Chapter 4: Newtons Laws of Motion

Due: 11:00pm on Tuesday, September 18, 2012

Note: You will receive no credit for late submissions. To learn more, read your instructor's Grading Policy

A Push or a Pull?

Learning Goal:

To understand the concept of force as a push or a pull and to become familiar with everyday forces.

A force can be simply defined as *a push or a pull exerted by one object upon another*.

Although such a definition may not sound too scientific, it does capture three essential properties of forces:

- Each force is created by some object.
- Each force acts upon some *other* object.
- The action of a force can be visualized as a push or a pull.

Since each force is created by one object and acts upon another, *forces must be described as interactions*. The proper words describing the force interaction between objects A and B may be any of the following:

- "Object A acts upon object B with force $\vec{F}$."
- "Object A exerts force $\vec{F}$ upon object B."
- "Force $\vec{F}$ is applied to object B by object A."
- "Force $\vec{F}$ due to object A is acting upon object B."

One of the biggest mistakes you may make is to think of a force as "something an object *has*." In fact, at least two objects are always required for a force to exist.

Each force has a direction: *Forces are vectors.* The main result of such interactions is that the objects involved change their velocities: *Forces cause acceleration*. However, in this problem, we will not concern ourselves with acceleration--not yet.

Some common types of forces that you will be dealing with include the gravitational force (weight), the force of tension, the force of friction, and the normal force.

It is sometimes convenient to classify forces as either *contact forces* between two objects that are touching or as *long-range forces* between two objects that are some distance apart. Contact forces include tension, friction, and the normal force. Long-range forces include gravity and electromagnetic forces. Note that such a distinction is useful but not really fundamental: For instance, on a microscopic scale the force of friction is really an electromagnetic force.

In this problem, you will identify the types of forces acting on objects in various situations.

First, consider a book resting on a horizontal table.

Part A

Which object exerts a downward force on the book?

ANSWER:

- ○ the book itself
- ◉ the earth
- ○ the surface of the table

Part B

The downward force acting on the book is __________.

ANSWER:

- ○ a contact force
- ◉ a long-range force

Part C

What is the downward force acting on the book called?

ANSWER:

- ○ tension
- ○ normal force
- ◉ weight
- ○ friction

Part D

Which object exerts an upward force on the book?

ANSWER:

- ○ the book itself
- ○ the earth
- ◉ the surface of the table

Part E

The upward force acting on the book is __________.

ANSWER:

- ◉ a contact force
- ○ a long-range force

Part F

What is the upward force acting on the book called?

ANSWER:

- ○ tension
- ◉ normal force
- ○ weight
- ○ friction

Now consider a different situation. A string is attached to a heavy block. The string is used to pull the block to the right along a rough horizontal table.

Part G

Which object exerts a force on the block that is directed toward the right?

ANSWER:

- ○ the block itself
- ○ the earth
- ○ the surface of the table
- ◉ the string

Part H

The force acting on the block and directed to the right is __________.

ANSWER:

- (selected) a contact force
- a long-range force

To exert a tension force, the string must be connected to (i.e., touching) the block.

Part I

What is the force acting on the block and directed to the right called?

ANSWER:

- (selected) tension
- normal force
- weight
- friction

Part J

Which object exerts a force on the block that is directed toward the left?

ANSWER:

- the block itself
- the earth
- (selected) the surface of the table
- the string

Part K

The force acting on the block and directed to the left is __________.

ANSWER:

- (selected) a contact force
- a long-range force

Part L

What is the force acting on the block and directed to the left called?

ANSWER:

- tension
- normal force
- weight
- (selected) friction

Now consider a slightly different situation. The same block is placed on the same rough table. However, this time, the string is disconnected and the block is given a *quick push* to the right. The block slides to the right and eventually stops. The following questions refer to the motion of the block *after* it is pushed but *before* it stops.

Part M

How many forces are acting on the block in the horizontal direction?

ANSWER:

- 0
- 1 (selected)
- 2
- 3

Once the push has commenced, there is *no force* acting to the right: The block is moving to the right because it was given a velocity in this direction by some force that is no longer applied to the block (probably, the normal force exerted by a student's hand or some spring launcher).

Once the contact with the launching object has been lost, the only horizontal force acting on the block is directed to the left--which is why the block eventually stops.

Part N

What is the force acting on the block that is directed to the *left* called?

ANSWER:

- tension
- normal force
- weight
- friction (selected)

The force of friction does not disappear as long as the block is moving. Once the block stops, fricion becomes zero (assuming the table is perfectly horizontal).

Applying Newton's 2nd Law

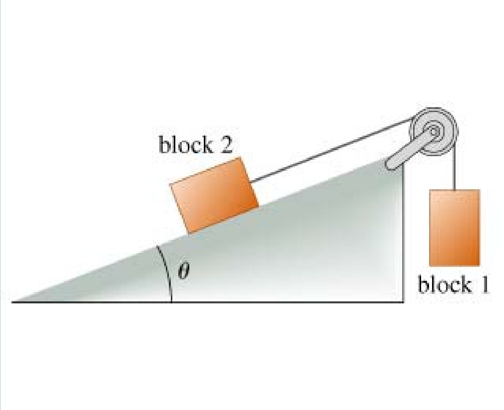
Learning Goal:

To learn a systematic approach to solving Newton's 2nd law problems using a simple example.

Once you have decided to solve a problem using Newton's 2nd law, there are steps that will lead you to a solution. One such prescription is the following:

- Visualize the problem and identify special cases.
- Isolate each body and draw the forces acting on it.
- Choose a coordinate system for each body.
- Apply Newton's 2nd law to each body.
- Write equations for the constraints and other given information.
- Solve the resulting equations symbolically.
- Check that your answer has the correct dimensions and satisfies special cases.
- If numbers are given in the problem, plug them in and check that the answer makes sense.
- Think about generalizations or simplfications of the problem.

As an example, we will apply this procedure to find the acceleration of a block of mass m_2 that is pulled up a frictionless plane inclined at angle θ with respect to the horizontal by a perfect string that passes over a perfect pulley to a block of mass m_1 that is hanging vertically.



Visualize the problem and identify special cases

First examine the problem by drawing a picture and visualizing the motion. Apply Newton's 2nd law, $\sum \vec{F} = m\vec{a}$, to each body in your mind.

Don't worry about which quantities are given. Think about the forces on each body: How are these consistent with the direction of the acceleration for that body? Can you think of any special cases that you can solve quickly now and use to test your understanding later?

One special case in this problem is if $m_2 = 0$, in which case block 1 would simply fall freely under the acceleration of gravity: $\vec{a}_1 = -g\hat{y}$.

Part A

Consider another special case in which the inclined plane is vertical ($\theta = \pi/2$). In this case, for what value of m_1 would the acceleration of the two blocks be equal to zero?

Express your answer in terms of some or all of the variables m_2 and g.

ANSWER:

m_1 = m_2

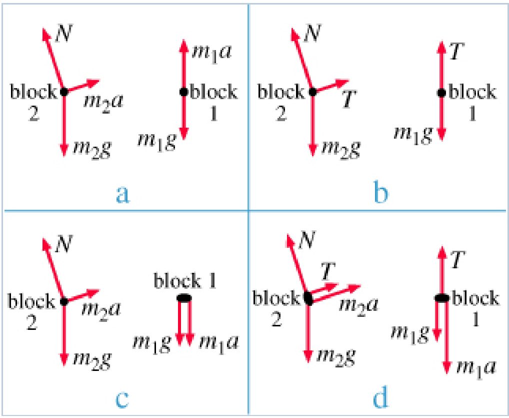
Isolate each body and draw the forces acting on it

A force diagram should include only *real* forces that act on the body and satisfy Newton's 3rd law. One way to check if the forces are real is to detrmine whether they are part of a Newton's 3rd law pair, that is, whether they result from a physical interaction that also causes an opposite force on some other body, which may not be part of the problem. Do not decompose the forces into components, and do not include resultant forces that are combinations of other real forces like centripetal force or fictitious forces like the "centrifugal" force.

Assign each force a symbol, but don't start to solve the problem at this point.

Part B

Which of the four drawings is a correct force diagram for this problem?



ANSWER:

- ○ a
- ◉ b
- ○ c
- ○ d

Choose a coordinate system for each body

Newton's 2nd law, $\sum \vec{F} = m\vec{a}$, is a vector equation. To add or subtract vectors it is often easiest to decompose each vector into components.

Whereas a particular set of vector components is only valid in a particular coordinate system, the vector equality holds in *any* coordinate system, giving you freedom to pick a coordinate system that most simplifies the equations that result from the component equations.

It's generally best to pick a coordinate system with as many unknowns as possible along the coordinate axes. Vectors that lie along the axes appear in only one of the equations for each component, rather than in two equations with trigonometric prefactors. Note that it is sometimes advantageous to use *different* coordinate systems for each body in the problem.

In this problem, you should use Cartesian coordinates and your axes should be stationary with respect to the inclined plane.

Part C

Given the criteria just described, what orientation of the coordinate axes would be best to use in this problem?

In the answer options, "tilted" means with the *x* axis oriented parallel to the plane (i.e., at angle θ to the horizontal), and "level" means with the *x* axis horizontal.

ANSWER:

- tilted for both block 1 and block 2
- tilted for block 1 and level for block 2
- (selected) level for block 1 and tilted for block 2
- level for both block 1 and block 2

Apply Newton's 2nd law to each body

Part D

What is $\sum F_{2x}$, the sum of the *x* components of the forces acting on block 2? Take forces acting up the incline to be positive.

Express your answer in terms of some or all of the variables tension T, m_2, the magnitude of the acceleration of gravity g, and θ.

Hint 1. Decompose the force of gravity on block 2

In this problem, the hardest force vector to express in terms of its coordinates is the force of gravity on block 2. The magnitude of the weight is $m_2 g$. Find the force of gravity in terms of its components, using a tilted coordinate system whose *x* axis is parallel to and pointing up the inclined plane.

Express the force of gravity on block 2, $\vec{F}_{g2}$, in terms of some or all of the variables m_2, g, and θ. Express your answer as a vector in terms of the unit vectors $\hat{x}$ and $\hat{y}$.

ANSWER:

$\vec{F}_{g2} = -m_2 g\left(\sin(\theta)\,\hat{x} + \cos(\theta)\,\hat{y}\right)$

ANSWER:

$m_2 a_{2x} = \sum F_{2x} = T - m_2 g \sin(\theta)$

Part E

Now determine $m_1 a_{1y} = \sum F_{1y}$, the sum of the *y* components of the forces acting on block 1. Take forces acting upward as positive.

Express your answer in terms of some or all of the variables T, m_1, and g.

ANSWER:

$m_1 a_{1y} = \sum F_{1y} = T - m_1 g$

Part F

Write equations for the constraints and other given information
In this problem, the fact that the length of the string does not change imposes a constraint on relative accelerations of the two blocks. Find a relationship between the *x* component of the acceleration of block 2, a_{2x}, and the acceleration of block 1. Pay careful attention to signs.

Express a_{2x} in terms of a_{1x} and/or a_{1y}, the components of the acceleration vector of block 1.

Hint 1. Visualize the motion

If block 2 has an acceleration a_{2x} up the incline, must the acceleration of block 1 be upward or downward to keep the string taut?

ANSWER:

$a_{2x} = -a_{1y}$

Part G

Solve and check

In the previous parts, you obtained the following equations using Newton's 2nd law and the constraint on the motion of the two blocks:

$$m_2 a_{2x} = T - m_2 g \sin(\theta), \quad (1)$$

$$m_1 a_{1y} = T - m_1 g, \quad (2)$$

and

$$a_{2x} = -a_{1y}. \quad (3)$$

Solve these equations to find a_{1y}.

Before you enter your answer, make sure it satisfies the special cases you already identified:

- $a_{1y} = -g$ if $m_2 = 0$ and
- $a_{1y} = 0$ if $m_1 = m_2$ and $\theta = \pi/2$.

Also make sure that your answer has dimensions of acceleration.

Express a_{1y} in terms of some or all of the variables m_1, m_2, θ, and g.

Hint 1. How to solve the equations

Substitute for T from equation (1) into equation (2) and then use a_{2x} from equation (3) in the new equation (2). This will yield a linear equation in a_{1y} that is easy to solve.

ANSWER:

a_{1y} = $\frac{(m_2 \sin(\theta) - m_1) g}{m_1 + m_2}$

Can you see how a simple generalization of the problem could be solved with a little extra work or how you could solve a nontrivial problem that is a subset of this one?

For example, imagine that there is friction in this problem between the plane and block 2. This would lead to an additional force on block 2: $F_{f2} = \mu N$, where the normal force N is given by $N = m_2 g \cos(\theta)$.

This additional force would lead to a new term in the expression for the acceleration of block 1:

$$a_{1y} = \frac{m_2 \sin(\theta) - \mu m_2 \cos(\theta) - m_1}{m_1 + m_2} g.$$

Now, by choosing whether or not $\mu = 0$, you have a result that can be applied whether the plane is frictionless or not!

Free-Body Diagrams

Learning Goal:

To gain practice drawing free-body diagrams

Whenever you face a problem involving forces, always start with a free-body diagram.
To draw a free-body diagram use the following steps:

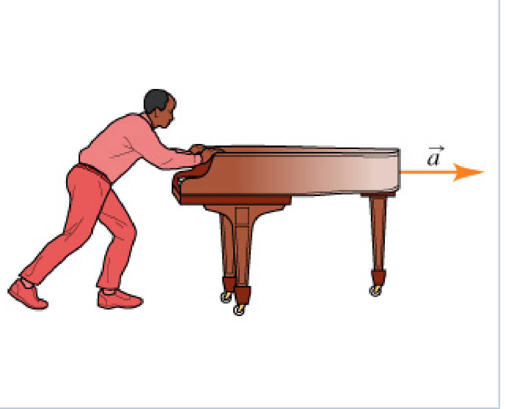
1. Isolate the object of interest. It is customary to represent the object of interest as a point in your diagram.
2. Identify all the forces acting on the object and their directions. Do not include forces acting on other objects in the problem. Also, do not include quantities, such as velocities and accelerations, that are not forces.
3. Draw the vectors for each force acting on your object of interest. When possible, the length of the force vectors you draw should represent the relative magnitudes of the forces acting on the object.

In most problems, after you have drawn the free-body diagrams, you will explicitly label your coordinate axes and directions. Always make the object of interest the origin of your coordinate system. Then you will need to divide the forces into *x* and *y* components, sum the *x* and *y* forces, and apply Newton's first or second law.

In this problem you will only draw the free-body diagram.

Suppose that you are asked to solve the following problem:
Chadwick is pushing a piano across a level floor (see the figure). The piano can slide across the floor without friction. If Chadwick applies a horizontal force to the piano, what is the piano's acceleration?

To solve this problem you should start by drawing a free-body diagram.



Part A

Determine the object of interest for the situation described in the problem introduction.

Hint 1. How to approach the problem

You should first think about the question you are trying to answer: What is the acceleration of the piano? The object of interest in this situation will be the object whose acceleration you are asked to find.

ANSWER:

For this situation you should draw a free-body diagram for

- ◯ the floor.
- ◯ Chadwick.
- ◉ the piano.

Part B

Identify the forces acting on the object of interest. From the list below, select the forces that act on the piano.

Check all that apply.

ANSWER:

- ☐ acceleration of the piano
- ☑ gravitational force acting on the piano (piano's weight)
- ☐ speed of the piano
- ☐ gravitational force acting on Chadwick (Chadwick's weight)
- ☑ force of the floor on the piano (normal force)
- ☐ force of the piano on the floor
- ☑ force of Chadwick on the piano
- ☐ force of the piano pushing on Chadwick

Part C

Select the choice that best matches the free-body diagram you have drawn for the piano.

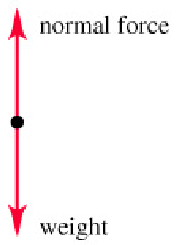
Hint 1. Determine the directions and relative magnitudes of the forces

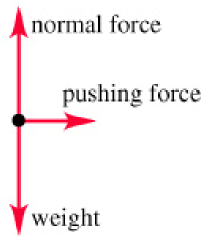
Which of the following statements best describes the correct directions and relative magnitudes of the forces involved?

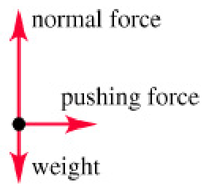
ANSWER:

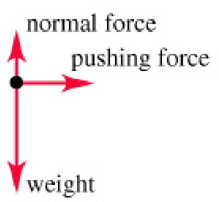
- The normal force and weight are both upward and the pushing force is horizontal.
- The normal force and weight are both downward and the pushing force is horizontal.
- The normal force is upward, the weight is downward, and the pushing force is horizontal. The normal force has a greater magnitude than the weight.
- The normal force is upward, the weight is downward, and the pushing force is horizontal. The normal force and weight have the same magnitude.
- The normal force is upward, the weight is downward, and the pushing force is horizontal. The normal force has a smaller magnitude than the weight.

ANSWER:









If you were actually going to solve this problem rather than just draw the free-body diagram, you would need to define the coordinate system. Choose the position of the piano as the origin. In this case it is simplest to let the *y* axis point vertically upward and the *x* axis point horizontally to the right, in the direction of the acceleration.

Part D

Determine the object of interest for this situation.

ANSWER:

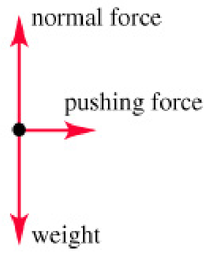
For this situation, you should draw a free-body diagram for

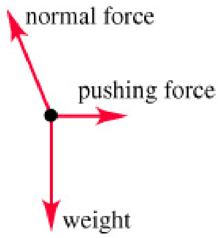
- ○ the ramp.
- ○ Chadwick.
- ◉ the piano.

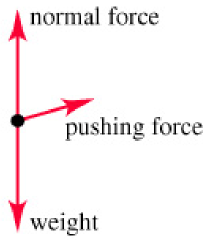
Part E

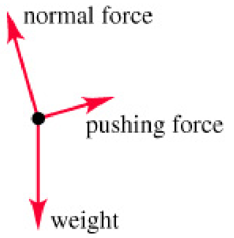
Which diagram accurately represents the free-body diagram for the piano?

ANSWER:

○ 

○ 

○ 

◉ 

In working problems like this one that involve an incline, it is most often easiest to select a coordinate system that is not vertical and horizontal. Instead, choose the *x* axis so that it is parallel to the incline and choose the *y* axis so that it is perpendicular to the incline.

Newton's 1st and 2nd Laws

Learning Goal:

To understand the meaning and the basic applications of Newton's 1st and 2nd laws.

Newton's laws are fundamental in mechanics. Their mathematical expressions are very simple but conceptual understanding of Newton's laws, which is necessary for solving nontrivial problems, is not simple at all.

Newton's 1st law

The common textbook statement of Newton's 1st law may seem rather straightforward. Here it is:
An object has a constant velocity (possibly zero) if and only if the net force acting on the object is zero.

In other words, if the vector sum of the forces applied to the object is zero, the object would be either at rest or at constant velocity (that is, the object would have zero acceleration). If such a sum is *not* zero, the object cannot possibly be moving at a constant velocity.

Frames of reference

The statement of Newton's 1st law becomes a bit more complicated in actual applications. Imagine yourself in a car. To understand Newton's 1st law fully, we need the concept of a *frame of reference*. A frame of reference is a set of coordinates used to measure distances and times. In your frame of reference, any distance would be measured relative to you. For example, the radio in the car is 0.75 m to the right of you. The radio is at rest in your frame of reference, because the radio doesn't change its distance or direction from you.

In your frame of reference, the car is always at rest. It is entirely possible that the net force acting on the car is *not* zero: The car may (in the frame of reference of an observer standing on the ground) be accelerating, turning, or braking. Yet in *your frame of reference*, the car would remain at rest because, relative to you, it is not moving at all. So, the car is at rest or accelerating, depending upon who you ask.

Inertial frames of reference

It's tempting to ignore this difficulty by saying that the frame of reference attached to the car is somehow wrong. The observer on the ground, in contrast, is right: The observer sees the motion of the car as it *really* is. However, such a line of reasoning seems flawed, because it raises the question of how to determine which frames of reference are "right" and which ones are "wrong."

This is what Newton's 1st law settles. Newton established the concept of an *inertial frame of reference*. An inertial frame of reference, by definiton, is one in which the statement of Newton's 1st law is, in fact, true.

Newton's 2nd law

It is important to know that the frame of reference being used is, in fact, inertial. Only then does Newton's 2nd law work in a simple and elegant form. Newton's 2nd law establishes the relationship between the net force acting on an object, the mass of the object, and its acceleration:

$$\vec{F}_{\rm net} = m\vec{a},$$

or

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

Note that Newon's 2nd law allows one to find the *magnitude* of the object's acceleration. It also establishes the fact that the acceleration of an object has the same *direction* as the net force acting on the object.

Applying Newton's laws in inertial and noninertial frames

If the frame of reference is *not* inertial, using Newton's 2nd law to calculate acceleration is still possible but may be far more complicated. Objects that experience zero net force may accelerate, and objects that move at constant velocity may experience a net force not equal to zero. The important question is: Which frames of reference are inertial and which ones are not? This also raises the following question: Are there *any* inertial frames of reference in this universe?

Newton postulated that inertial frames of reference do exist. This statement, coupled with the definition of inertial frames of reference, may be considered a more proper way to state Newton's 1st law.

Only an experiment can establish whether a particular frame of reference is inertial (or, to be precise, "inertial enough" for the purposes needed). Let us go back to the car example. The frame of reference attached to the ground, we would usually say, is inertial. That is, if we get an object and make sure that all external forces acting on it add up to zero, we can then *observe* that the object is, in fact, moving at constant velocity (or, possibly, remaining at rest). In most problems that we will be solving, the frame of reference of the earth will be considered an inertial frame of reference. For all practical purposes, this means that Newton's 2nd law will work in it.

However, it is instructive to understand that the earth provides a reference frame that is less than "perfectly inertial." An observer on the sun, for instance, would notice that the object in question does, in fact, have an acceleration: the centripetal acceleration associated with the orbital motion of the earth around the sun! The best inertial frame of reference is the one assoicated with distant stars and any other frame of reference that is moving at a constant velocity relative to distant stars.

The conceptual questions that follow should help you learn to apply Newton's 1st and 2nd laws properly. Note that, throughout this problem, we will assume that the frame of reference associated with the earth is perfectly inertial.

Part A

Which object provides an inertial frame of reference?

ANSWER:

- ( ) the tip of the moving second hand of a clock
- ( ) a rock thrown vertically upward
- ( ) a pendulum swinging with no air resistance
- (•) a skydiver falling at terminal velocity

Assuming that the earth provides an inertial frame of reference, an object moving at a constant velocity relative to the earth would also provide an inertial frame of reference.

Part B

You are conducting an experiment inside an elevator that can move in a vertical shaft. A load is hung vertically from the ceiling on a string, and is stationary with respect to you. The tension in the string is measured to be 10% less than the weight of the load. No other forces are acting on the load. Which of the following statements about the elevator are correct?

Check all that apply.

ANSWER:

- [ ] The elevator is an inertial frame of reference.
- [x] The elevator is not an inertial frame of reference.
- [ ] The elevator may be at rest for the duration of the entire experiment.
- [ ] The elevator may be moving at a constant velocity upward.
- [ ] The elevator may be moving at a constant velocity downward.
- [x] The elevator must be accelerating.

Part C

You are conducting an experiment inside an elevator that can move in a vertical shaft. A load is hung vertically from the ceiling on a string. The tension in the string is measured to be exactly equal to the weight of the load. No other forces are acting on the load. Which of the following statements about the elevator are correct?

Check all that apply.

ANSWER:

- [x] The elevator is an inertial frame of reference.
- [ ] The elevator is not an inertial frame of reference.
- [x] The elevator may be at rest.
- [x] The elevator may be moving at a constant velocity upward.
- [x] The elevator may be moving at a constant velocity downward.
- [ ] The elevator *may* be accelerating.
- [ ] The elevator *must* be accelerating.

Part D

You are conducting an experiment inside a train car that may move horizontally along rail tracks. A load is hung from the ceiling on a string. The load is not swinging, and the string is observed to make a constant angle of 45° with the horizontal. No other forces are acting on the load. Which of the following statements are correct?

Check all that apply.

ANSWER:

- [ ] The train is an inertial frame of reference.
- [x] The train is not an inertial frame of reference.
- [x] The train may be instantaneously at rest.
- [ ] The train may be moving at a constant speed in a straight line.
- [x] The train may be moving at a constant speed in a circle.
- [ ] The train must be speeding up.
- [ ] The train must be slowing down.
- [x] The train must be accelerating.

Since the tension and the weight are not directed opposite to each other, the net force cannot possibly be zero–and yet the load is at rest relative to the train car. Therefore, the car is not an inertial frame of reference. It must be accelerating relative to the earth, although it is not clear exactly how.

Part E

Consider the train car described in the previous part. Another experiment is conducted in it: A net force of $20 \mathrm{~N}$ is applied to an object of mass $5 \mathrm{~kg}$. Can you determine the acceleration of the object with respect to the train, and, if so, what is its value?

ANSWER:

- ○ Yes; $0.25 \mathrm{~m/s^2}$.
- ○ Yes; $4.0 \mathrm{~m/s^2}$.
- ○ Yes; $100 \mathrm{~m/s^2}$.
- ◉ No; there is not enough information.

The train car is not an inertial frame of reference, so $\vec{F}_{\mathrm{net}} = m\vec{a}$ would not work here.

Part F

A 1000-kg car is moving along a straight road down a $30°$ slope at a constant speed of $20.0 \mathrm{~m/s}$. What is the net force acting on the car?

ANSWER:

- ◉ $0 \mathrm{~N}$
- ○ $10000 \mathrm{~N}$
- ○ $17320 \mathrm{~N}$
- ○ $20000 \mathrm{~N}$

The car has zero acceleration; therefore, it experiences zero net force. According to Newton's 1st law, *no net force is required to maintain a constant velocity* (in an inertial frame of reference, of course). The car has a constant veclocity relative to the earth; therefore, the car is also an inertial frame of reference.

Part G

Consider two cars moving along the same straight road in opposite directions. Car A has a mass of $500 \mathrm{~kg}$ and has a constant speed of $20 \mathrm{~m/s}$; car B has a mass of $800 \mathrm{~kg}$ and a constant speed of $15 \mathrm{~m/s}$. What can you say about the net forces on the cars?

ANSWER:

- ○ Car A experiences greater net force than car B.
- ○ Car B experiences greater net force than car A.
- ◉ Both cars experience equal net forces.

Each car has zero acceleration; therefore, the net force on each car, according to Newton's 1st law, is zero.

Part H

In an inertial frame of reference, a series of experiments is conducted. In each experiment, two or three forces are applied to an object. The magnitudes of these forces are given. No other forces are acting on the object. In which cases may the object *possibly* remain at rest?

The forces applied are as follows:

Check all that apply.

Hint 1. Using the net force

In an inertial frame of reference, the state of rest is only possible when the net force acting on the object is zero. In which cases can the forces acting on the object *possibly* add up to zero? You may want to draw some diagrams.

ANSWER:

- [x] 2 N; 2 N
- [x] 200 N; 200 N
- [ ] 200 N; 201 N
- [x] 2 N; 2 N; 4 N
- [x] 2 N; 2 N; 2 N
- [x] 2 N; 2 N; 3 N
- [ ] 2 N; 2 N; 5 N
- [x] 200 N; 200 N; 5 N

Part I

In an inertial frame of reference, a series of experiments is conducted. In each experiment, two or three forces are applied to an object. The magnitudes of these forces are given. No other forces are acting on the object. In which cases may the object *possibly* move at a constant velocity of $256 \ \mathrm{m/s}$?

The forces applied are as follows:

Check all that apply.

Hint 1. Using the net force

In an inertial frame of reference, moving at a constant velocity is only possible when the net force acting on the object iz zero.

ANSWER:

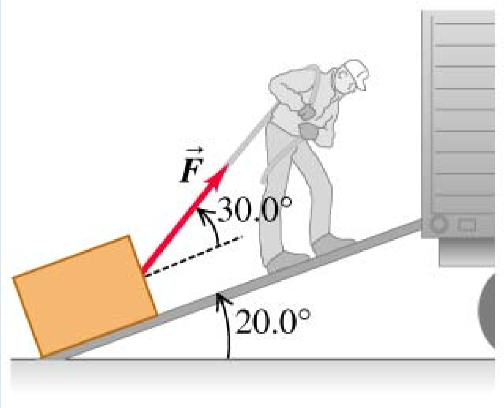
- [x] 2 N; 2 N
- [x] 200 N; 200 N
- [ ] 200 N; 201 N
- [x] 2 N; 2 N; 4 N
- [x] 2 N; 2 N; 2 N
- [x] 2 N; 2 N; 3 N
- [ ] 2 N; 2 N; 5 N
- [x] 200 N; 200 N; 5 N

You should have noticed that the sets of forces applied to the object are the same as the ones in the prevous question. Newton's 1st law (and the 2nd law, too) makes no distinction between the state of rest and the state of moving at a constant velocity (even a high velocity). In both cases, the net force applied to the object must equal zero.

Although some of the questions in this problem may have seemed tricky and unfair, the subtleties here are important in improving conceptual understanding. That understanding, in turn, will enable you to correctly solve complex computational problems using Newton's laws.

Exercise 4.4

A man is dragging a trunk up the loading ramp of a mover's truck. The ramp has a slope angle of 20.0 °, and the man pulls upward with a force $\vec{F}$ whose direction makes an angle of 30.0 ° with the ramp .



Part A

How large a force $\vec{F}$ is necessary for the component F_x parallel to the ramp to be 60.0 N?

ANSWER:

$\vec{F}$ = 69.3 N

Part B

How large will the component F_y perpendicular to the ramp then be?

ANSWER:

F_y = 34.6 N

Enhanced EOC: Exercise 4.5

Two dogs pull horizontally on ropes attached to a post; the angle between the ropes is 63.0°. Dog A exerts a force of 282N , and dog B exerts a force of 346N .

You may want to review (pages 105 - 108) .

For help with math skills, you may want to review:

Vector Magnitudes

Determining the Angle of a Vector

Vector Addition

For general problem-solving tips and strategies for this topic, you may want to view a Video Tutor Solution of Superposition of forces.

Part A

Find the magnitude of the resultant force.

Hint 1. How to approach the problem

Imagine you were sitting in a tree directly above the post, so that you were looking down on the dogs and the ropes tying them to the post.

Start by drawing a sketch of the two dogs pulling on their ropes as seen by you from above, and choose a coordinate system so that the post is at the origin and the rope tied to dog A is along the *x*-axis.

In what direction would dog B be seen pulling its rope?

Now, find the resultant force. How is the magnitude of a vector related to its components?

ANSWER:

F = $\sqrt{(F_A{}^2 + F_B{}^2 + 2F_AF_B\cos(\alpha))}$ = 537 N

Part B

Find the angle the resultant force makes with the rope of dog A.

Hint 1. How to approach the problem

How can you find the angle the resultant force vector makes with the *x*-axis (the rope of dog A) from the components of that vector?

ANSWER:

θ = $\dfrac{\mathrm{asin}\left(\dfrac{\sin(\alpha)F_B}{\sqrt{(F_A{}^2+F_B{}^2+2F_AF_B\cos(\alpha))}}\right)\cdot 180}{\pi}$ = 35.1 °

Exercise 4.8

You walk into an elevator, step onto a scale, and push the "up" button. You also recall that your normal weight is w = 615N .

Part A

Make a free-body diagram of your body if the elevator has an acceleration of magnitude a = 2.42$\mathrm{m/s^2}$.

Draw the force vectors with their tails at the dot. The orientation of your vectors will be graded. The exact lengths of your vectors will not be graded but the relative length of one to the other will be graded.

ANSWER:

Part B

What does the scale read with the conditions given in part (A)?

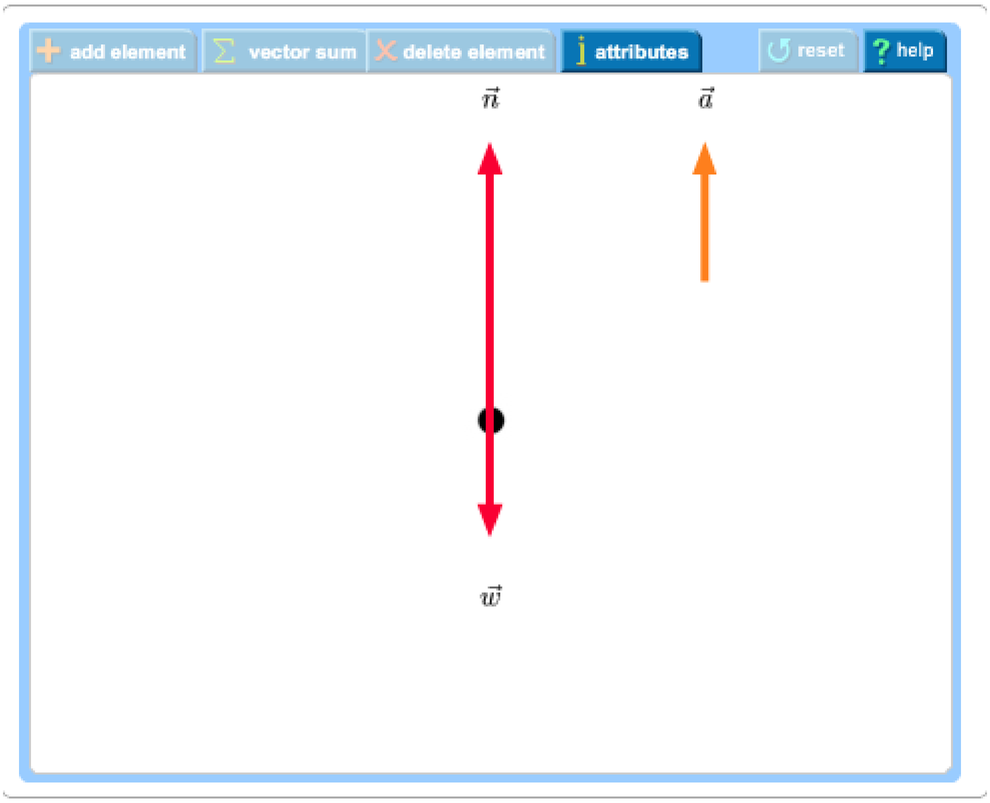
ANSWER:

F = $w + \dfrac{w}{g}a$ = 767 N

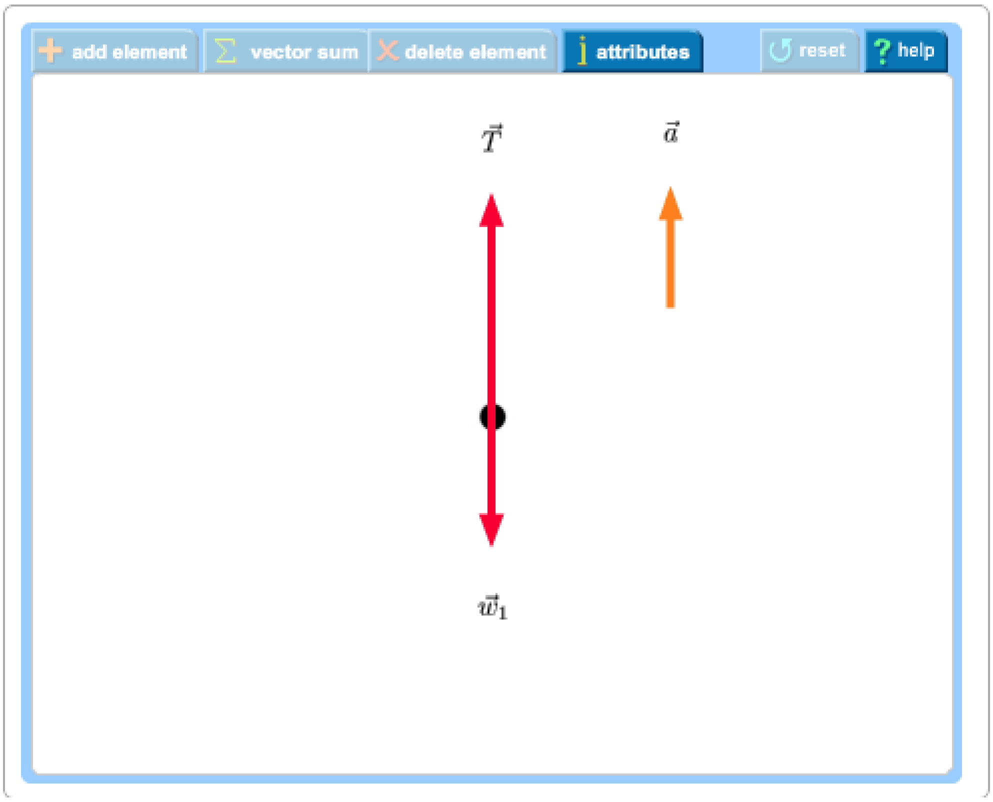
Part C

If you start holding a 3.85kg package by a light vertical string, make a free-body diagram of the package.

Part A ANSWER:



Part C ANSWER:



Draw the force vectors with their tails at the dot. The orientation of your vectors will be graded. The exact lengths of your vectors will not be graded but the relative length of one to the other will be graded.

ANSWER:

Part D

What will be the tension in the string in part (C) once the elevator begins accelerating?

ANSWER:

T = $m(9.80+a)$ = 47.0 N

Exercise 4.11

A hockey puck with mass 0.160 kg is at rest at the origin (x=0) on the horizontal, frictionless surface of the rink. At time t = 0 a player applies a force of 0.250 N to the puck, parallel to the x-axis; he continues to apply this force until t = 2.00 s.

Part A

What is the position of the puck at t = 2.00 s?

ANSWER:

x = 3.13 m

Part B

In this case what is the speed of the puck?

ANSWER:

v = 3.13 $\mathrm{m/s}$

Part C

If the same force is again applied at t = 5.00 s, what is the position of the puck at t = 7.00 s?

ANSWER:

x = 21.9 m

Part D

In this case what is the speed of the puck?

ANSWER:

v = 6.25 $\mathrm{m/s}$

Exercise 4.17

Part A

Superman throws a boulder of weight 3000N at an adversary on the surface of the earth, where the magnitude of the acceleration due to gravity, g = 9.80$\mathrm{m/s^2}$. What horizontal force must Superman apply to the boulder to give it a horizontal acceleration of 12.0$\mathrm{m/s^2}$?

ANSWER:

F = $\frac{wa}{g}$ = 3670 N

Exercise 4.22

A small car (mass 450kg) is pushing a large truck (mass 920kg) due east on a level road. The car exerts a horizontal force of 1400N on the truck.

Part A

What is the magnitude of the force that the truck exerts on the car?

Express your answer with the appropriate units.

ANSWER:

F = F = 1400N

Exercise 4.31

A chair of mass 15.5kg is sitting on the horizontal floor; the floor is not frictionless. You push on the chair with a force F = 44.0N that is directed at an angle of 34.0° below the horizontal and the chair slides along the floor.

Part A

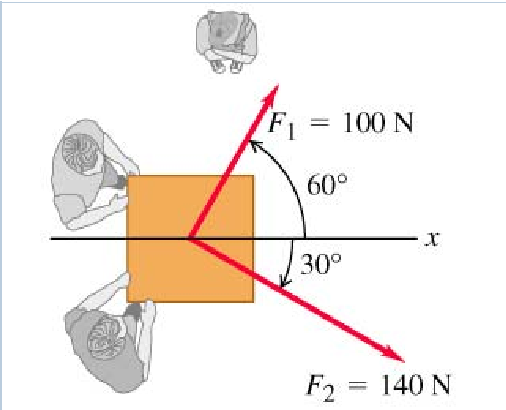
Use Newton's laws to calculate the normal force that the floor exerts on the chair.

ANSWER:

n = $mg + F\sin\left(\alpha\right)$ = 177 N

Problem 4.37

Two adults and a child want to push a wheeled cart in the direction marked x in the figure . The two adults push with horizontal forces $\vec{F_1}$ and $\vec{F_2}$ as shown in the figure.



Part A

Find the magnitude of the *smallest* force that the child should exert. You can ignore the effects of friction.

ANSWER:

F = 16.6 N

Part B

Find the angle that the force makes with the +*x*-direction. Take angles measured counterclockwise from the +*x*-direction to be positive.

ANSWER:

θ = 270 $^\circ$

Also accepted: -90

Part C

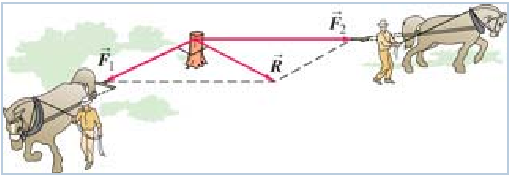
If the child exerts the minimum force found in part (A) and in part (B) , the cart accelerates at 2.00 $\mathrm{m/s^2}$ in the +*x* - direction. What is the weight of the cart?

ANSWER:

W = 840 N

Problem 4.35

Two horses pull horizontally on ropes attached to a stump. The two forces $\vec{F}_1$ = 1300N and $\vec{F}_2$ that they apply to the stump are such that the net (resultant) force $\vec{R}$ has a magnitude equal to that of $\vec{F}_1$ and makes an angle of 90° with $\vec{F}_1$.



Part A

Find the magnitude of $\vec{F}_2$.

ANSWER:

F_2 = $\sqrt{2{F_1}^2}$ = 1840 N

Part B

Find the direction of $\vec{F}_2$ (relative to $\vec{F}_1$).

ANSWER:

θ = 135 $^\circ$

Problem 4.39

Basketball player Darrell Griffith is on record as attaining a standing vertical jump of 1.2 m (4 ft). (This means that he moved upward by 1.2 m after his feet left the floor.) Griffith weighed 890 N (200 lb).

Part A

What is his speed as he leaves the floor?

Express your answer using two significant figures.

ANSWER:

v = 4.9 m/s

Part B

If the time of the part of the jump before his feet left the floor was 0.300 s, what was the magnitude of his average acceleration while he was pushing against the floor?

Express your answer using two significant figures.

ANSWER:

a = 16 m/s^2

Part C

What is its direction?

ANSWER:

- upward
- downward

Part D

Use Newton's laws and the results of part (B) to calculate the average force he applied to the ground.

Express your answer using two significant figures.

ANSWER:

F = 2.4×10^3 N

Also accepted: 2.3×10^3