Homework 3-1

Due: 11:59pm on Tuesday, November 4, 2014

To understand how points are awarded, read the Grading Policy for this assignment.

Tactics Box 5.1 Drawing Force Vectors

Learning Goal:

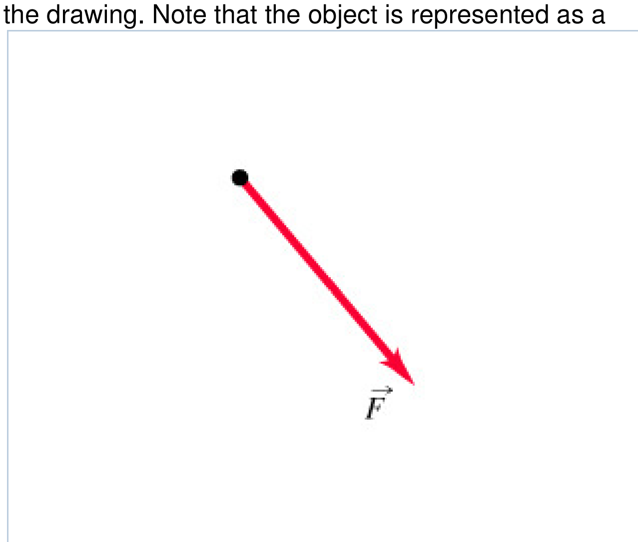
To practice Tactics Box 5.1 Drawing Force Vectors.

To visualize how forces are exerted on objects, we can use simple diagrams such as vectors. This Tactics Box illustrates the process of drawing a force vector by using the particle model, in which objects are treated as points.

TACTICS BOX 5.1 Drawing force vectors

1. Represent the object as a particle.
2. Place the *tail* of the force vector on the particle.
3. Draw the force vector as an arrow pointing in the proper direction and with a length proportional to the size of the force.
4. Give the vector an appropriate label.

The resulting diagram for a force $\vec{F}$ exerted on an object is shown in the drawing. Note that the object is represented as a black dot.



Part A

A book lies on a table. A pushing force $\vec{F}_{\rm push}$ parallel to the table top and directed to the right is exerted on the book.

Follow the steps above to draw the force vector $\vec{F}_{\rm push}$. Use the black dot as the particle representing the book.

Draw the vector starting at the black dot. The location and orientation of the vector will be graded. The length of the vector will not be graded.

ANSWER:

Correct

Part B

Now, instead of being parallel to the table top, the pushing force $\vec{F}_{\rm push}$ is directed 30° below the plane of the table top, pushing the book to the right. Follow the steps above to draw the force vector $\vec{F}_{\rm push}$. Use the black dot as the particle representing the book.

Draw the vector starting at the black dot. The location and orientation of the vector will be graded. The length of the vector will not be graded.

ANSWER:

Correct

Part C

As the book is pushed along the table by the pushing force $\vec{F}_{\rm p}$ described in Part B, a second force $\vec{F}_2$, equal in magnitude to $\vec{F}_{\rm p}$ but opposite in direction, is exerted on the book. Add the force vector $\vec{F}_2$ to the diagram below.

Draw the vector starting at the black dot. The location, orientation, and length of the vector will be graded.

Hint 1. How to draw the second force vector

Because the magnitude of $\vec{F}_2$ is equal to the magnitude of $\vec{F}_{\rm p}$, you can draw $\vec{F}_2$ starting at the tip of $\vec{F}_{\rm p}$ and ending at its tail. Then, move $\vec{F}_2$, without changing its orientation or length, so that it starts at the black dot. Use the **vector info** button to verify the length and orientation of $\vec{F}_2$.

ANSWER:

Correct

As you saw in this problem, the use of vectors to visualize forces acting on an object can be quite straightforward. Still, this is an important step in understanding and solving any mechanics problem, and it should not be neglected. In fact, you will soon learn how diagrams made up of force vectors can provide crucial information when you try to solve a physics problem!

± Two Forces Acting at a Point

Two forces, $\vec{F}_1$ and $\vec{F}_2$, act at a point. $\vec{F}_1$ has a magnitude of 9.40$\rm N$ and is directed at an angle of 57.0° above the negative *x* axis in the second quadrant. $\vec{F}_2$ has a magnitude of 5.60$\rm N$ and is directed at an angle of 54.1° below the negative *x* axis in the third quadrant.

Part A

What is the *x* component of the resultant force?

Express your answer in newtons.

Hint 1. How to approach the problem

The resultant force is defined as the vector sum of all forces. Thus, its *x* component is the sum of the *x* components of the forces, and its *y* component is the sum of the *y* components of the forces.

Hint 2. Find the *x* component of $\vec{F}_1$

Find the *x* component of $\vec{F}_1$.

Express your answer in newtons.

Hint 1. Components of a vector

Consider a vector $\vec{A}$ that forms an angle θ with the positive *x* axis. The *x* and *y* components of $\vec{A}$ are, respectively,

$$A_x = A\cos\theta \text{ and } A_y = A\sin\theta,$$

where A is the magnitude of the vector. Note that

$$A_x < 0 \text{ and } A_y > 0 \text{ if } \frac{\pi}{2} < \theta < \pi,$$

$$A_x < 0 \text{ and } A_y < 0 \text{ if } \pi < \theta < \frac{3\pi}{2}.$$

Hint 2. Find the direction of $\vec{F}_1$

$\vec{F}_1$ is directed at an angle of 57.0° above the *x* axis in the second quadrant. When you calculate the components of $\vec{F}_1$, however, the direction of the force is commonly expressed in terms of the angle that the vector representing the force forms with the *positive x* axis. What is the angle that $\vec{F}_1$ forms with the positive *x* axis? Select an answer from the following list, where $\theta =$ 57.0°.

ANSWER:

- θ
- $180^\circ - \theta$
- $180^\circ + \theta$
- $90^\circ + \theta$

ANSWER:

-5.12 N

Correct

Hint 3. Find the *x* component of $\vec{F}_2$

Find the *x* component of $\vec{F}_2$.

Express your answer in newtons.

Hint 1. Components of a vector

Consider a vector $\vec{A}$ that forms an angle θ with the positive *x* axis. The *x* and *y* components of $\vec{A}$ are, respectively,

$$A_x = A\cos\theta \text{ and } A_y = A\sin\theta,$$

where A is the magnitude of the vector. Note that

$$A_x < 0 \text{ and } A_y > 0 \text{ if } \frac{\pi}{2} < \theta < \pi,$$

$$A_x < 0 \text{ and } A_y < \text{ if } \pi < \theta < \frac{3\pi}{2}.$$

Hint 2. Find the direction of $\vec{F}_2$

$\vec{F}_2$ is directed at an angle of 54.1° below the *x* axis in the third quadrant. When you calculate the components of $\vec{F}_2$, however, the direction of the force is commonly expressed in terms of the angle that the vector representing the force forms with the *positive x* axis. What is the angle that $\vec{F}_2$ forms with the positive *x* axis? Select an answer from the following list, where $\theta =$ 54.1°.

ANSWER:

- ○ θ
- ○ $180^\circ - \theta$
- ◉ $\theta - 180^\circ$
- ○ $-90^\circ - \theta$

ANSWER:

-3.28 N

Correct

Now simply add the *x* component of $\vec{F}_1$ to the *x* component of $\vec{F}_2$.

ANSWER:

-8.40 N

Correct

Part B

What is the *y* component of the resultant force?

Express your answer in newtons.

Hint 1. How to approach the problem

Follow the same procedure that you used in Part A to find the *x* component of the resultant force, though now calculate the *y* components of the two forces.

Hint 2. Find the *y* component of $\vec{F}_1$

Find the *y* component of $\vec{F}_1$.

Express your answer in newtons.

Hint 1. Components of a vector

Consider a vector $\vec{A}$ that forms an angle θ with the positive *x* axis. The *x* and *y* components of $\vec{A}$ are, respectively,

$$A_x = A\cos\theta \text{ and } A_y = A\sin\theta,$$

where A is the magnitude of the vector. Note that

$$A_x < 0 \text{ and } A_y > 0 \text{ if } \frac{\pi}{2} < \theta < \pi,$$

$$A_x < 0 \text{ and } A_y < 0 \text{ if } \pi < \theta < \frac{3\pi}{2}.$$

ANSWER:

7.88 N

Hint 3. Find the *y* component of $\vec{F}_2$

Find the *y* component of $\vec{F}_2$.

Express your answer in newtons.

Hint 1. Components of a vector

Consider a vector $\vec{A}$ that forms an angle θ with the positive *x* axis. The *x* and *y* components of $\vec{A}$ are, respectively,

$$A_x = A\cos\theta \text{ and } A_y = A\sin\theta,$$

where A is the magnitude of the vector. Note that

$$A_x < 0 \text{ and } A_y > 0 \text{ if } \frac{\pi}{2} < \theta < \pi,$$

$$A_x < 0 \text{ and } A_y < 0 \text{ if } \pi < \theta < \frac{3\pi}{2}.$$

ANSWER:

-4.54 N

ANSWER:

3.35 N

Correct

Part C

What is the magnitude of the resultant force?

Express your answer in newtons.

Hint 1. Magnitude of a vector

Consider a vector $\vec{A}$, whose components are A_x and A_y. The magnitude of $\vec{A}$ is

$$A = \sqrt{A_x^2 + A_y^2}.$$

ANSWER:

9.05 N

Correct

Tactics Box 5.2 Identifying Forces

Learning Goal:

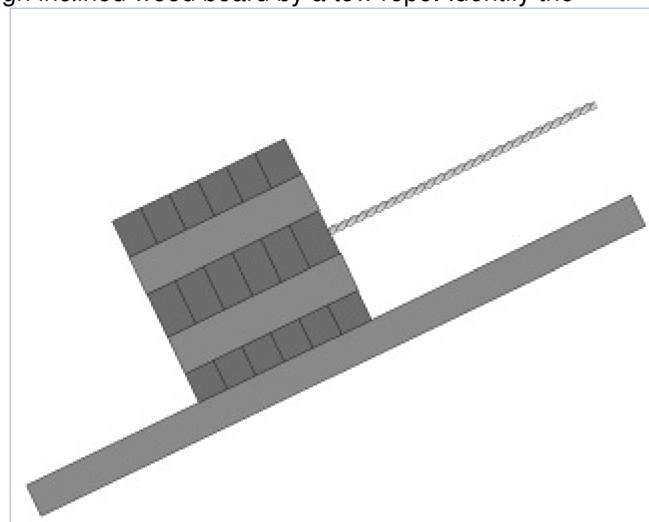
To practice Tactics Box 5.2 Identifying Forces.

The first basic step in solving force and motion problems generally involves identifying all of the forces acting on an object. This tactics box provides a step-by-step method for identifying each force in a problem.

TACTICS BOX 5.2 Identifying forces

1. Identify the object of interest. This is the object whose motion you wish to study.
2. Draw a picture of the situation. Show the object of interest and all other objects—such as ropes, springs, or surfaces—that touch it.
3. Draw a closed curve around the object. Only the object of interest is inside the curve; everything else is outside.
4. Locate every point on the boundary of this curve where other objects touch the object of interest. These are the points where contact forces are exerted on the object.
5. Name and label each contact force acting on the object. There is at least one force at each point of contact; there may be more than one. When necessary, use subscripts to distinguish forces of the same type.
6. Name and label each long-range force acting on the object. For now, the only long-range force is the gravitational force.

Apply these steps to the following problem: A crate is pulled up a rough inclined wood board by a tow rope. Identify the forces on the crate.



Part A

Which of the following objects are of interest?

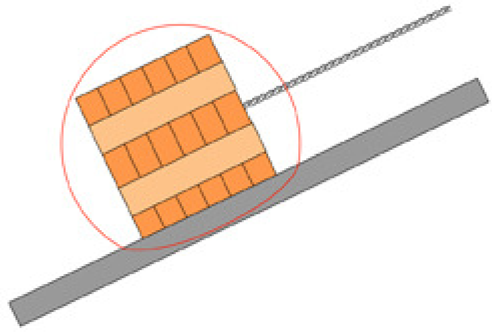
Check all that apply.

ANSWER:

- [ ] wood board
- [ ] rope
- [x] crate
- [ ] earth

Correct

Now that you have identified the object of interest, draw a sketch of the situation and draw a closed curve around the object, as shown in the figure below.



Part B

Identify the *contact* forces exerted on the crate.

Check all that apply.

ANSWER:

- [x] kinetic friction
- [ ] spring force
- [ ] static friction
- [ ] gravitational force
- [ ] thrust
- [x] tension
- [x] normal force
- [ ] drag

All attempts used; correct answer displayed

Part C

Identify the long-range forces acting on the crate.

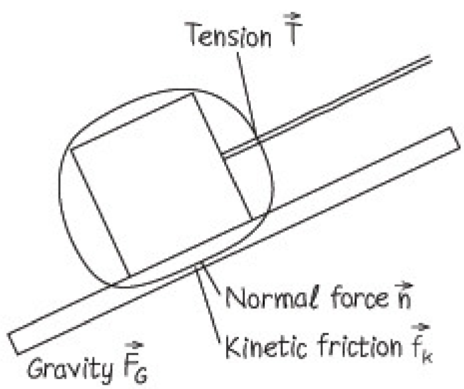
Check all that apply.

ANSWER:

- [ ] static friction
- [ ] normal force
- [ ] drag
- [x] gravitational force
- [ ] tension
- [ ] thrust
- [ ] spring force
- [ ] kinetic friction

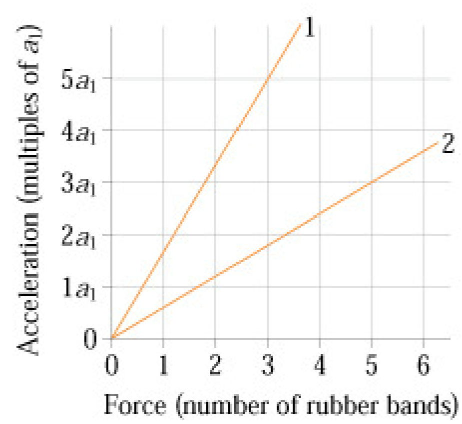
Correct

Now that you have identified all the forces acting on the system, your final sketch describing the situation might look like this:



Enhanced EOC: Problem 5.9

The figure shows acceleration-versus-force graphs for two objects pulled by rubber bands.



You may want to review (pages 127 - 130) .

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

Finding the Slope of a Line from a Graph

Part A

What is the mass ratio $\frac{m_1}{m_2}$?

Express your answer using two significant figures.

Hint 1. How to approach the problem

How are the acceleration and the force on an object related to its mass? How is the slope of each line in the figure related to each object's mass?

For each line, what two points are easy to measure accurately to determine the slope of line? How is the slope determined from the *x* and *y* coordinates of the two points you chose for each line?

ANSWER:

$\frac{m_1}{m_2}$ = 0.36

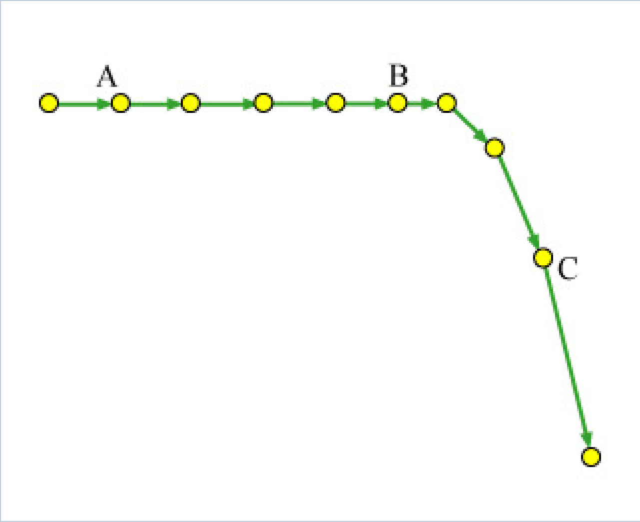
Correct

Conceptual Questions on Newton's 1st and 2nd Laws

Learning Goal:

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

In this problem, you are given a diagram representing the motion of an object--a *motion diagram*. The dots represent the object's position at moments separated by equal intervals of time. The dots are connected by arrows representing the object's *average* velocity during the corresponding time interval.



Your goal is to use this motion diagram to determine the direction of the net force acting on the object. You will then determine which force diagrams and which situations may correspond to such a motion.

Part A

What is the direction of the net force acting on the object at position A?

Hint 1. Using Newton's 2nd law

According to Newton's 2nd law, vectors $\vec{a}$ and $\vec{F}_{\text{net}}$ have the same direction. Can you determine the direction of acceleration at position A by analyzing the diagram?

ANSWER:

- upward
- downward
- to the left
- to the right
- The net force is zero.

Correct

The velocity vectors connecting position A to the adjacent positions appear to have the same magnitude and direction. Therefore, the acceleration is zero--and so is the net force.

Part B

What is the direction of the net force acting on the object at position B?

ANSWER:

- upward
- downward
- to the left
- to the right
- The net force is zero.

Correct

The velocity is directed to the right; however, it is decreasing. Therefore, the acceleration is directed to the left--and so is the net force.

Part C

What is the direction of the net force acting on the object at position C?

Hint 1. Consider the components of the velocity

The horizontal component of the velocity appears to remain constant. What about the vertical one?

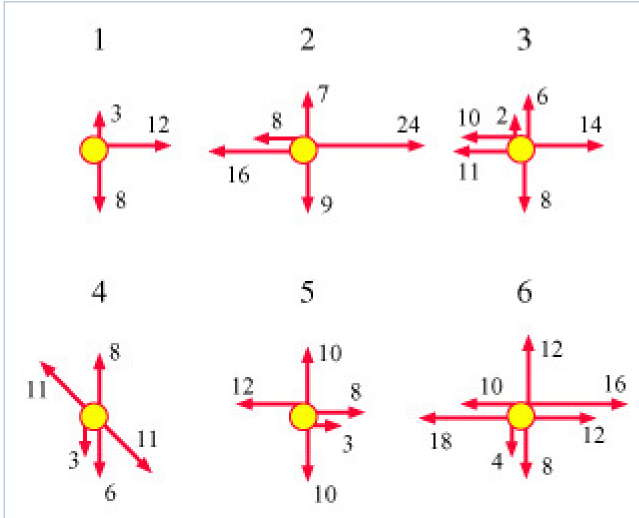
ANSWER:

- upward
- downward
- to the left
- to the right
- The net force is zero.

Correct

The horizontal component of the velocity does not change. The vertical component of the velocity increases. Therefore, the acceleration--and the net force--are directed straight downward.

The next four questions are related to the *force diagrams* numbered 1 to 6. These diagrams represent the forces acting on a moving object. The number next to each arrow represents the magnitude of the force in newtons.



Part D

Which of these diagrams may *possibly* correspond to the situation at point A on the motion diagram?

Type, in increasing order, the numbers corresponding to the correct diagrams. Do not use commas. For instance, if you think that only diagrams 3 and 4 are correct, type `34`.

ANSWER:

6

All attempts used; correct answer displayed

Part E

Which of these diagrams may *possibly* correspond to the situation at point B on the motion diagram?

Type, in increasing order, the numbers corresponding to the correct diagrams. Do not use commas. For instance, if you think that only diagrams 3 and 4 are correct, type `34`.

ANSWER:

35

All attempts used; correct answer displayed

Part F

Which of these diagrams may *possibly* correspond to the situation at point C on the motion diagram?

Type, in increasing order, the numbers corresponding to the correct diagrams. Do not use commas. For instance, if you think that only diagrams 3 and 4 are correct, type `34`.

ANSWER:

24

All attempts used; correct answer displayed

Part G

Which of these diagrams correspond to a situation where the moving object (not necessarily the one shown in the motion diagram) is changing its velocity?

Type, in increasing order, the numbers corresponding to the correct diagrams. Do not use commas. For instance, if you think that only diagrams 3 and 4 are correct, type `34`.

Hint 1. What does a change in velocity mean?

If the velocity of the moving object is changing, the net force applied to the object must be ___________.

ANSWER:

- ○ directed to the right
- ○ directed to the left
- ○ directed upward
- ○ directed downward
- ○ directed the same way as the velocity
- ○ directed opposite to the velocity
- ◉ of magnitude greater than zero

ANSWER:

12345

All attempts used; correct answer displayed

Consider the following situations:

A. A car is moving along a straight road at a constant speed.
B. A car is moving along a straight road while slowing down.
C. A car is moving along a straight road while speeding up.
D. A hockey puck slides along a horizontal icy (frictionless) surface.
E. A hockey puck slides along a rough concrete surface.
F. A cockroach is speeding up from rest.
G. A rock is thrown horizontally; air resistance is negligible.
H. A rock is thrown horizontally; air resistance is substantial.
I. A rock is dropped vertically; air resistance is negligible.
J. A rock is dropped vertically; air resistance is substantial.

Part H

Which of these situations describe the motion shown in the motion diagram at point A?

Type the letters corresponding to all the right answers in alphabetical order. Do not use commas. For instance, if you think that only situations C and D are correct, type CD.

ANSWER:

AD

Correct

Part I

Which of these situations describe the motion shown in the motion diagram at point B?

Type the letters corresponding to all the right answersin alphabetical order. Do not use commas. For instance, if you think that only situations C and D are correct, type CD.

ANSWER:

BE

Correct

Part J

Which of these situations describe the motion shown in the motion diagram at point C?

Type the letters corresponding to all the right answers in alphabetical order. Do not use commas. For instance, if you think that only situations C and D are correct, type CD.

ANSWER:

G

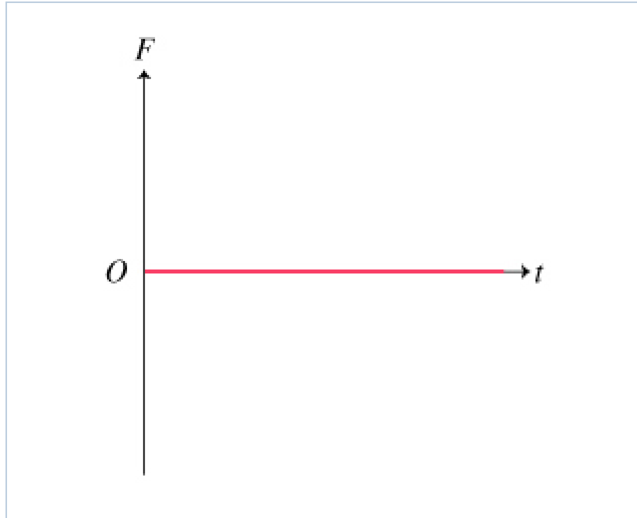
All attempts used; correct answer displayed

Motion from Force Graphing Question

For each of the net force versus time graphs in Parts A, B, and C, construct a *possible* corresponding graph of velocity $v(t)$, or position $x(t)$, versus time. Assume one-dimensional motion.

Part A

Plot velocity versus time.



Hint 1. Relating force and kinematics graphs

Newton's 2nd law states that the net force acting on an object is proportional to its acceleration. Therefore, graphs of net force versus time and acceleration versus time must have the same general shape.
From the graph of acceleration versus time, you can then construct a velocity versus time graph. The velocity at a time T is the initial velocity plus the area under the acceleration curve between $t = 0$ and $t = T$.

By the same process, you can construct a *position* versus time graph from the graph of velocity versus time. The position at a time T is the initial position plus the area under the velocity curve between $t = 0$ and $t = T$.

Hint 2. Initial values

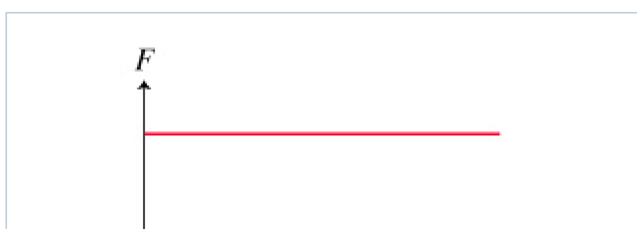
Knowing the net force that acts on an object does not allow you to determine the initial velocity or position of the object. Therefore, the velocity or position graph can begin at any initial value.

ANSWER:

Correct

Part B

Plot velocity versus time.



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Newton's 2nd law states that the net force acting on an object is proportional to its acceleration. Therefore, graphs of net force versus time and acceleration versus time must have the same general shape.
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By the same process, you can construct a *position* versus time graph from the graph of velocity versus time. The position at a time T is the initial position plus the area under the velocity curve between $t = 0$ and $t = T$.

Hint 2. Initial values

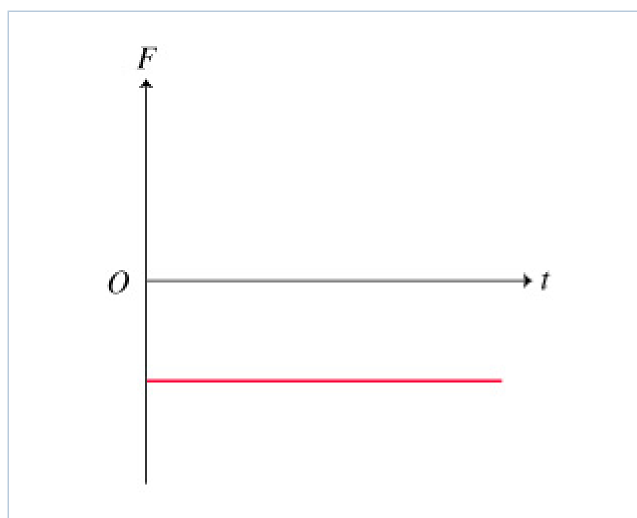
Knowing the net force that acts on an object does not allow you to determine the initial velocity or position of the object. Therefore, the velocity or position graph can begin at any initial value.

ANSWER:

Correct

Part C

Plot *position* versus time.



Hint 1. Relating force and kinematics graphs

Newton's 2nd law states that the net force acting on an object is proportional to its acceleration. Therefore, graphs of net force versus time and acceleration versus time must have the same general shape.

From the graph of acceleration versus time, you can then construct a velocity versus time graph. The velocity at a time T is the initial velocity plus the area under the acceleration curve between $t = 0$ and $t = T$.

By the same process, you can construct a *position* versus time graph from the graph of velocity versus time. The position at a time T is the initial position plus the area under the velocity curve between $t = 0$ and $t = T$.

Hint 2. Initial values

Knowing the net force that acts on an object does not allow you to determine the initial velocity or position of the object. Therefore, the velocity or position graph can begin at any initial value.

ANSWER:

Correct

Free-Body Diagrams

Learning Goal:

To gain practice drawing free-body diagrams

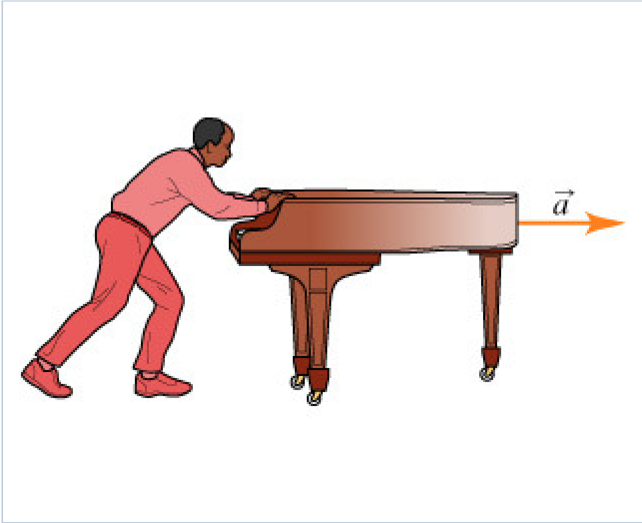
Whenever you face a problem involving forces, always start with a free-body diagram.
To draw a free-body diagram use the following steps:

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.

Correct

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

All attempts used; correct answer displayed

Now that you have identified the forces acting on the piano, you should draw the free-body diagram. Draw the length of your vectors to represent the relative magnitudes of the forces, but you don't need to worry about the exact scale. You won't have the exact value of all of the forces until you finish solving the problem. To maximize your learning, you should draw the diagram yourself before looking at the choices in the next part. You are on your honor to do so.

Part C

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

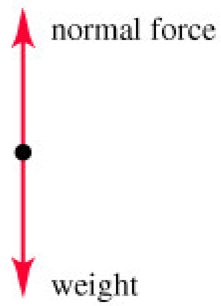
Hint 1. Determine the directions and relative magnitudes of the forces

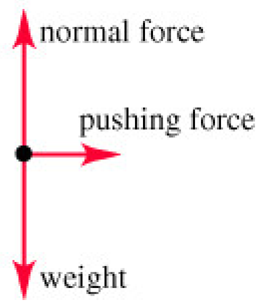
Which of the following statements best describes the correct directions and relative magnitudes of the forces involved?

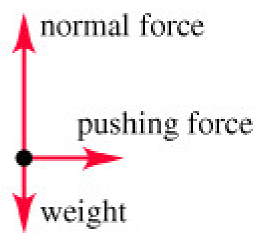
ANSWER:

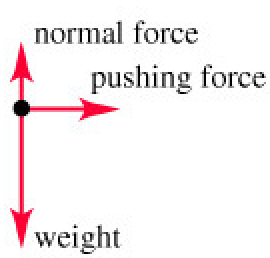
- ○ The normal force and weight are both upward and the pushing force is horizontal.
- ○ The normal force and weight are both downward and the pushing force is horizontal.
- ○ The normal force is upward, the weight is downward, and the pushing force is horizontal. The normal force has a greater magnitude 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:









Correct

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.

Chadwick now needs to push the piano up a ramp and into a moving van. at left. The ramp is frictionless. Is Chadwick strong enough to push the piano up the ramp alone or must he get help?

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

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.

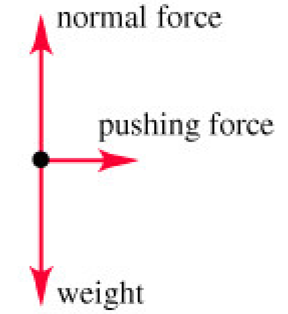
Correct

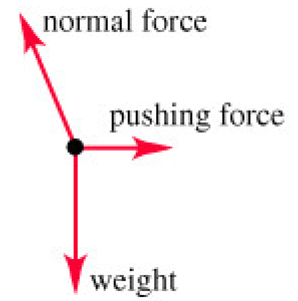
Now draw the free-body diagram of the piano in this new situation. Follow the same sequence of steps that you followed for the first situation. Again draw your diagram before you look at the choices below.

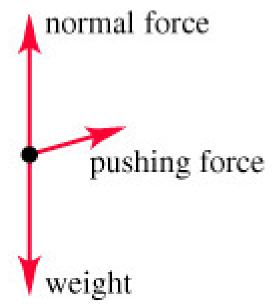
Part E

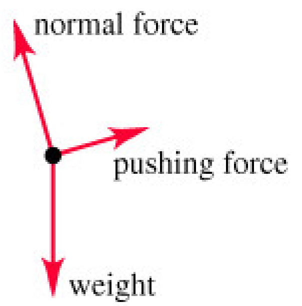
Which diagram accurately represents the free-body diagram for the piano?

ANSWER:









Correct

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

Correct

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 force due to gravity on 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.

All attempts used; correct answer displayed

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 force due to gravity on 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.

All attempts used; correct answer displayed

Part D

You are conducting an experiment inside a train car that may move along level 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.

All attempts used; correct answer displayed

Since the tension and the force due to gravity 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.

Correct

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 N
- 10000 N
- 17320 N
- 20000 N

Correct

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 kg and has a constant speed of 20 m/s; car B has a mass of 800 kg and a constant speed of 15 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.

Correct

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

All attempts used; correct answer displayed

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 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

Correct

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.

Newton's 1st Law

Learning Goal:

To understand Newton's 1st law.

Newton's *Principia* states this first law of motion:
An object subject to no net force maintains its state of motion, either at rest or at constant speed in a right line.
This law may be stated as follows: If the sum of all forces acting on an object is zero, then the acceleration of that object is zero. Mathematically this is just a special case of the 2nd law of motion, $\vec{F} = m\vec{a}$ when $\vec{F} = 0$, prompting scholars to advance the following reasons (among others) for Newton's spelling it out separately:

1. This expression only holds in an inertial coordinate system--one that is not accelerating--and this law really says you have to use this type of coordinate system (i.e., Newton's laws won't work inside an accelerating rocket ship.)
2. This was a direct challenge to the Impetus theory of motion, described as follows:
   A mover, while moving a body, impresses on it a certain impetus, a certain power capable of moving this body in the direction in which the mover set it going, whether upwards, downwards, sideways or in a circle. By the same amount that the mover moves the same body swiftly, by that amount is the impetus that is impressed on it powerful. It is by this impetus that the stone is moved after the thrower ceases to move it; but because of the resistance of the air and the gravity of the stone, which inclines it to move in a direction opposite to that towards which the impetus tends to move it, this impetus is continually weakened. Therefore the movement of the stone will become continually slower, and at length, the impetus is so diminished or destroyed that the gravity of the stone prevails over it and moves the stone down towards its natural place.

   A. C. Crombie, *Medieval and Early Modern Science*</>
   This theory is sometimes called the Animistic theory of motion since it envisions a "life force" being associated with motion.

Newton's 1st law is often very difficult to grasp because it contradicts various common-sense ideas of motion that they have acquired from experience in everyday life. For example, unaccounted for forces like friction might cause a ball rolling on the playground to eventually stop, even though no obvious forces seem to be acting.
When studying Newtonian mechanics, it is best to remember this as two laws:

1. If the *net* force (i.e., sum of all forces) acting on an object is zero, the object will keep moving with constant velocity (which may be zero).
2. If an object is moving with constant velocity (not speed), that is, with zero acceleration, then the net force acting on that object must be zero.

Complete the following sentences to see if you can apply these ideas.

Part A

If a car is moving to the left with constant velocity, one can conclude that

ANSWER:

- there must be no forces applied to the car.
- the net force applied to the car is directed to the left.
- the net force applied to the car is zero.
- there is exactly one force applied to the car.

Correct

Part B

An object cannot remain at rest unless

ANSWER:

- there are no forces at all acting on it.
- the net force acting on it is zero.
- the net force acting on it is constant.
- there is only one force acting on it.

Correct

Understanding Newton's Laws

Part A

An object cannot remain at rest unless which of the following holds?

Hint 1. How to approach the problem

This problem describes a situation of static equilibrium (i.e., a body that remains at rest). Hence, it is appropriate to apply Newton's 1st law.

Hint 2. Newton's 1st law: a body at rest

According to Newton's 1st law, a body at rest remains at rest if the net force acting on it is zero.

ANSWER:

- The net force acting on it is zero.
- The net force acting on it is constant and nonzero.
- There are no forces at all acting on it.
- There is only one force acting on it.

Correct

If there is a net force acting on a body, regardless of whether it is a constant force, the body accelerates. If the body is at rest and the net force acting on it is zero, then it will remain at rest. The net force could be zero either because there are no forces acting on the body at all or because several forces are acting on the body but they all cancel out.

Part B

If a block is moving to the left at a constant velocity, what can one conclude?

Hint 1. How to approach the problem

This problem describes a situation of dynamic equilibrium (i.e., a body that moves at a constant velocity). Hence, it is appropriate to apply Newton's 1st law.

Hint 2. Newton's 1st law: a body in motion

According to Newton's 1st law, a body initially in motion continues to move with constant velocity if the net force acting on it is zero.

ANSWER:

- ○ There is exactly one force applied to the block.
- ○ The net force applied to the block is directed to the left.
- ◉ The net force applied to the block is zero.
- ○ There must be no forces at all applied to the block.

Correct

If there is a net force acting on a body, regardless of whether the body is already moving, the body accelerates. If a body is moving with constant velocity, then it is not accelerating and the net force acting on it is zero. The net force could be zero either because there are no forces acting on the body at all or because several forces are acting on the body but they all cancel out.

Part C

A block of mass $2\ \mathrm{kg}$ is acted upon by two forces: $3\ \mathrm{N}$ (directed to the left) and $4\ \mathrm{N}$ (directed to the right). What can you say about the block's motion?

Hint 1. How to approach the problem

This problem describes a situation of dynamic motion (i.e., a body that is acted on by a net force). Hence, it is appropriate to apply Newton's 2nd law, which allows you to relate the net force acting on a body to the acceleration of the body.

Hint 2. Newton's 2nd law

Newton's 2nd law states that a body accelerates if a net force acts on it. The net force is proportional to the acceleration of the body and the constant of proportionality is equal to the mass of the body. In other words,

$$F = ma,$$

where F is the net force acting on the body, and m and a are the mass and the acceleration of the body, respectively.

Hint 3. Relating acceleration to velocity

Acceleration is defined as the change in velocity per unit time. Keep in mind that both acceleration and velocity are vector quantities.

ANSWER:

- ○ It must be moving to the left.
- ○ It must be moving to the right.
- ○ It must be at rest.
- ◉ It could be moving to the left, moving to the right, or be instantaneously at rest.

Correct

The acceleration of an object tells you nothing about its velocity--the direction and speed at which it is moving. In this case, the net force on (and therefore the acceleration of) the block is to the right, but the block could be moving left, right, or in any other direction.

Part D

A massive block is being pulled along a horizontal frictionless surface by a constant horizontal force. The block must be ___________.

Hint 1. How to approach the problem

This problem describes a situation of dynamic motion (i.e., a body that is acted on by a net force). Hence, it is appropriate to apply Newton's 2nd law, which allows you to relate the net force acting on a body to the acceleration of the body.

Hint 2. Newton's 2nd law

Newton's 2nd law states that a body accelerates if a net force acts on it. The net force is proportional to the acceleration of the body and the constant of proportionality is equal to the mass of the body. In other words,

$$F = ma,$$

where F is the net force acting on the body, and m and a are the mass and the acceleration of the body, respectively.

ANSWER:

- continuously changing direction
- moving at constant velocity
- moving with a constant nonzero acceleration
- moving with continuously increasing acceleration

Correct

Since there is a net force acting, the body does not move at a constant velocity, but it accelerates instead. However, the force acting on the body is constant. Hence, according to Newton's 2nd law of motion, the acceleration of the body is also constant.

Part E

Two forces, of magnitude 4 N and 10 N, are applied to an object. The relative direction of the forces is unknown. The net force acting on the object ___________.

Check all that apply.

Hint 1. How to approach the problem

By definition, the net force is the vector sum of all forces acting on the object. To find the magnitude of the net force you need to add the components of the two forces acting. Try adding the two forces graphically (by connecting the head of one force to the tail of the other). The directions of the two forces are arbitrary, but by trying different possibilities you should be able to determine the maximum and minimum net forces that could act on the object.

Hint 2. Find the net force when the two forces act on the object in opposite directions

Find the magnitude of the net force if both the forces acting on the object are horizontal and the 10-N force is directed to the right, while the 4-N force is directed to the left.

Express your answer in newtons.

Hint 1. Vector addition

The magnitude of the vector sum of two parallel forces is the sum of the magnitudes of the forces. The magnitude of the vector sum of two antiparallel forces is the absolute value of the difference in magnitudes of the forces.

ANSWER:

6.0 N

Hint 3. Find the direction of the net force when the two forces act in opposite directions

If both the forces acting on the object are horizontal and the 10-N force is directed to the right, while the 4-N force is directed to the left, the net force is horizontal and directed ___________.

ANSWER:

- in the same direction as the 10-N force
- in the opposite direction to the 10-N force

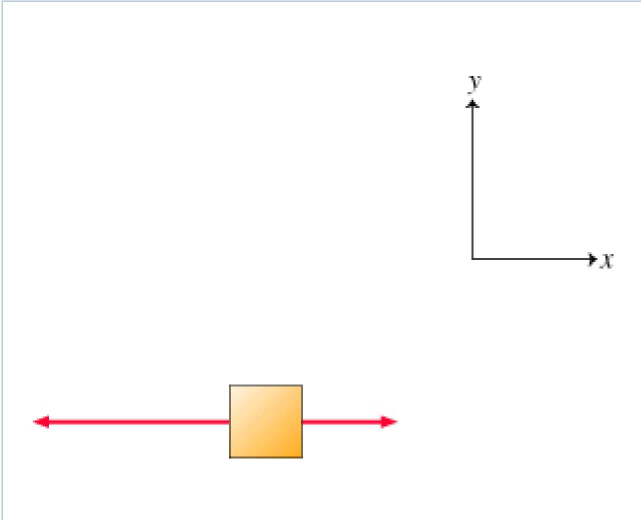
ANSWER:

- [x] cannot have a magnitude equal to $5\ \mathrm{N}$
- [ ] cannot have a magnitude equal to $10\ \mathrm{N}$
- [ ] cannot have the same direction as the force with magnitude $10\ \mathrm{N}$
- [ ] must have a magnitude greater than $10\ \mathrm{N}$

All attempts used; correct answer displayed

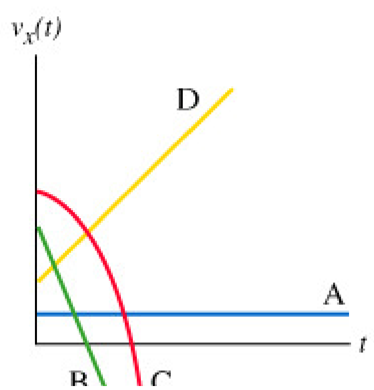
Relating Graphs and Free-Body Diagrams

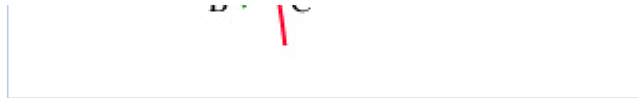
Two forces are exerted on an object of mass m in the *x* direction as illustrated in the free-body diagram. Assume that these are the only forces acting on the object.



Part A

Which of the curves labeled A to D on the graph could be a plot of $v_x(t)$, the velocity of the object in the *x* direction as a function of time?





Hint 1. How to approach the problem

Analyze the free-body diagram to determine whether there is a net force acting on the object along the *x* axis. If the object is experiencing a net force, then its velocity must be changing in that direction.

Hint 2. Relate force, acceleration, and velocity

If a constant nonzero net force is applied to an object, what will the object's acceleration and velocity be?

Hint 1. Relating force and acceleration

Recall that Newton's 2nd law applied in the *x* direction gives

$$\sum F_x = ma_x,$$

where m is the mass of the object and a_x is the acceleration of the object along the *x* axis.

Because the object's mass is constant, $\sum F_x$ is proportional to a_x. This means that if $\sum F_x$ increases, a_x must also increase.

Hint 2. Relating acceleration and velocity

The average acceleration $a_{\text{avg},\ x}$ of an object along the *x* direction is defined as the rate of change of velocity,

$$a_{\text{avg},\ x} = \frac{\Delta v_x}{\Delta t} = \frac{v_{2x} - v_{1x}}{t_2 - t_1},$$

where time t_2 occurs after time t_1.

It may also help to recall that, on a graph of velocity versus time, the slope of the velocity curve is the average acceleration.

ANSWER:

- ○ Both acceleration and velocity will be constant.
- ○ Acceleration will not be constant and velocity will change at a nonconstant rate.
- ◉ Acceleration will be constant and velocity will change at a constant rate.
- ○ Acceleration will be constant and velocity will change at a nonconstant rate.

ANSWER:

- A
- B
- C
- D

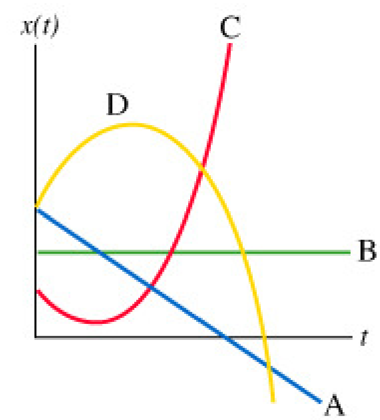
Correct

The net force on the object in the $-x$ direction indicates that the object is accelerating in the $-x$ direction. But accelerating doesn't necessarily mean *speeding up*. As depicted by curve B, at the time the net force was applied to the object, the object had already been moving with nonzero velocity in the *+x* direction. The effect of the acceleration in the $-x$ direction on the object was to

1. slow down the object,
2. bring the object to an instantaneous stop (which occurs when line B intersects the horizontal *t* axis), and
3. speed up the object in the $-x$ direction.

Part B

Which of the curves labeled A to D on the graph could be a plot of $x(t)$, the position of the object along the *x* axis as a function of time?



Hint 1. How to approach the problem

The average velocity $v_{\mathrm{avg},\,x}$ of an object along the *x* direction is defined as the rate of change of position,

$$v_{\mathrm{avg},\,x} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1},$$

where time t_2 occurs after time t_1. On a graph of position versus time, the slope of the position curve is the average velocity. Determine what kind of position graph will yield the average velocity found in Part A.

ANSWER:

- A
- B
- C
- D

Correct

Notice that the correct $x(t)$ graph shows the object

- first, moving in the $+x$ direction with decreasing speed,
- then, stopping momentarily (at the top of the curve), and
- finally, moving in the $-x$ direction with increasing speed.

The graphs in Parts A and B were not the only possible velocity and position graphs for the given net force. However, all graphs illustrating motion under the influence of a constant force will have the same characteristics.

In this particular problem, the acceleration of the object was constant. This caused the velocity graph to be a linear curve of constant slope (i.e., a straight line). When velocity obeys a linear relationship, the position of the object follows a curve whose shape is quadratic (also called parabolic). You saw examples of this type of motion when you studied motion under constant velocity in an earlier chapter.

Score Summary:

Your score on this assignment is 90.3%.
You received 9.94 out of a possible total of 11 points.