$\vec{F}_{net}$ = 230 N [left] + 20 N [right] + $\vec{F}_s$
0 = 230 N [left] - 20 N [left] + $\vec{F}_s$
-$\vec{F}_s$ = 210 N [left]
$\vec{F}_s$ = 210 N [right]

You can now find the coefficient of static friction.

$\mu_s = \frac{F_s}{F_N}$

$\mu_s = \frac{F_s}{mg}$

$\mu_s = \frac{210\ N}{(70\ kg)(9.8\ m/s^2)}$

$\mu_s = 0.31$

The coefficient of static friction is 0.31.

2) A person moving into a new apartment is dragging a large trunk (mass of 35 kg) down the hallway at a constant velocity with a force of 72 N [right]. Find the coefficient of kinetic friction for the trunk and the floor.

Solution:

Using the protocol *Back to Basics: Solving Word Problems*

Step 1:

$F_K = 21,\ m = 25.0\text{kg},\ g = 9.8\text{m/s}^2$

Step 2:

$\mu_K = ?$

Step 3:

$\mu_K = \frac{F_s}{F_N}$

$F_N = F_g = mg$

Step 4:

$\mu_K = \frac{F_s}{mg}$

Step 5:

$\mu_K = \frac{72\ N}{(35\ kg)(9.8\ m/s^2)}$

$\mu_K = 0.20991$

Step 6:

The coefficient of kinetic friction is 0.21. There are only 2 significant digits in the given data.

3) A 72 kg person wearing skates with steel blades is on an ice rink. You will need to look up values in Table 5.1 to find the appropriate coefficients of friction to answer the following two questions.

a) What is the maximum static friction experienced by the person?

Solution:

Using the protocol *Back to Basics: Solving Word Problems*

Step 1: $m = 72.0\text{kg}$, $g = 9.8\text{m/s}^2$

In Table 5.1, you can find the μ_s of ice on steel, so that information becomes a piece of given data as well:

$\mu_S = 0.1$

Step 2:

$F_S = ?$

Step 3:

$\mu_S = \frac{F_S}{F_N}$

$F_N = F_g = mg$

Step 4:

$F_S = \mu_S mg$

Step 5:

$F_S = (0.1)(72\text{ kg})(9.8\text{m/s}^2)$

$F_S = 70.56\text{ N}$

Step 6:

This value is about 71 N, but because the given data include the value 0.1, which has only one significant digit, the answer has to be reported to only one significant digit. Thus, the maximum static friction is $7 \times 101\text{ N}$.

b) What is the kinetic friction when coasting across the ice?

Solution:

Using the protocol *Back to Basics: Solving Word Problems*

Step 1: $m = 72.0\text{ kg}$, $g = 9.8\text{m/s}^2$

Table 5.1, you can find the of ice on steel. This value (0.01) is also part of the given data:

Step 2:

$F_K = ?$

Step 3:

$\mu_K = \frac{F_K}{mg}$

$F_N = F_g = mg$

Step 4:

$F_K = \mu_K mg$

Step 5:

$F_S = (0.01)(72\text{kg})(9.8\text{m/s}^2)$

$F_S = 7.056\text{ N}$

Step 6:

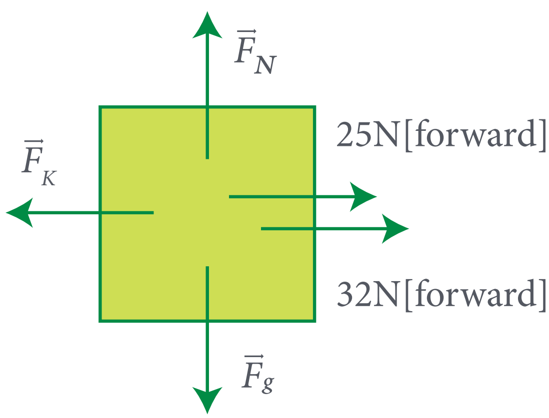
The maximum kinetic friction is 7 N. The given data include a value that has only one significant digit!

4) Two librarians pull forward on a cart filled with books to bring them to a storage room. One librarian pulls with 25 N [forward] and the other pulls with 32 N [forward]. The total mass of the cart and books is 35 kg. The cart moves at a constant velocity.

a) Find the force of kinetic friction acting on the cart.

Solution:

a) First draw the FBD of the cart:



The normal force and the force of gravity balance and cancel. The cart moves at a constant velocity, so this is a Newton's first law situation and the net force on the cart must be zero in the horizontal direction as well.

$\vec{F}_{net} = 25\text{ N [forward]} + 32\text{ N [forward]} + \vec{F}_K$

$0 = 57\text{ N [forward]} + \vec{F}_K$

$\vec{F}_K = -57\text{ N [left]}$

$\vec{F}_K = 57\text{ N [backward]}$

The kinetic friction acting on the cart is 57 N [backward].

b) Find the coefficient of kinetic friction.

Solution:

$\mu_K = \frac{F_K}{F_N}$

$\mu_K = \frac{F_K}{mg}$

$\mu_K = \frac{57\ N}{(35\ kg)(9.8\ m/s^2)}$

$\mu_K = 0.17$

The coefficient of kinetic friction is 0.17.

5) In an action movie, a 1200 kg car is pulled forward by a tow truck with a force of 7000 N [E]. The hero in the movie hits the brakes in the car to try to get free from the tow truck. The coefficient of kinetic friction between the car's tires and the road is 0.80.

a) Find the force of kinetic friction acting on the car as the tires skid across the road.

Solution:

$F_K = \mu_K F_N$

$F_K = \mu_K mg$

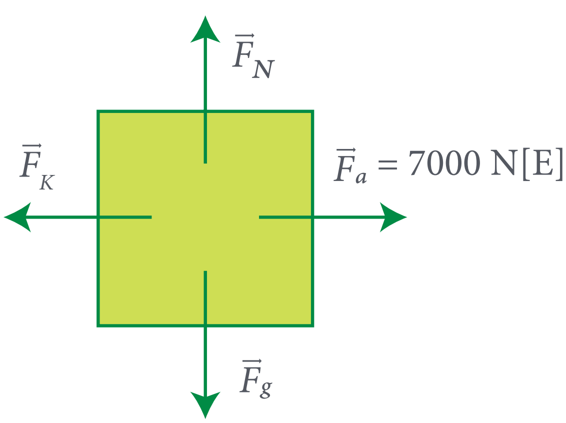
$F_K = (0.80)(1200 kg)(9.8 m/s^2)$

$F_K = 9408$

b) Find the acceleration of the car when the tires slide across the road and the tow truck pulls it forward.

Solution:

First draw the FBD of the truck:



The normal force and gravity balance and cancel.

Step 1:

$m = 1200\ \text{kg}$

$F_K = 9408\ \text{N [W]}$

$F_A = 7000\ \text{N [E]}$

Step 2:

$\vec{a} = ?$

Step 3:

$\vec{F}_{net} = \vec{F}_a + \vec{F}_K$

$\vec{F}_{net} = \overrightarrow{ma}$

Step 4:

$\vec{a} = \frac{\vec{F}_{net}}{m}$

Step 5:

$\vec{F}_{net} = 7000\ \text{N [E]} + 9400\ \text{N [W]}$

$\vec{F}_{net} = -7000\ \text{N [W]} + 9400\ \text{N [W]}$

$\vec{F}_{net} = 2400\ \text{N [W]}$

$\vec{a} = \frac{2400\ \text{N [W]}}{5.0s}$

$\vec{a} = 2.8\ \text{m/s}^2\ \text{[W]}$

Step 6:

The acceleration of the car is $2.0\ \text{m/s}^2\ \text{[W]}$

