Forces
Newton's First Law of Motion

CONCEPT EXPLORATION

In the last lesson, we investigated the basic characteristics of forces. Now we will study how multiple forces can act on a body and yet the body does not change its state of motion.

Are you moving or stationary at the moment? Do you have forces acting on you right now? If so, how many forces act on you and in what direction?

Engagement Questions

A man sits still in a chair.

1. How many forces act on this man? What are these forces?

2. In the diagram to the right, draw and label the forces that act on this man.

3. Of the forces that you drew, which one is the biggest? Explain your answer.

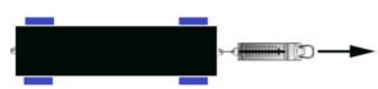
The Challenge

You will determine the minimum number of forces required to keep an object at rest (assuming there are forces present) as well as the magnitude and direction of these forces.

Your Ideas about the Challenge

A student pulls a lab cart with a constant force.

4. If there is no friction opposing the motion of this lab cart, what will it do?



5. In what direction would another student have to pull on this lab cart in order to keep it from moving?

6. How hard would this second student have to pull to keep this lab cart from moving? Would their force have to be bigger, smaller, or the same size as the force of the first student?

At each lab station you should find the following materials:
a low-friction cart and two spring scales

The Investigation

a. Attach two spring scales to opposite ends of a lab cart.
b. One student should pull on one spring scale, while a different student should pull on the other spring scale in such a way that the lab cart doesn't move.
c. Each student should pull lightly at first. At the moment that they have the lab cart at rest each student should say out loud the reading on their spring scale. Record this reading in the data table that follows.
d. Each student should pull a little harder. Again, each student should say out loud what the reading is on their spring scale when the lab cart isn't moving. Record this second reading in the data table that follows.

Data	**Student 1**	**Student 2**
Light pull reading (Newtons)		
Stronger pull reading (Newtons)		

7. In each situation were the readings on the two scales pretty much the same or were they considerably different?

8. Draw the free body diagram for the lab cart when it was at rest and the two students were pulling on it. Only show the horizontal forces in your diagram.

9. In general, if opposing forces act on a body that is at rest, are the forces the same size or is one force bigger than the other force?

10. Evaluate the following student statements about the investigation that you just performed. Indicate whether you agree or disagree with each student and cite the evidence that you have to support your opinion.

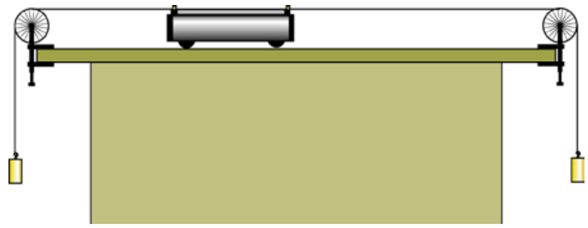
<u>Student A</u>
"If I push or pull on an object there would have to be an equal push or pull in the opposite direction to keep the body from moving."

<u>Student B</u>
"Just because I'm not moving doesn't mean that all of the forces acting on me are equal and opposite. If I'm sitting still in a chair, the force of gravity would have to be bigger than the force of the chair pushing up on me. Otherwise I would begin to float."

Check your work with your teacher. ☐

When two equal forces act on a body in the opposite direction, the forces are said to be **in balance**. When only balanced forces act on a body it will remain in equilibrium. **Equilibrium**, in this sense, means that a body continues in a constant state of motion. In other words the body is not accelerating.

Your teacher has set up the arrangement seen in the diagram to the right. Two equal weights have been attached by strings that pass over low-friction pulleys to opposite ends of a low-friction cart.



11. When your teacher releases this system from rest, what will it do? Why do you think that this will happen?

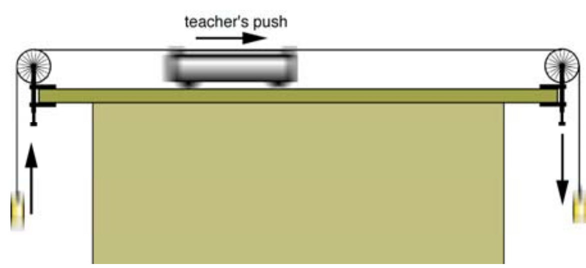
12. Draw the free-body diagram for this situation.

13. Were the horizontal forces that acted on the lab cart in balance? Explain how you know.

14. What would your teacher have had to do in order to get the lab cart to move? In other words, what seems to be required to get an object at rest to move?

Your teacher is going to push on the lab cart, set up as before, so that it will begin to slowly move.

15. What do you think will happen to this system after your teacher stops pushing on the cart? Will it stop, or will it keep moving?



16. After your teacher pushed on the cart did it seem to slow down, go at a constant speed, or did it speed up?

17. Draw the free-body diagram for this new situation.

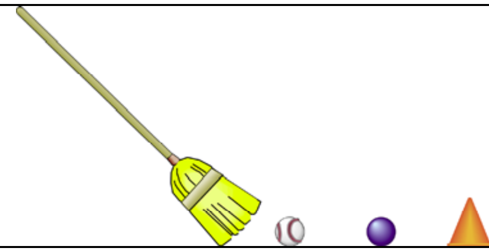
18. Were the horizontal forces that acted on the moving lab cart in balance? Explain how you know.

19. What would your teacher have had to do in order to change the velocity of the moving cart?

Why does a moving object continue to move in the absence of an unbalanced force? Why is it harder to change the motion of some objects than others?

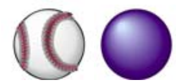
The Challenge

Groups of students will form a broom-ball relay team. Your task is to use the broom to push the softball from your starting position to the cone and back again. Once everyone in your group has completed the loop with the softball, go through the same process with the bocci ball.



Your Ideas about the Challenge

20. Other than color and texture, what is the primary difference between the two balls?



21. If you had to push one of these objects from rest up to a speed of 1m/s, which one do you think you would have to push harder? Why?

22. Which ball do you think would be easier to stop once it was moving at 1m/s? Why?

Your teacher will provide your lab group with the following materials:
a softball, a bocci ball, a cone, and a broom

The Investigation (continued)

a. Your teacher will divide the class up into equal size teams.
b. Your teacher will explain the rules.
c. When your teacher gives the signal, students on each team will take turns moving the softball and then the bocci ball around the cone and back again using their broom.
d. The objective is for all of the team members to complete the task in as short a time as possible.

23. When you applied a similar force to the softball and then the bocci ball, which ball experienced a greater change in velocity?

24. After a force was applied, the balls rolled for a while without additional contact from the broom. If you gave each ball a velocity of 1m/s, which ball do you think would roll farther? Why?

A body's resistance to a change in its motion is called **inertia**.

25. Based on your observations, which ball has a greater inertia? Why do you think that this ball had more inertia than the other ball?

26. A pair of students in your class had different ideas about forces and inertia. Carefully read the student arguments and decide which student's statement is best supported by the evidence.

<u>Student A</u>
"I could use a tennis racket to change the velocity of a tennis ball pretty easily, but I would have a hard time changing the velocity of a bowling ball with a tennis racket. This is because the bowling ball has a lot more mass than a tennis ball. The more mass an object has, the more inertia it must have."

<u>Student B</u>
"The mass of an object does not matter. What matters is friction. It would be just as easy for me to start a refrigerator moving as it would be to get a book moving, if both of them were on a smooth sheet of ice. I could use the same size force on both of them and they would experience the same change in velocity."

Check your work with your teacher.

The Challenge (continued)
You will determine the nature of the forces that act on a body that is moving with a uniform velocity.

Your Ideas about the Challenge
A car is moving at a constant speed in a straight line down the freeway.

27. How many forces act on this car? What are these forces? Do *not* ignore air resistance.

28. Draw the free-body diagram for this car.

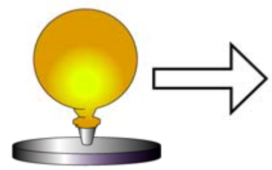
29. Of the horizontal forces that you drew in the diagram above, which one, if any, has to be bigger if this car is moving with a constant velocity? Explain how you know.

At each lab station you will find a balloon puck.

The Investigation (continued)
a. Inflate the balloon puck and set it down on the counter so that it is moving. Observe how the balloon behaves before it runs into something or it runs out of air.
b. After the balloon has run out of air try to push on it in such a way that it moves at a constant speed in a straight line. Take note of how hard you have to push on the puck to keep it moving with a uniform velocity.

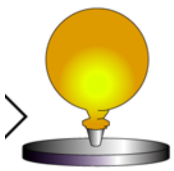
30. Did you have to push on the balloon puck to keep it moving at constant speed in a straight line, when the balloon was still inflated? How do you explain this?

31. Can an object continue to move if there are no forces acting on it? If so, what make it continue to move?



32. Why did you have to continue to push on the deflated puck in order to keep it moving at a constant speed?

33. Complete the free-body diagrams for both the inflated balloon puck and the deflated balloon puck that represents the forces that acted on these objects while they were moving with constant velocity. Assume that both of them are moving to the right.



34. In the absence of a frictional force or any other opposing forces, would you have to continue to apply a force to keep a moving object moving? Explain your answer.

35. A pair of students in your class argue about how much force is required to keep an object moving with uniform velocity. Select the argument that you think is best supported by the evidence, and list the evidence that supports that idea.

<u>Student A</u>

"I think that you always have to apply a force to keep an object moving at a constant speed. The deflated puck won't move at all unless I'm pushing it."

<u>Student B</u>

"That's not right. You only have to keep pushing if a friction force opposes the motion. If there is no friction, then you don't have to keep pushing. An object moving without friction will glide at a steady speed forever if it doesn't run into anything."

Check your work with your teacher.

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CONCEPT DEVELOPMENT

In the exploration section, we observed that an unbalanced forcer is required to change an objects state of motion. An object's resistance to a change of motion is defined as the **inertia** of the object. Mass is a quantitative measure of inertia. The more mass an object has, the more inertia the object has.

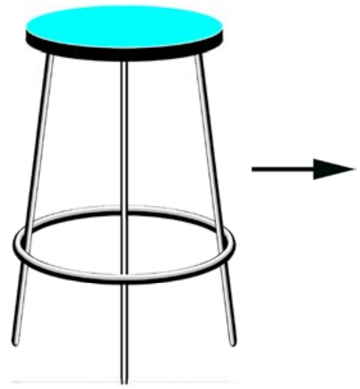
Would you want to put a small engine in a large truck or would you need to put a large engine in a small car?

In this development section we will take another look at forces that are exerted on objects that are moving with a uniform velocity and objects that are at rest.

Engagement Question

You give a stool, in the classroom, a shove so that it begins to slide across the floor.

1. Would the stool slide with constant speed until it ran into something or would it stop sliding after it had slid for a distance? Explain why you think that this would happen.

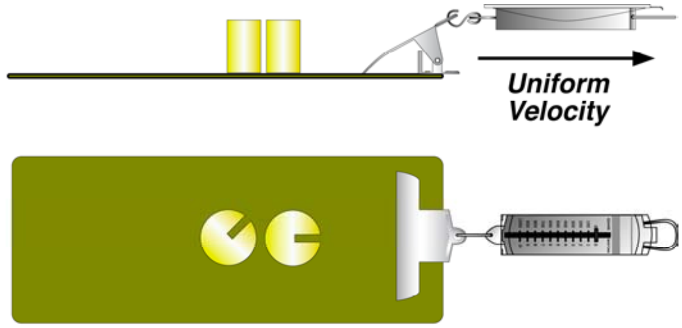


The Challenge

You will predict the amount of friction that exists when a given object is slid across a surface.

Your Ideas about the Challenge

A clipboard loaded with some mass is dragged across a table top, with a uniform velocity, at the end of a spring scale.



2. What horizontal forces <u>and</u> what vertical forces act on this clipboard as it moves with a uniform velocity.

3. Draw the free-body diagram for this situation. Include both the horizontal forces and the vertical forces that you mentioned in question 2 in your diagram. Be sure to label all of the forces. Assume that the clipboard is sliding to the right.

4. Are the horizontal forces in balance for this situation? Explain how you know.

5. Are the two horizontal forces equal to each other or is one bigger than the other? Explain how you know.

6. Are the vertical forces in balance for this situation? Explain how you know.

7. Are the two vertical forces equal to each other or is one bigger than the other? Explain how you know.

At each lab station you will find the following materials:
a clip board, four 9.8 Newton weights (1 kg masses), one 4.9 Newton weight (0.5 kg mass), and a spring scale

The Investigation

a. Lift a clipboard off of the table with the spring scale. Record the weight of the clipboard in the data table that follows.
b. Place the clipboard on the table. Attach the spring scale to the front of the clipboard.
c. Using the spring scale, drag the clipboard across the table so that it has a slow uniform velocity. Be sure to hold the spring scale parallel to the table surface while pulling.
d. Record the force displayed on the spring scale that you observed, while you were pulling with a steady force in the data table that follows.
e. Place a 9.8 Newton weight on the center of the clipboard.
f. Repeat steps “c” through “d”.
h. Repeat steps “c” through “e” for 2, 3, and 4 weights.

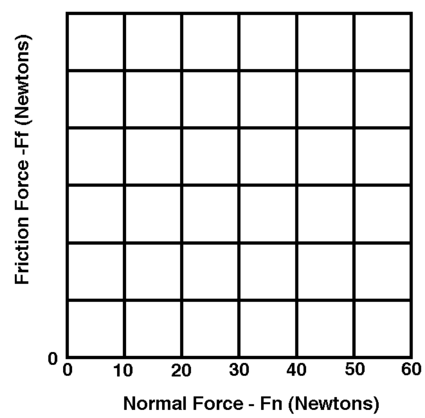
Data Table

System dragged with **uniform velocity**	Total Weight (F_g) (Clipboard + weights) (Newtons)	Normal Force ($F_n = F_g$) (Newtons)	Pulling Force (F_{pull}) (from spring scale) (Newtons)	Friction Force (F_f) ($F_f = F_{pull}$) (Newtons)
Clipboard alone				
Clipboard +1 weight				
Clipboard +2 weights				
Clipboard +3 weights				
Clipboard +4 weights				

8. Plot friction force vs. normal force on the provided grid.

9. Is the relationship between the friction force and the normal force linear or nonlinear?

10. Draw a best-fit line that follows the trend of the points.



The slope of the best-fit line on a friction force versus normal force graph allows us to predict the friction force for any given normal force between the two sliding surfaces that we were working with. An equation in the form of the linear equation y = mx can be used in making predictions of this kind.

The equation that relates the force of friction acting on an object to the normal force acting on the object being dragged across a surface is:

$$F_f = \mu \cdot F_n$$

The letter "μ" (pronounced "mew") can be determined by the slope of the best-fit line of your graph. It is referred to as the coefficient of friction. The **coefficient of friction** is a measure of how much friction exists between two surfaces. Smooth surfaces that exert small friction forces have a very low coefficient of friction, while rough surfaces have a high coefficient of friction.

If you were to calculate the slope of your best-fit line you would wind up dividing the frictional force units by the normal force units. $\mu = \dfrac{\Delta F_f}{\Delta F_N}$

11. What units would you receive for your coefficient of friction (μ)?

12. Calculate the slope of the best-fit line from the graph that you drew.

Coefficient of Friction (μ)

Your teacher will provide you with two 9.8 N weights and one 4.9 N (500g) weight. You will use the equation $F_f = \mu \cdot F_n$ to calculate the amount of friction that should take place when you place these weights on the clipboard and drag it with the spring scale.

13. Calculate the amount of friction that should act on the clipboard when you drag it with the two 9.8 N weights and the one 4.9 N weight. Don't forget about the additional weight of the clipboard in your calculations. Be sure to show all of your calculations.

Predicted friction force (Newtons)

Place two 9.8 N weights and one 4.9 N weight on the clipboard. Drag the clipboard on the surface as you did before using the spring scale. Be sure to use the same spring scale as before.

14. Read and record the pulling force (equal to the friction force) required to drag the clipboard and weights at a constant velocity.

Actual friction force (Newtons)

15. Calculate the difference between your predicted frictional force and the actual frictional force. Do you think this was a significant difference? If it was, what do you think happened?

Check your work with your teacher.

The Challenge (continued)

You will predict the weight of an unknown object as it hangs from the middle of a string.

Your Ideas about the Challenge

16. Is it possible to lift an object with a horizontal rope, and keep the rope perfectly straight with no bend in the middle? If not, explain why you think that this would not be possible.

The teacher will select a pair of volunteers to attempt to lift an object with a string or rope by pulling in the horizontal direction. Observe the line to see if it is possible for the two students to pull the string or rope perfectly straight.

17. Were the two students able to pull the string or rope perfectly straight? If not, why do you think that they were unable to do this?

18. If you consider each side of the rope to be separate forces, how many forces were acting on the suspended weight? In addition to the "two" rope forces what other force(s) acted on the weight?

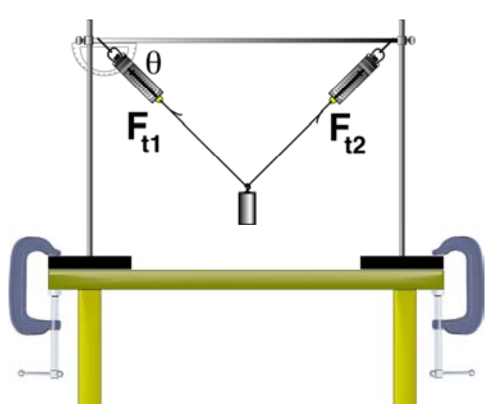
19. Draw the free-body diagram that represents all of the forces acting on the bucket or other object, suspended from the line, on the diagram you see to the right.

Remember the system was in equilibrium, so the length of each vector is important.

20. What force(s) act in the opposite direction of the weight of the bucket?

21. Are there any horizontal forces acting on the bucket? If so what are these forces? Are they equal in size or are they different sizes?

Consider the following situation. The weight shown in the illustration below is suspended in place by the string. Spring scales measure the tension force (F_t) on either side of the weight. This situation is similar to the one with the bucket. First we will analyze the forces acting on the weight, then we will use our understanding of the way that forces act on a body in equilibrium to predict the size of an unknown weight in a similar set up.



At each lab station you will find the following materials:
a weight suspended from the middle of a string attached to two spring scales, and a protractor.

The Investigation (continued)

a. Prepare the set up illustrated in the preceding diagram.
b. Measure the tensions on each side of the string F_{t1} and F_{t2}. Record these spring-scale readings in the data table that follows.
c. Measure the angle each line makes with the horizontal. Record these measurements in the data table that follows.

Data Table

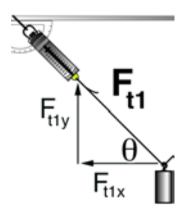
Tension 1 F_{t1} (Newtons)	Angle $\theta 1$ (degrees)	Tension 2 F_{t2} (Newtons)	Angle $\theta 2$ (degrees)

22. Is this system in equilibrium? Are the forces acting on the weight balanced or unbalanced? Explain how you know.

23. Is the weight (F_g) balanced by one side of the string alone, or by both sides acting together?

24. On the picture of the weight seen to the right draw a free-body diagram that represents all of the forces acting on the weight as it hung suspended in the middle of the string.
Treat each side of the string as a separate tension force.

What could you do to determine the part of each tension force that acts to balance the weight? What equation could you use to calculate the *vertical component* of each tension force? In order to do this you will need to break down each tension force into its vertical and horizontal components. For example, the string on the left side could be broken down as seen in the diagram below.



The vertical component of the tension (F_{t1}) is F_{t1y}. The horizontal component of the tension is F_{t1x}.
25. Which trigonometric function could you use to calculate the vertical component of the tension? Use this function to calculate both of the vertical components of the two tensions (F_{t1} and F_{t2}). Show your calculations.

26. How do you think the weight (F_g) of the unknown object should compare to the *sum* of the vertical components of the tension forces? Should it be more than, less than, or the same as the sum of the two vertical components? Explain your answer.

27. Calculate the *sum* of the vertical components of the tension forces in the space below. Be sure to label your answer appropriately.

28. Which trigonometric function could you use to calculate the horizontal component of the tension? Use this function to calculate both of the horizontal components of the two tensions (F_{t1} and F_{t2}). Show your calculations.

29. Were the two horizontal components roughly the same value or were they considerably different? Should they have been the same value or should one of these values have been larger than the other? Explain your answer.

Check your work with your teacher.

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CONCEPT REFINEMENT

Review

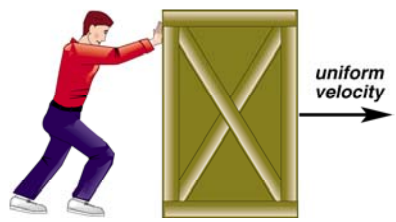
In this lesson we investigated the tendency of an object to continue with its present state of motion. Galileo Galilei (1564-1642) stated that every object resists change to its state of motion. We use the term **inertia** to describe this resistance to change in motion. Mass is a quantitative measure of inertia. The more mass an object has, the more inertia it has.
Sir Isaac Newton (1642-1727) refined this idea in his ***First Law of Motion:***

An object will continue to be in a state of rest, or of motion at constant speed in a straight line, unless it is acted upon by an unbalanced force.

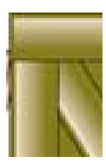
A stationary object remains stationary unless an unbalanced force acts on it. An object moving with a uniform velocity will continue to do so unless an unbalanced force acts on it. We observed that friction often acts as an unbalanced force to change the motion of a moving object. If friction forces are sufficiently reduced, we observed objects moving with uniform velocity experience very little change in motion. This means that an object moving in the absence of friction does **not** require a constant force to sustain its motion.

We investigated systems experiencing balanced forces. Such systems are said to be in equilibrium. Stationary systems, or systems moving with uniform velocity are in **equilibrium**. We measured and calculated the size of friction forces ($F_f = \mu \cdot F_n$) and tension forces. We used basic trigonometry to break force vectors into vertical and horizontal components to better understand the forces acting on systems in equilibrium.

Jack applies a constant force as he pushes the crate, shown in the illustration to the right, with a uniform velocity.



1. Draw the free-body diagram for the crate that represents all of the forces acting on it while Jack continues to apply a constant force so that the crate moves with a uniform velocity. Be sure to label all of the forces in your diagram.



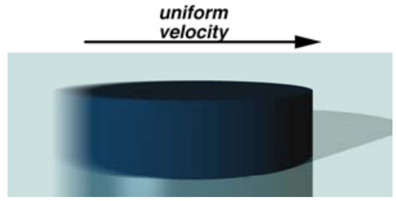
2. Which of the vertical forces is the largest? Explain how you know.

3. Which of the horizontal forces is the largest? Explain how you know.

4. Is the crate in equilibrium? Explain how you know.

A hockey puck glides along smooth ice with a uniform velocity.

Assume that there is no friction acting on the hockey puck.

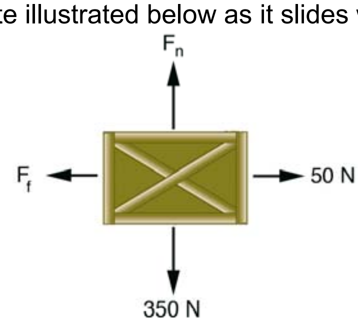


5. Draw the free-body diagram for the puck that represents all of the forces acting on it as it glides across the ice with a uniform velocity. Be sure to label all of the forces in your diagram.

6. Why does a force have to be applied to the crate to keep it moving at a uniform velocity (see question 1), but no force is required to keep the hockey puck moving at a uniform velocity (see question 5)? Why does the hockey puck continue to move?

Check your work with your teacher.

Four forces are acting on the crate illustrated below as it slides with a uniform velocity to the right.

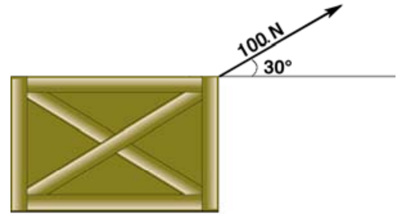


7. If the weight of this crate is 350 N, what must be the normal force of the floor (F_n) acting on this crate? Explain how you know the answer to this question.

8. If the force that is sliding it to the right is 50 N, how much friction (F_f) must be acting on this crate? Explain how you know the answer to this question.

A force of 100 N is exerted on a crate at an angle of 30° with respect to horizontal as illustrated in the diagram seen to the right.

The crate is sliding to the right with a constant velocity of 20 m/s.



9. What is the magnitude of the vertical component of this force? Be sure to show your calculations.

10. What does the vertical component of this force do to the crate?

11. What is magnitude of the horizontal component of this force? Be sure to show your calculations.

12. If the crate is being dragged to the right with a uniform velocity, what is the magnitude of the frictional force acting on the crate?

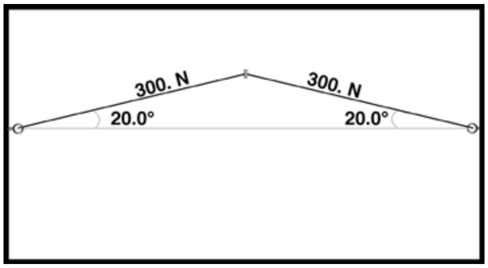
The gymnast illustrated below has a weight of 650 N.

13. Draw the free-body diagram for this gymnast that represents all of the forces acting on him as he hangs from the rings. Assume that both of the lines hang straight down.

14. What is the tension in each of the lines supporting the gymnast? How do you know?

Check your work with your teacher.

The diagram below illustrates the back of a picture frame, and the cable that supports the frame on the wall. The tension in the cable on each side is 300 N. Each cable makes an angle of 20^0 with respect to horizontal.

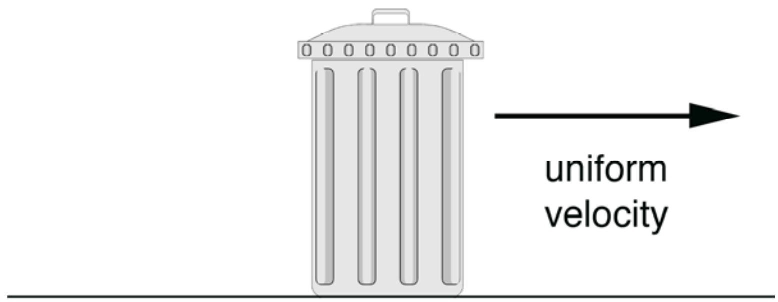


15. Calculate the weight of the picture frame. Be sure to show all of your calculations.

Check your work with your teacher.

A garbage can is slid across a sidewalk with a uniform velocity as seen in the diagram to the right.

16. Calculate the amount of friction that acts on this garbage can if it has a weight of 250 N and the coefficient of friction between the garbage can and the sidewalk is 0.4.



17. How hard would you have to push on this garbage can under these circumstances if you have to move it with a uniform velocity?

Check your work with your teacher.