Chapter 5

Newton's Laws of Motion

Kinematics: The study of how objects move
Dynamics: The study of why objects move

Fundamental Forces

	Force	Relative Strength	Range
1.	Gravity	10^{-38}	∞
2.	Electromagnetic	10^{-2}	∞
3.	Weak Nuclear	10^{-1}	$\approx 10^{-18}$ m
4.	Strong Nuclear	1	$\approx 10^{-15}$ m

The forces we experience come from these four forces:

- Pull of the earth?
- Tension?
- Normal Force?
- Friction?

Newton's First Law

Every object continues in its state of rest or of uniform speed in a straight line unless acted on by a nonzero net force.

1. If an object is either stationary, or moving at a constant speed in a straight line, there is *no net force* acting on the object.
    - In either case, there may be forces acting on the object, but there is no *net* force acting on the object.
2. Force can be loosely defined as a push or pull.
    - Most forces we encounter in Physics 1205 will be contact forces, two objects will actually be touching.
        – The force of gravity is not a contact force

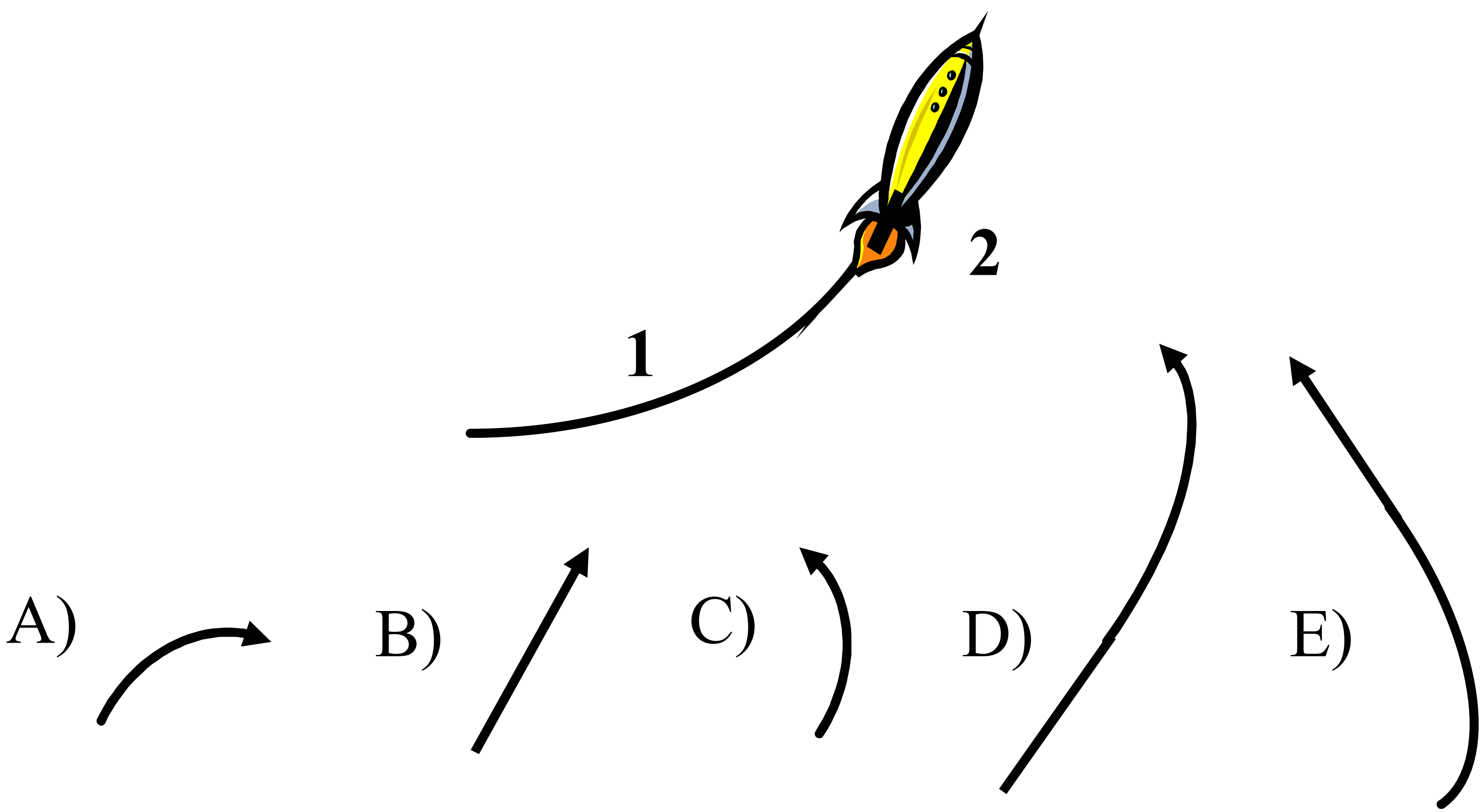
Interactive Question

When the rocket engines of a starship are suddenly turned off, while traveling in empty space, the starship will

A) stop immediately
B) slowly slow down, and then stop
C) go faster and faster
D) move with a constant velocity

Interactive Question

A rocket ship in space has its engines firing and is following path **1**. At point **2**, the engines shut off. Which path does the rocket ship follow?



Interactive Question

You are driving your car down a straight road at a constant velocity of 65 mph. What can you conclude about the forces acting on your car?

A) There must be greater forward forces acting on the car than backward forces, or the car would not go forward.

B) The forces acting to make the car go forward must be equal to the forces acting to make the car go backward.

C) There are no forces acting on the car at a constant velocity

D) There is not enough information to say anything.

Inertia

- The force required to change an object’s state of motion is a measure of the inertia of the body.
- This measure of inertia could be called “inertial charge”, but we actually call it “mass”.
- Objects with large inertia, or mass, require a larger force to achieve the same change in the state of motion.
- A change in the state of motion is described as an acceleration.
- SI unit of mass is kilograms (kg)
- British unit of mass is slugs.

Newton's Second Law

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. The direction of the acceleration is in the direction of the applied net force.

$$\mathbf{a} = \sum \mathbf{F}/m$$

usually written

$$\sum \mathbf{F} = m\mathbf{a}$$

This is a vector equation. So it implies three equations:

$\sum F_x = \mathrm{m}a_x$

$\sum F_y = \mathrm{m}a_y$

$\sum F_z = \mathrm{m}a_z$

$$\sum \mathbf{F} = m\mathbf{a}$$

- The left hand side is the *net* force acting *on* the object with the mass m.
- The SI unit of force is a Newton (N) = $kg \cdot m/s^2$
- The British unit of force is a pound (lb)
- Newton's 1st law is a special case of the 2nd law when $\mathbf{a}=0$.
- Newton's 1st law is more than that, though, since it defines what is meant by zero net force and an inertial reference frame (one in which Newton's laws work.)

What is a force?

In everyday language it is a push or a pull.

Some forces we are familiar with:

1) Gravity
2) Friction (static or kinetic)
3) Normal
4) Tension
5) Restoring, or spring, ($-k\,\Delta x$)

- Force is *always* the interaction between two objects!
- When dealing with forces, you should identify the two objects.

Interactive Question

A net force **F** is required to give a mass *m* an acceleration **a**. If a net force of 6**F** is applied to a mass 2*m*, what acceleration results.

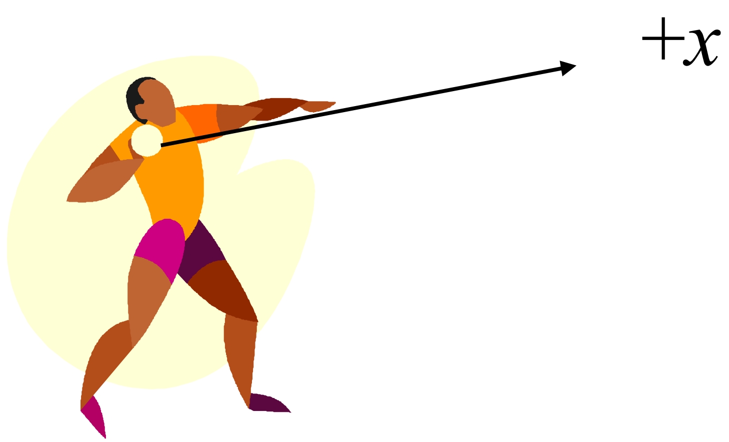
A) **a**
B) 2**a**
C) 3**a**
D) 4**a**
E) 6**a**

Interactive Question

A constant force is exerted for a short time interval on a cart that is initially at rest on an air track with no friction. This force gives the cart a certain final speed. We repeat the experiment but, instead of starting from rest, the cart is already moving with constant speed in the direction of the force at the moment we apply the force. After we exert the same constant force for the same short time interval, the increase in the cart's speed

A) is equal to two times its initial speed.
B) is equal to the square of its initial speed.
C) is equal to four times its initial speed.
D) is the same as when it started from rest.
E) cannot be determined from this information.

Problem: During a track and field competition, an athlete releases a shot with a speed of 13 m/s. If the shot moved through a total distance of 2.8 m while it was being accelerated, what was the average net force exerted by the athlete? The shot has a mass of 7.0 kg.



Interactive Question

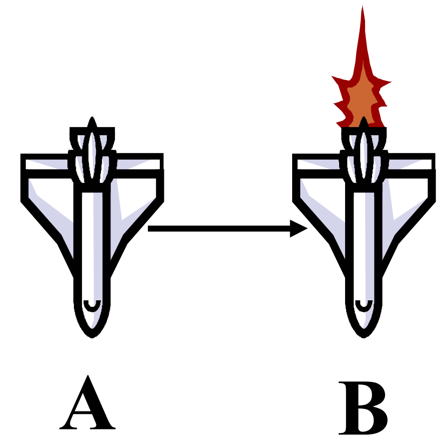
A constant force is exerted on a cart that is initially at rest on an air track. Friction between the cart and the track is negligible. The force acts for a short time interval and gives the cart a certain final speed. To reach the same final speed with a force that is only half as big, the force must be exerted on the cart for a time interval

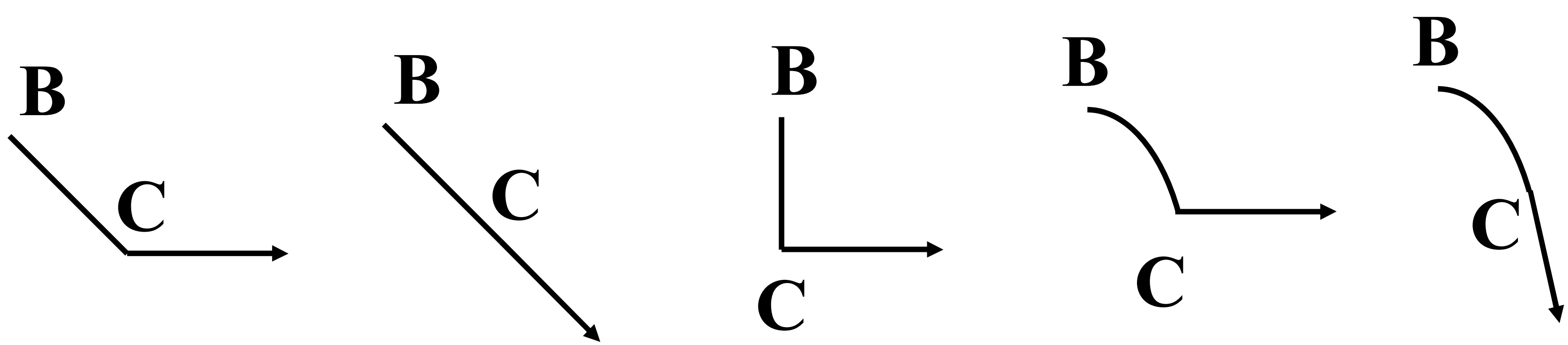
A) four times as long as
B) twice as long as
C) equal to
D) half as long as
E) a quarter of

that for a stronger force.

Interactive Question

A rocket is moving sideways in deep space from point **A** to **B**, with its engine off. Its engine is fired at point **B** and left on for 2 seconds while the rocket travels from point **B** to some point **C**? What path does the rocket travel from **B** to **C**, then from point **C**, after the engine is turned off?

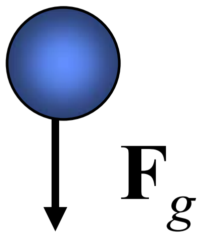




(A) (B) (C) (D) (E)

The Force of Gravity: Weight

Consider an object that has only the force of gravity acting on it.



$$\mathbf{F}_g = m\mathbf{a} = m\mathbf{g}$$

This force is called the object's weight.

The mass of an object does not depend on the force of gravity, but the weight does.

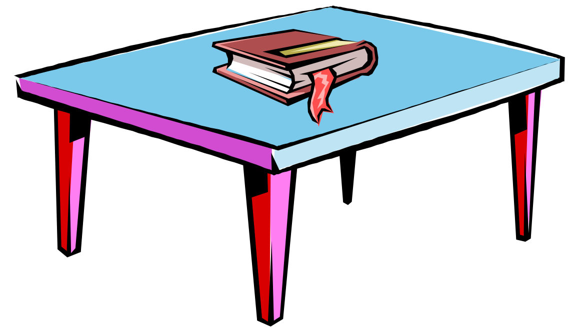
We say that 1.0 kg is 2.2 lbs, but this is not an accurate statement because pounds is a unit of weight and kg is a unit of mass. What we really mean is that 9.8 N is 2.2 lb, because a mass of 1 kg feels a force of 9.8 N on earth.

$F = mg = (1 \text{ kg}) (9.8 \text{ m/s}^2) = 9.8 \text{ N}$

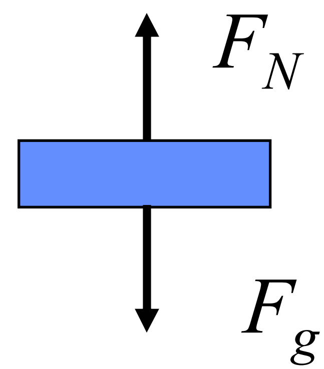
So 2.2 lb = 9.8 N, or 1 lb = 4.45 N

The Normal Force

Consider an stationary object on a surface. According to Newton's second law, the object has no net force acting on it. The force of gravity is pulling the object toward the center of the earth. What other force is balancing out the force of gravity?



To solve problems with Newton's second law, always draw a free body diagram showing *all* of the forces acting *on* each object in the problem.



Problem: A book with a mass of 0.80 kg is stationary on a table. What is the normal force acting on the book?

Is the Normal force always equal to the weight?

Problem: A book with a mass of 0.80 kg is stationary on a table. You tie a string to the book and pull up with a force of 2.5 N? What is the normal force acting on the book?

Interactive Question

Consider a person standing in an elevator that is moving upward at a constant velocity. The upward normal force *N* exerted by the elevator floor on the person is

A) larger than
B) identical to
C) smaller than

the downward weight *W* of the person

Interactive Question

Consider a person standing in an elevator that is *accelerating upward.* The upward normal force N exerted by the elevator floor on the person is

A) larger than
B) identical to
C) smaller than

the downward weight W of the person

Problem Solving Steps

1. Think about the problem:
   (Steps 1, 3, and 4 are the same as for kinematic problems)
2. Draw a "physics diagram" and define variables.
   A. For problems using Newton's second law, draw a free body diagram for every object. Draw all forces acting *on* the object only.
   B. Choose one axis along the direction of acceleration.
   C. Determine the components of every force.
   D. Use $\sum \mathbf{F} = m\mathbf{a}$ (Each axis gives an independent equation.)
   E. Determine if there are other equations to be used. If you need kinematic equations, draw a motion diagram
3. Do the calculation.
4. Think about the answer.

Problem: For a summer job, you are working on the set of a movie about Navy pilots. The director has asked you to calculate how much force is supplied by the catapult of an aircraft carrier. You look on the web and find that the flight deck of an aircraft carrier is about 90 m long, that an F-14 has a mass of 33,000 kg and two engines each producing 27,000 lbs of force, and that the takeoff speed of such a plane is about 160 miles/hour.

Focus the Problem:

What is the problem asking for:

Outline the Approach:

Describe the Physics:

Draw physics diagrams and define all quantities uniquely

Which defined quantity is your target variable?

Write equations you will use to solve this problem.

PLAN the SOLUTION

Construct Specific Equations (Same Number as Unknowns)

Unknowns

Check Units:

EXECUTE the PLAN

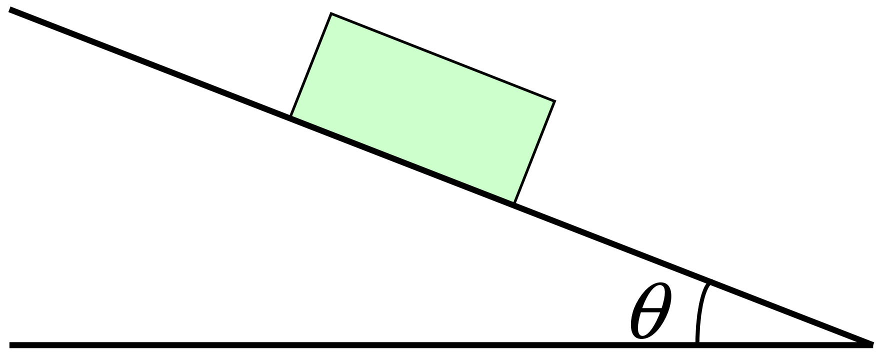
EVALUATE the ANSWER

Is Answer Properly Stated?

Is Answer Unreasonable?

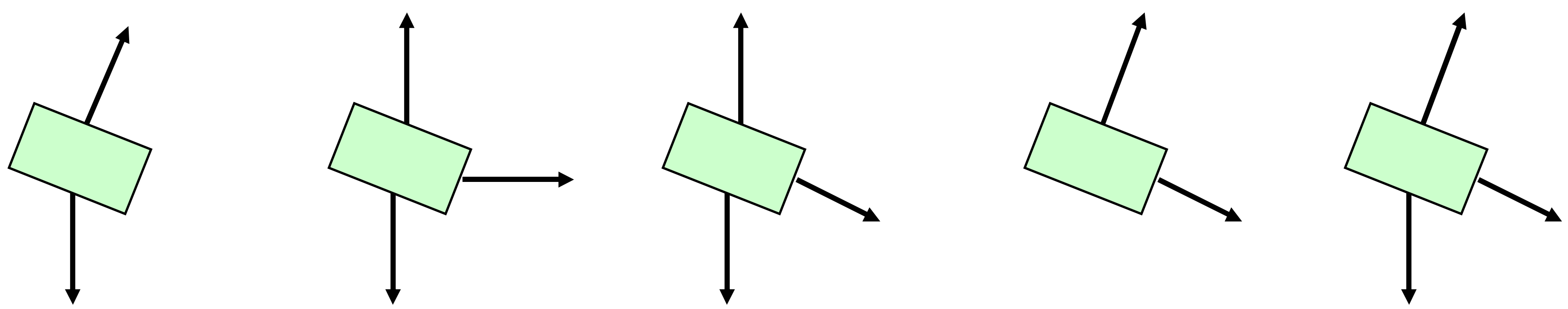
Is Answer Complete?

Problem: Determine the acceleration of gravity using an inclined air track.



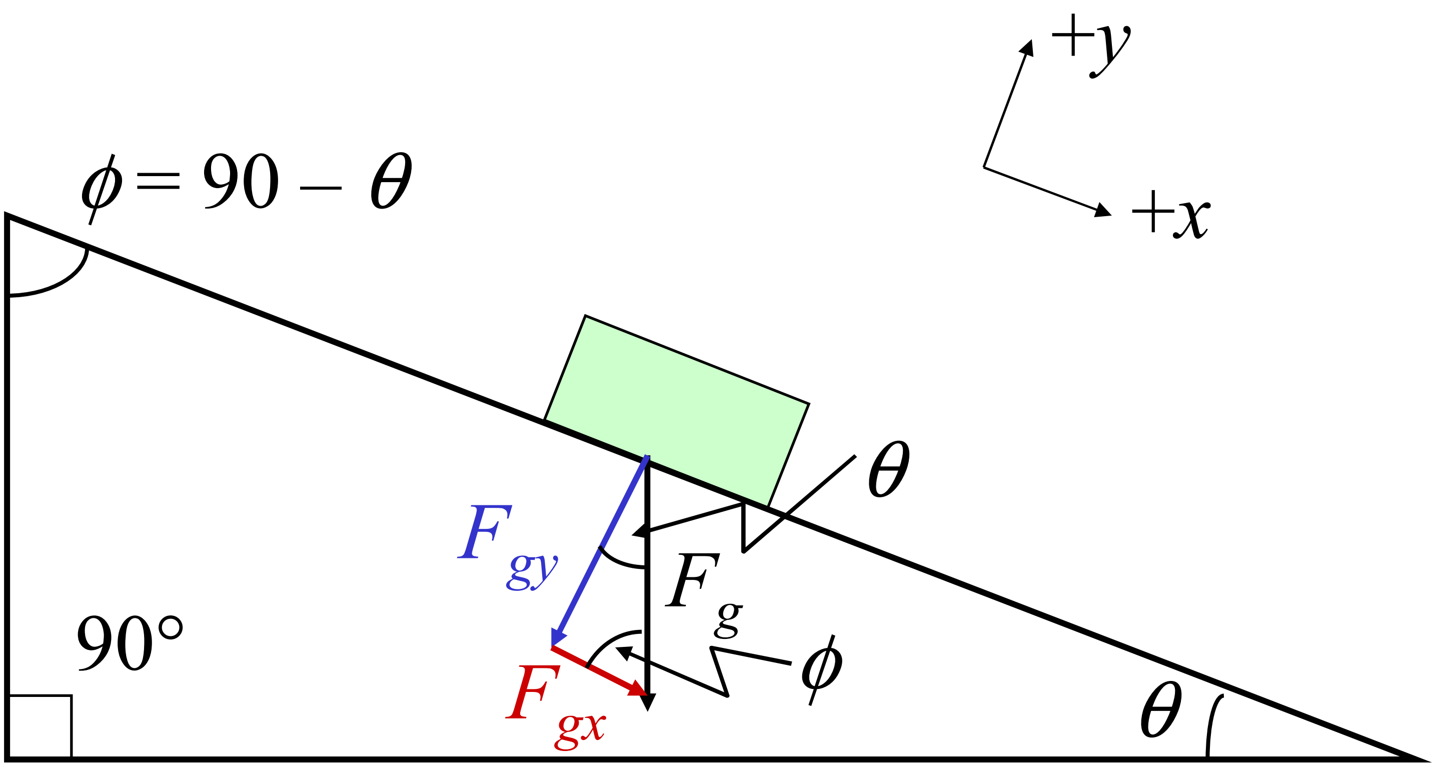
Interactive Question

Which of the following is the correct free body diagram for an object sliding down a frictionless incline. (A free body diagram shows all of the forces acting on the object.)



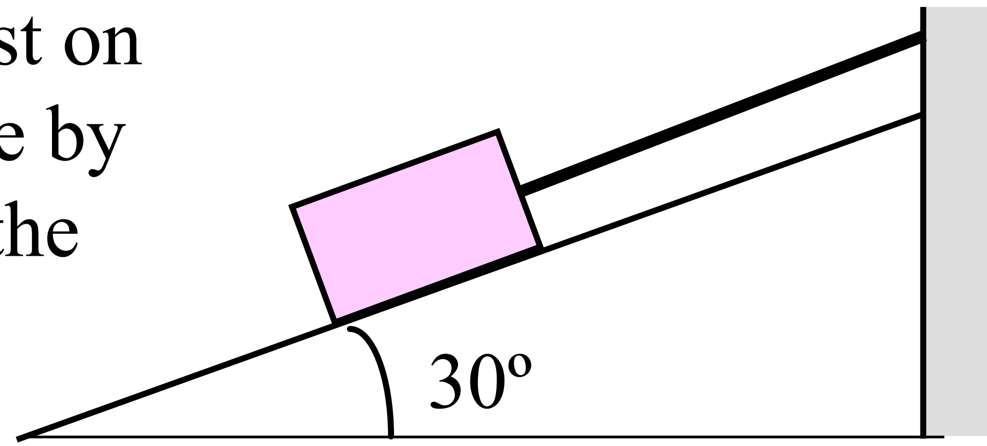
(A) (B) (C) (D) (E)

Always choose one axis along the direction of the acceleration.



Interactive Question

A 10 kg block is held at rest on a frictionless inclined plane by a rope as shown. What is the tension in the rope?



A) 9.8 N
B) 19.6 N
C) 49 N
D) 85 N
E) 98 N

Interactive Question

A 2.0 kg projectile is fired at an angle of 20 degrees. What is the magnitude of the force on the projectile when it is at the highest position in its trajectory?

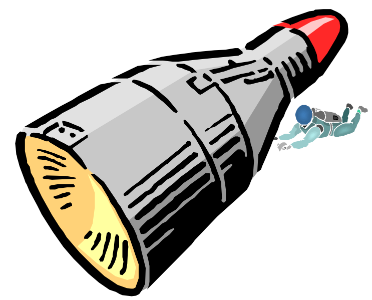
A) zero
B) 6.7 N
C) 9.8 N
D) 18.4 N
E) 19.6 N

Newton's Third Law

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. This action-reaction pair of forces always acts on different objects, and thus never add to produce zero net force on a single object.

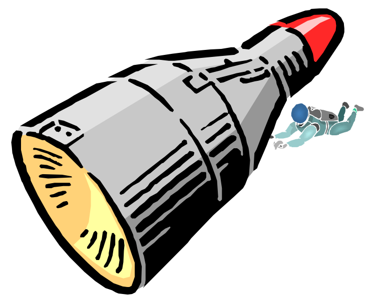
Interactive Question

An astronaut who is walking in space pushes on a spaceship with a force of 36 N. The astronaut has a mass of 92 kg and the spaceship has a mass of 11000 kg. Which statement is true?



A) The astronaut will accelerate, but not the spaceship.
B) No net force will be exerted on the astronaut or on the spaceship.
C) A force will be exerted on the astronaut but not on the spaceship.
D) The astronaut and the spaceship will have the same magnitude of acceleration.
E) None of the above.

<u>Problem:</u> An astronaut who is walking in space pushes on a spaceship with a force of 36 N. The astronaut has a mass of 92 kg and the spaceship has a mass of 11000 kg. What happens?



Problem for discussion: Suppose you throw a baseball. Your body exerts a force on the baseball and the baseball exerts an equal and opposite force back on your body. Why is the ball accelerated forward, but you are not accelerated backwards?

Note an important difference between Newton's second law and Newton's third law.

Newton's Second law deals with all of the forces acting on a single object.

Newton's third law deals with the forces acting and reacting on two different objects.

Interactive Question

A horse pulls a cart along a flat level road. Consider the following four forces that arise in this situation.

(1) The force of the horse pulling on the cart.
(2) The force of the cart pulling on the horse.
(3) The force of the horse pushing on the road.
(4) The force of the road pushing on the horse.

Which two forces form an "action-reaction" pair which obey Newton's third law.

A) (1) and (4)
B) (1) and (3)
C) (2) and (4)
D) (3) and (4)
E) (2) and (3)

Interactive Question

A book is resting on the surface of a table. Consider the following four forces that arise in this situation.

(1) the force of the earth pulling on the book
(2) the force of the table pushing on the book
(3) the force of the book pushing on the table
(4) the force of the book pulling on the earth

Which two forces form an "action-reaction" pair which obey Newton's third law?

A) 1 and 2
B) 1 and 3
C) 1 and 4
D) 2 and 4
E) 3 and 4

Interactive Question

A book is resting on the surface of a table. Consider the following four forces that arise in this situation.

(1) the force of the earth pulling on the book
(2) the force of the table pushing on the book
(3) the force of the book pushing on the table
(4) the force of the book pulling on the earth

The book has zero acceleration. Which pair of forces, excluding the "action-reaction" pairs, must be equal in magnitude and opposite in direction?

A) 1 and 2
B) 1 and 3
C) 1 and 4
D) 2 and 3
E) 2 and 4

Interactive Question

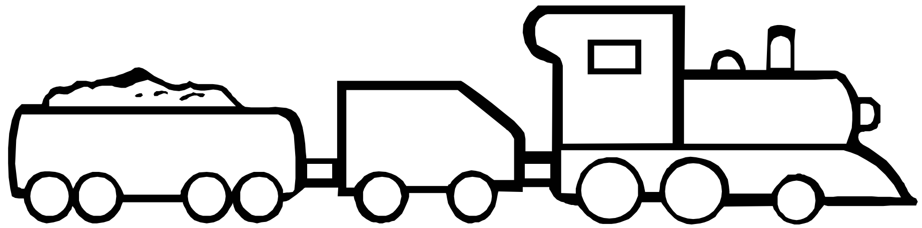
Consider a car at rest. We can conclude that the gravitational pull of the Earth on the car and the upward constant force of Earth on it are equal and opposite because

A) the two forces form an interaction pair (Newton's third law).

B) the net force on the car is zero (Newton's second law).

C) neither of the above.

Problem: A train is accelerating at a rate of 5.0 m/s^2. What is the tension between each of the cars?



Interactive Question

How does the tension in the string in Figure (a) compare with the tension in the string in Figure (b)?

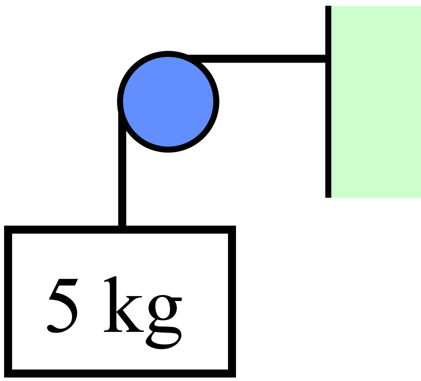


Figure (a)

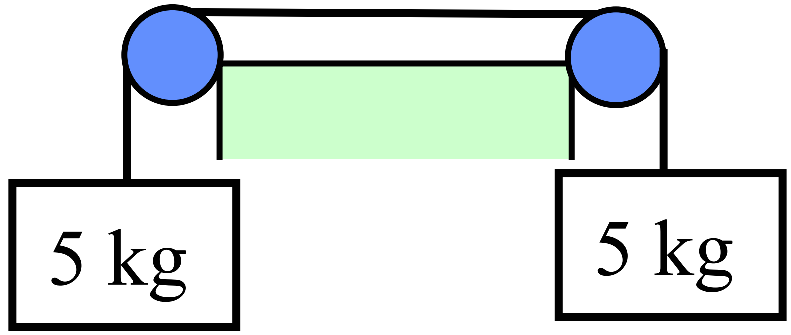


Figure (b)

A) They are the same
B) Figure (a) is greater
C) Figure (b) is greater
D) It is impossible to tell

Interactive Question

In the 17th century, Otto von Guricke fitted two hollow bronze hemispheres together and removed the air from the resulting sphere with a pump. Two eight horse teams could not pull the halves apart even though the hemispheres fell apart when air was readmitted. Suppose von Guricke had tied both teams of horses to one side and bolted the other side to a heavy tree trunk. In this case, the tension on the hemispheres would be

A) twice

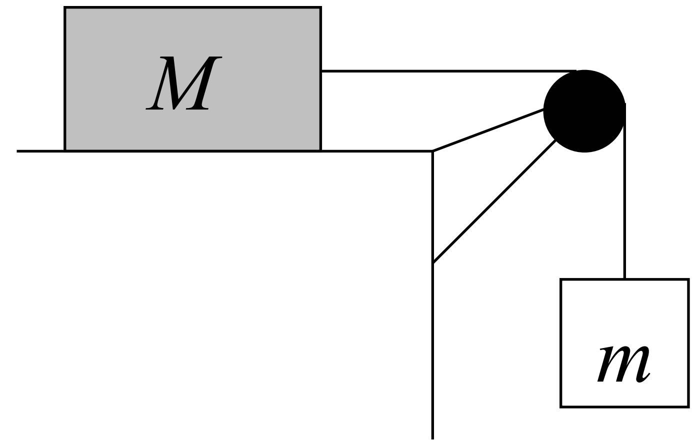
B) exactly the same as

C) half

what it was before.

Interactive Question

A cart with mass *M* is placed on a frictionless track. One end of a cord is attached to the cart and the other end is attached to an object with mass *m* as shown. The pulley has no friction.



When the system is released from rest, the cart has an acceleration given by *a*. If the mass of the cart is increased to 2*M*, what happens to the acceleration?

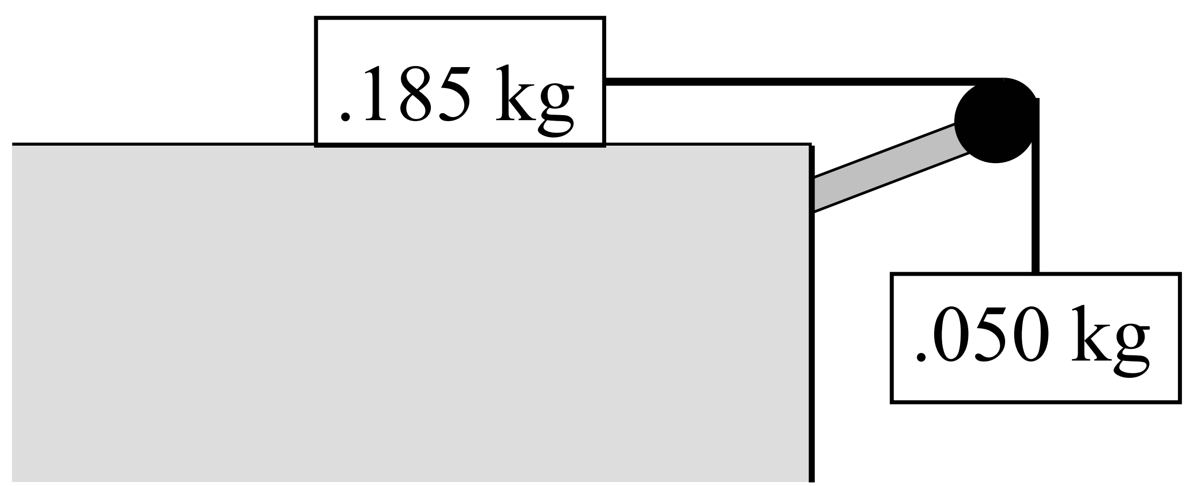
A) It increases by 2
B) It decreases by $1/\sqrt{2}$
C) It decreases by 1/2
B) It decreases by 1/4
E) None of the above

PROBLEM: Consider a block resting on a frictionless surface attached to another block by a "massless" cord that is stretched over a "frictionless" and "massless" pulley.

(a) What is the tension in the cord and the acceleration of each of the two blocks?

(b) Starting from rest, how long will it take each block to move 0.70 m?

(c) What happens if the mass of the top block is doubled?



Systems, Internal Forces, and External Forces

Up until now, we have always chosen our "system" to be a single object. Sometimes it is more convenient to chose a number of objects as a system.

Internal forces are forces that act only between objects in the system.

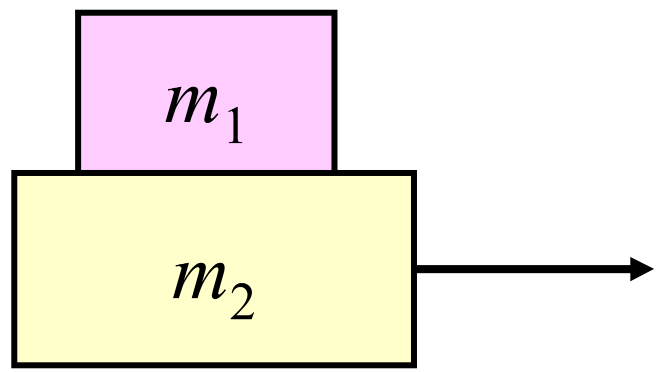
External forces act between an object outside of the system and an object inside the system.

In Newton's second law, only external forces need to be considered.

Problem: Block 1, with mass m_1 is glued to block 2, with mass m_2. A rope is attached to block 2 and pulled horizontally to the right. Write equations for the motion of block 1 in two ways.

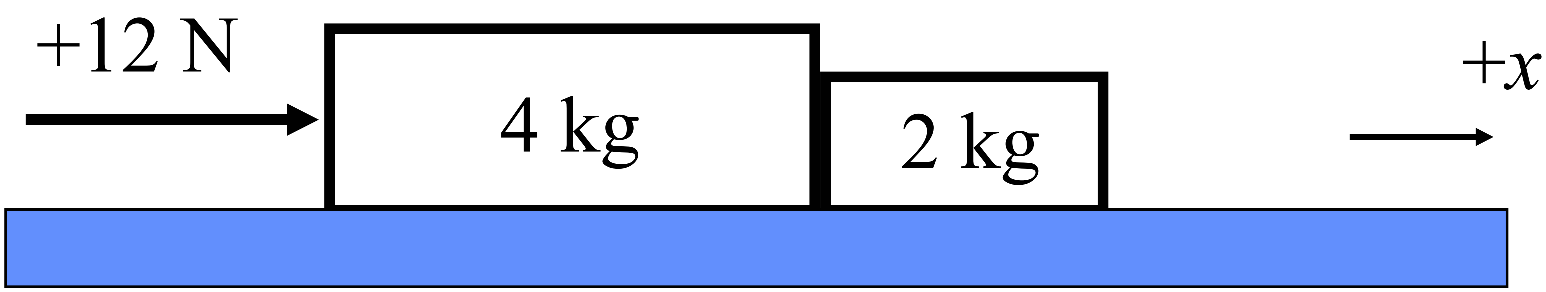
a) Consider the system of the two blocks glued together.

b) Consider each block separately.



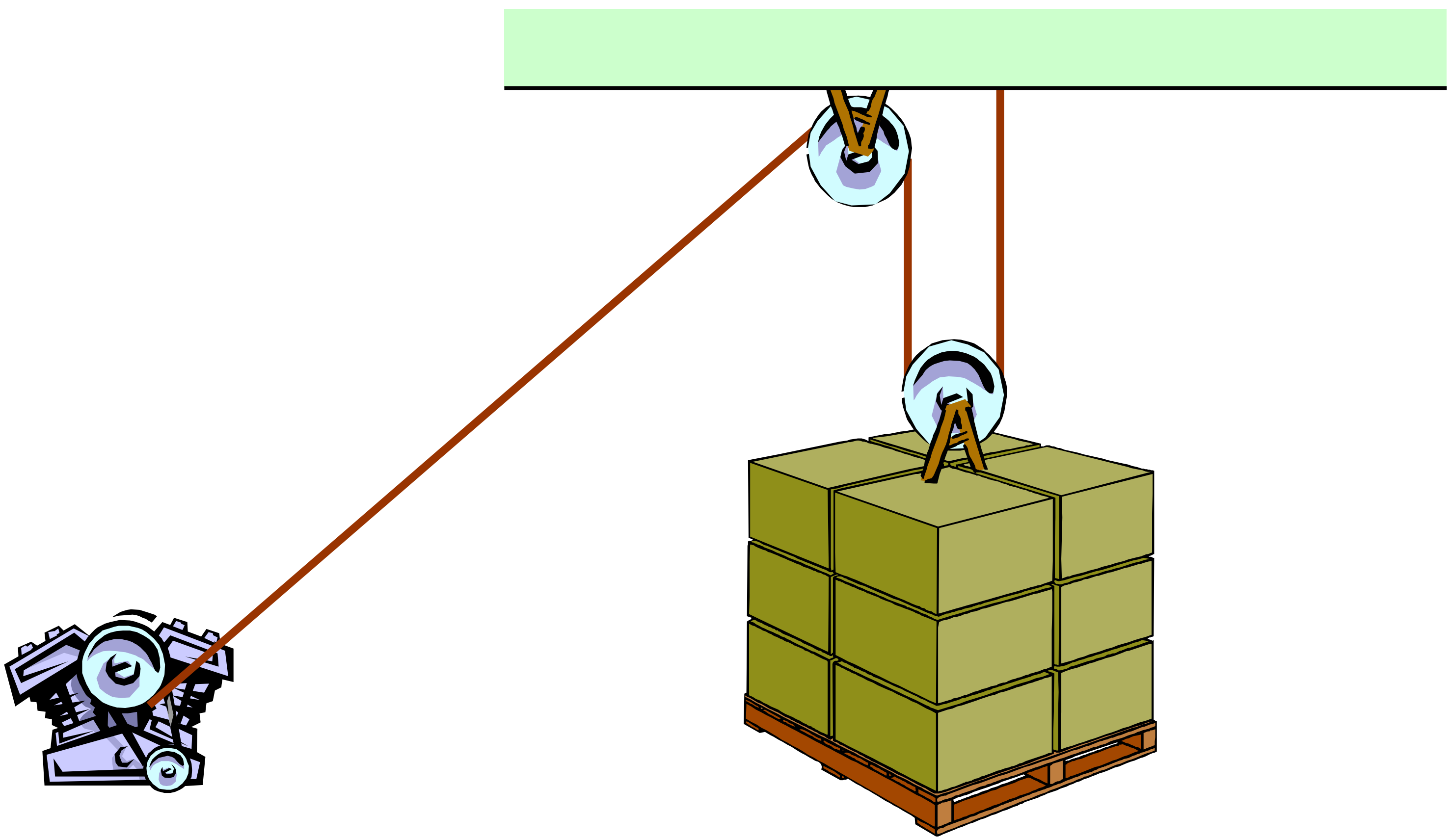
Interactive Question

A 4 kg block and a 2 kg block can move on a horizontal frictionless surface. The blocks are accelerated by a 12 N force in the positive *x* direction that pushes the larger block against the smaller one. Determine the force that the 2 kg block exerts on the 4 kg block.

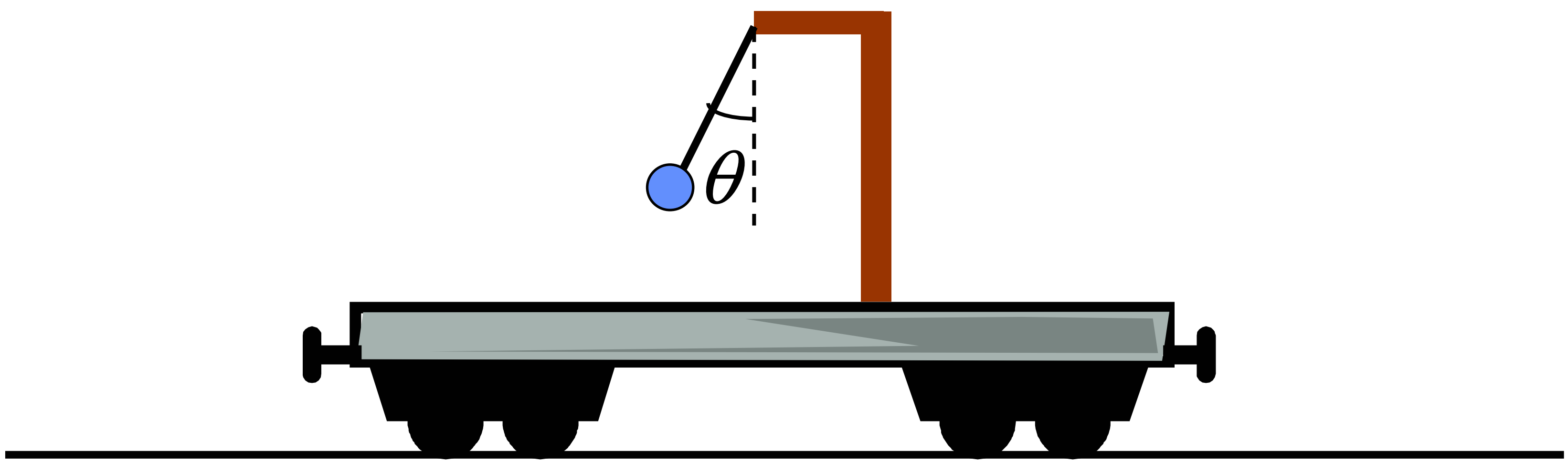


A) zero
B) –4 N
C) +4 N
D) +8 N
E) -12 N

Problem: An electric motor is lowering a 452 kg crate with an acceleration of 1.60 m/s^2 in the direction of motion. Assuming the cord and pulleys have a negligible mass and the pulleys have negligible friction, what is the tension in the cord attached to the motor?

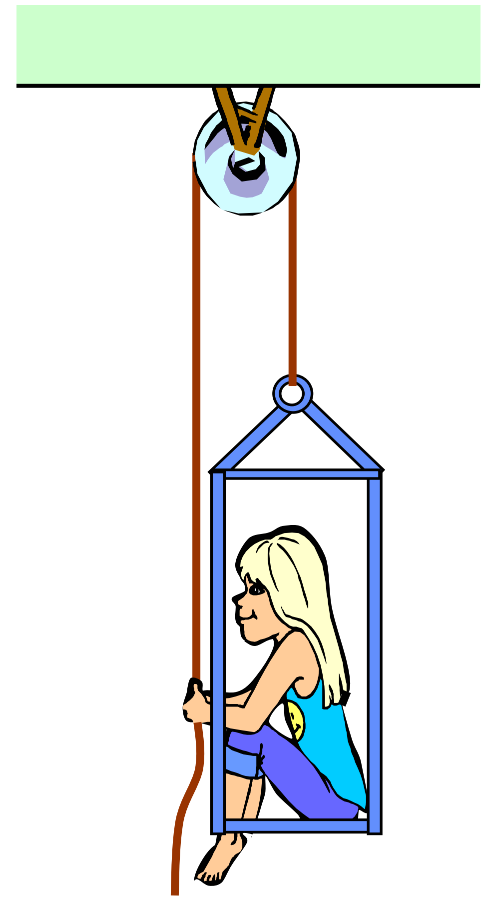


Problem: A 3.0 kg ball hangs at one end of a rope that is attached to a support on a railroad car. When the car accelerates to the right, the rope makes an angle of $\theta = 4.0°$ with the vertical. Find the acceleration of the car.

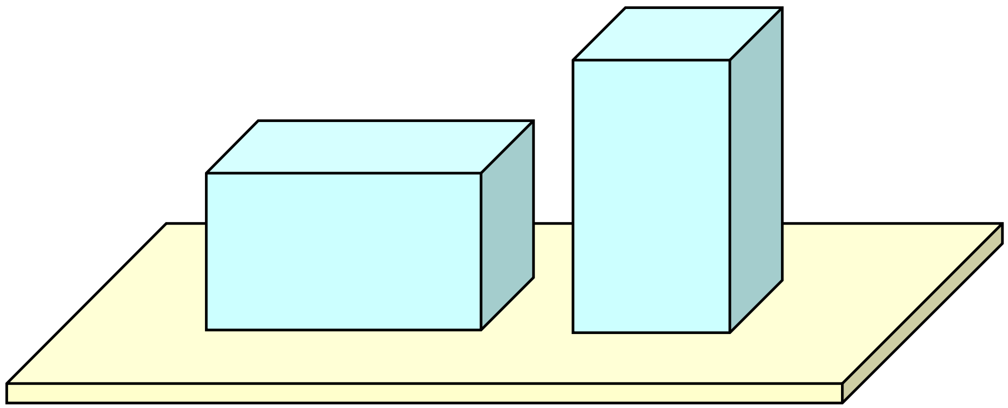


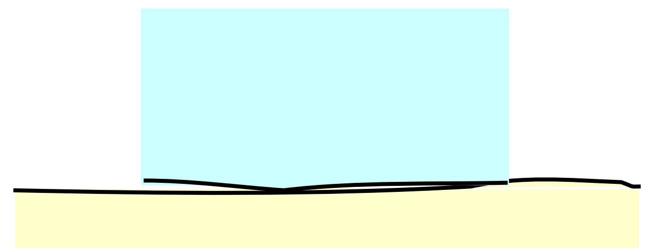
Problem: The girl and the chair have a combined mass of 85 kg.

a) What force must she pull on the rope to rise at a constant speed?
b) What force must she pull on the rope to accelerate upward at a rate of 1.20 m/s^2?
c) Repeat part (a) if the rope is held by a person on the ground.
d) Repeat part (b) if the rope is held by a person on the ground



Source of Friction and Mathematical Description





Experiments show that the force of friction is directly proportional to the normal force.

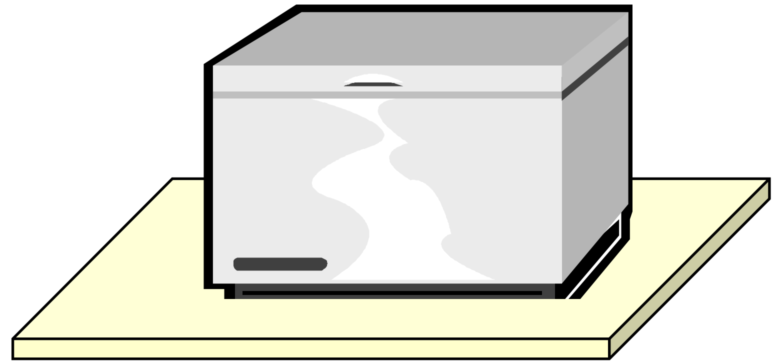
Kinetic Friction: $F_{kf} = \mu_k F_N$

Static Friction: $F_{sf} \leq \mu_s F_N$

Rolling Friction: $F_{rf} = \mu_r F_N$

Interactive Question

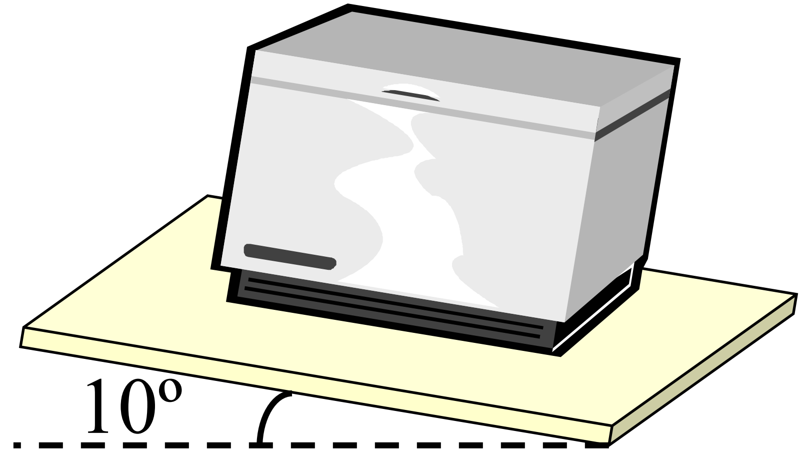
An 82-kg freezer sits on a horizontal surface without moving. What is the force of static friction between the surface and the freezer?



A) Zero
B) 82 N
C) 800 N
D) None of the above

Interactive Question

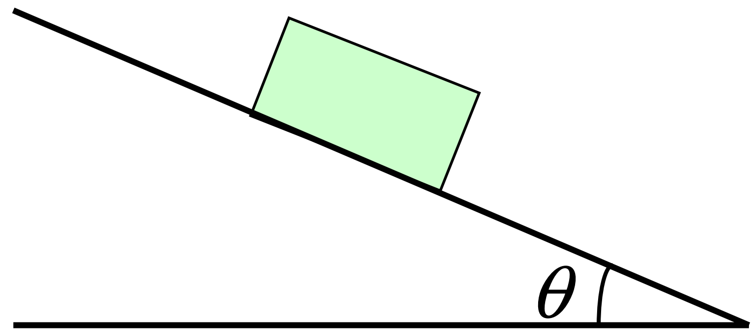
An 82-kg freezer sits on a surface that makes an angle of 10º with a horizontal plane. If the freezer does not move, what is the force of static friction between the surface and the freezer?

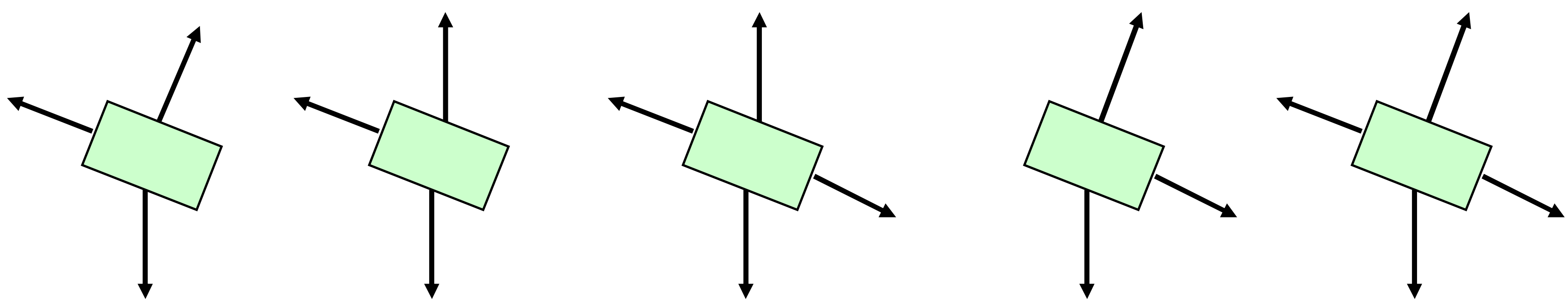


A) Zero
B) 140 N
C) 790 N
D) 800 N
E) None of the above

Interactive Question

Which is the correct free body diagram for an object sliding down a inclined surface? Don’t neglect friction.





(A) (B) (C) (D) (E)

Problem: You and some friends are attending the Oklahoma State Fair and decide to play one of the sideshow games. To play the game, you must slide a metal hockey-type puck up a wooden ramp so that it drops through a hole at the top of the ramp. Your prize, if you win, is a large, pink, and rather gaudy, stuffed poodle. You realize that the secret to winning is giving the puck just enough velocity at the bottom of the ramp to make it to the hole. You estimate the distance from the bottom of the ramp to the hole at about 3.0 meters and the ramp appears to be inclined with an angle of 15° from the horizontal. You remember from physics class that the coefficient of kinetic friction between steel and waxed wood is 0.08? The mass of the puck is about 1.0 kg. What speed should you slide the puck so that it will drop in the hole, and you will impress your friends and win the poodle?

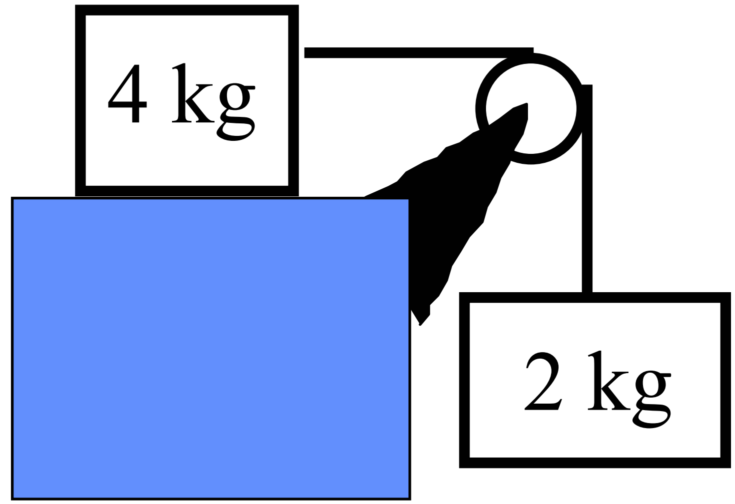
Interactive Question

An object is held in place by friction on an inclined plane. The angle of the inclination is increased until the object starts moving. If the surface is kept at this angle, the object

A) slows down.
B) moves at uniform speed.
C) speeds up.
D) none of the above.

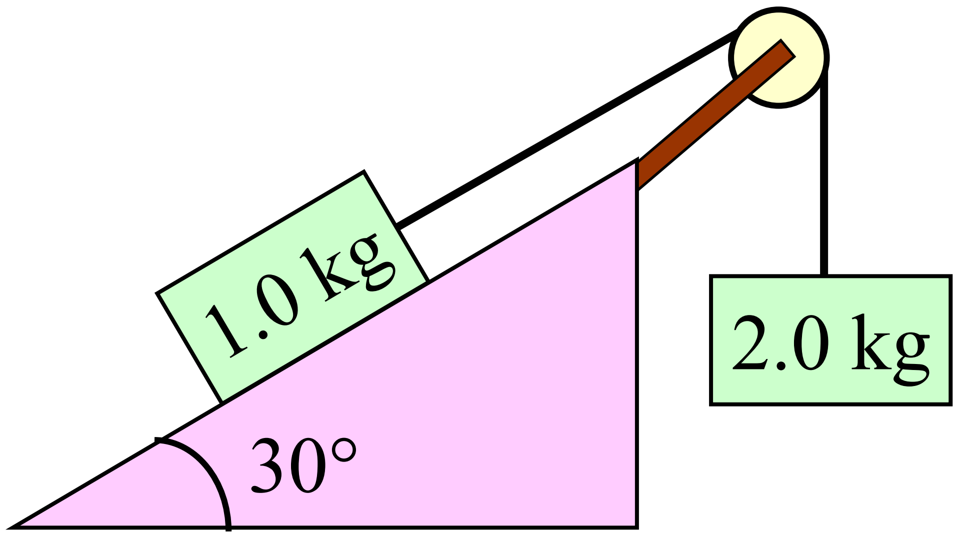
Interactive Question

A 4 kg block is connected by means of a light rope to a 2 kg block as shown. In order for the 4 kg mass to begin sliding, the coefficient of static friction between the 4 kg mass and the surface must be

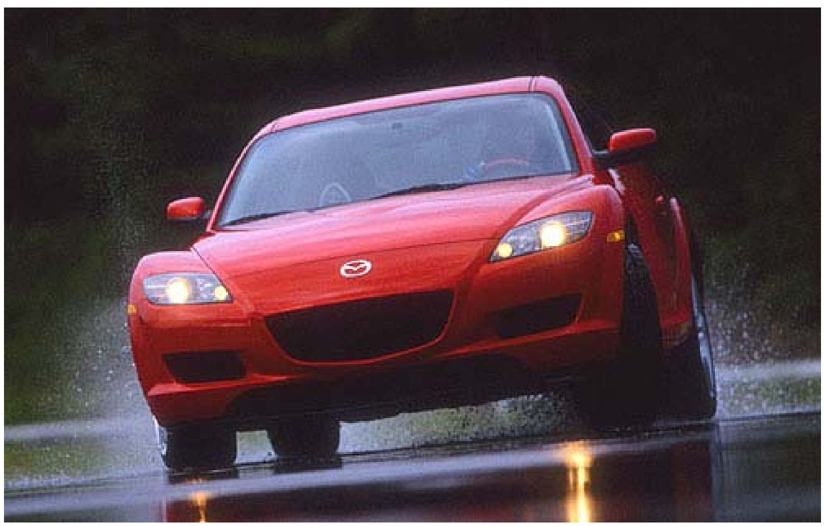


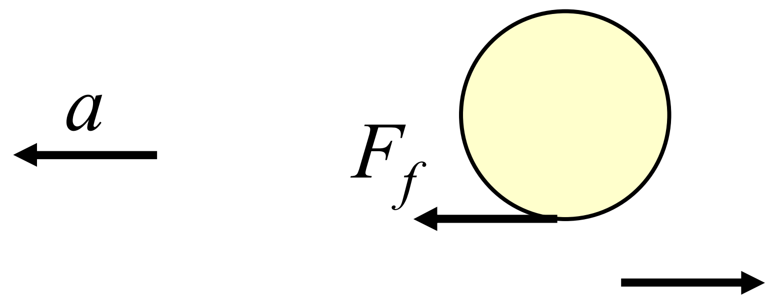
A) less than 0.5
B) greater than 0.5
C) less than 0
D) greater than 1
E) at least 2

Problem: In the figure below the coefficient of kinetic friction between the block and the ramp is 0.40. Assume the pulley has no mass and no friction. Determine the acceleration of the two blocks?



Friction and motion





$$F_{WG} = -F_f$$

F_{WG} is the force of the wheel on the ground in the horizontal direction.

Interactive Question

A locomotive engine pulls a series of wagons and accelerates forward. Which is the correct analysis of the situation?

A) The train moves forward because the engine pulls slightly harder on the wagons than the wagons pull on the engine.

B) Because action always equals reaction the engine cannot pull the wagons forward. Wagons and engine pull on each other with the same force.

C) The engine gets the wagons going with a tug during which the force on the wagons is momentarily greater than the force exerted by the wagons on the engine.

D) The engine's force on the wagons is as strong as the wagon's force on the engine, but the frictional force on the engine is forward and large while the frictional force on the wagons is backward and small.

E) The engine can pull the wagons only if it weighs more.

Air Resistance and Drag

$F_D = av^2 + bv$ a and b are constants

Often, $a = (1/2)\rho A C_D$

ρ: density of medium

A: cross sectional area of object

C_D: coefficient of drag

Let's look at an object falling in a gravitational field with a drag force proportional to velocity:

$$\sum F = ma$$

$$mg - bv = ma$$

$$mg - bv = m\, dv/dt$$

$$\frac{b\,dt}{m} = \frac{dv}{(mg/b) - v}$$

$$\int_0^t \frac{b\,dt}{m} = \int_0^v \frac{dv}{(mg/b) - v}$$

$$\left.\frac{bt}{m}\right|_0^t = -\ln\{(mg/b) - v\}\Big|_0^v$$

$$\frac{bt}{m} = -\ln\{(mg/b) - v\} + \ln(mg/b) = -\ln\frac{(mg/b) - v}{mg/b}$$

$$-\frac{bt}{m} = \ln\frac{(mg/b) - v}{mg/b}$$

$$e^{-\frac{bt}{m}} = \frac{(mg/b) - v}{mg/b}$$

$$v = \frac{mg}{b}\left(1 - e^{-\frac{bt}{m}}\right)$$

As *t* gets very large, the equation becomes $v = (mg/b)$

The falling object reaches a terminal velocity.

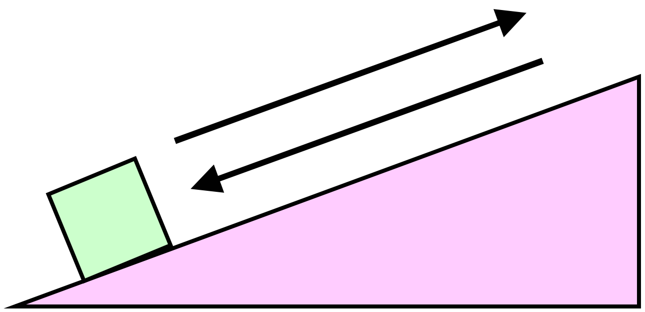
Interactive Question

You are riding your bike up a hill at 8 mph on a windless day. Assume that the drag force is proportional to your velocity. Which would cause a greater increase in the retarding force on your bicycle: doubling your speed or doubling the angle of the hill?

A) The speed.
B) The hill.
C) They would both be the same.
D) More information is needed to answer this question.

Interactive Question

A block is given an initial push up an inclined surface. It slides up the ramp, slows down and stops, then slides back down the ramp. From the time right after the initial push until the block slides back down, will it take longer for the block to slide up the surface or down the surface?



A) Up
B) Down
C) The same amount of time

Uniform Circular Motion and Force

For an object undergoing uniform circular motion:
$\sum \mathbf{F} = m\mathbf{a}_C = (mv^2/r)\hat{\mathbf{r}}$

This "net radial force" is sometimes called the centripetal, or "center-seeking" force.

It is simply the sum of all the forces acting on an object, like tension, gravity, friction, that has a net direction toward the center of a circle, or a "net radial force."

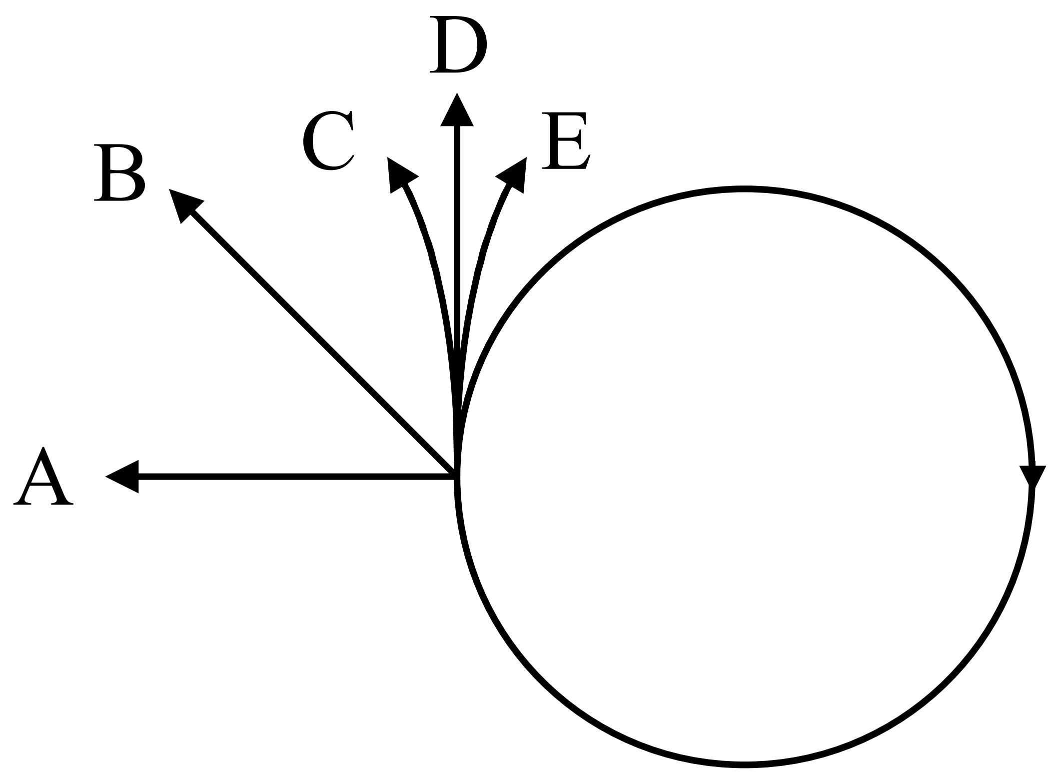
Interactive Question

A boy is whirling a stone around his head by means of a string. The string makes one revolution every second and the tension in the string is T. The boy then speeds up the stone, keeping the radius of the circle unchanged so that the string makes two complete revolutions every second. What happens to the tension in the string?

A) It remains unchanged
B) It is reduced to half of its original value.
C) It is increased to twice its original value.
D) It is reduced to one-fourth of its original value.
E) It is increased to four times its original value.

Interactive Question

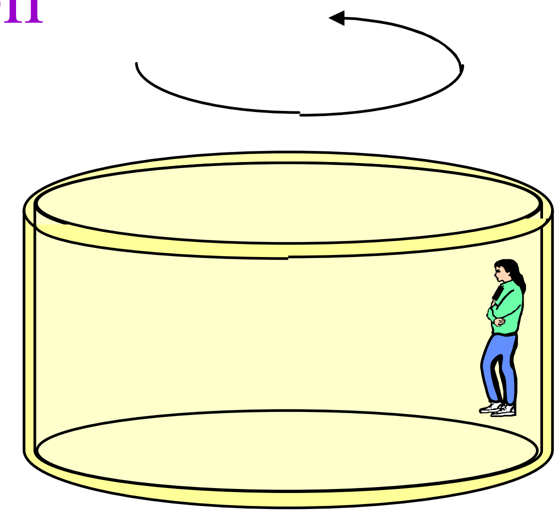
A girl attaches a rock to a string which he then swings clockwise in a horizontal circle. The string breaks at point P on the sketch which shows a view from above. What path will the rock follow?

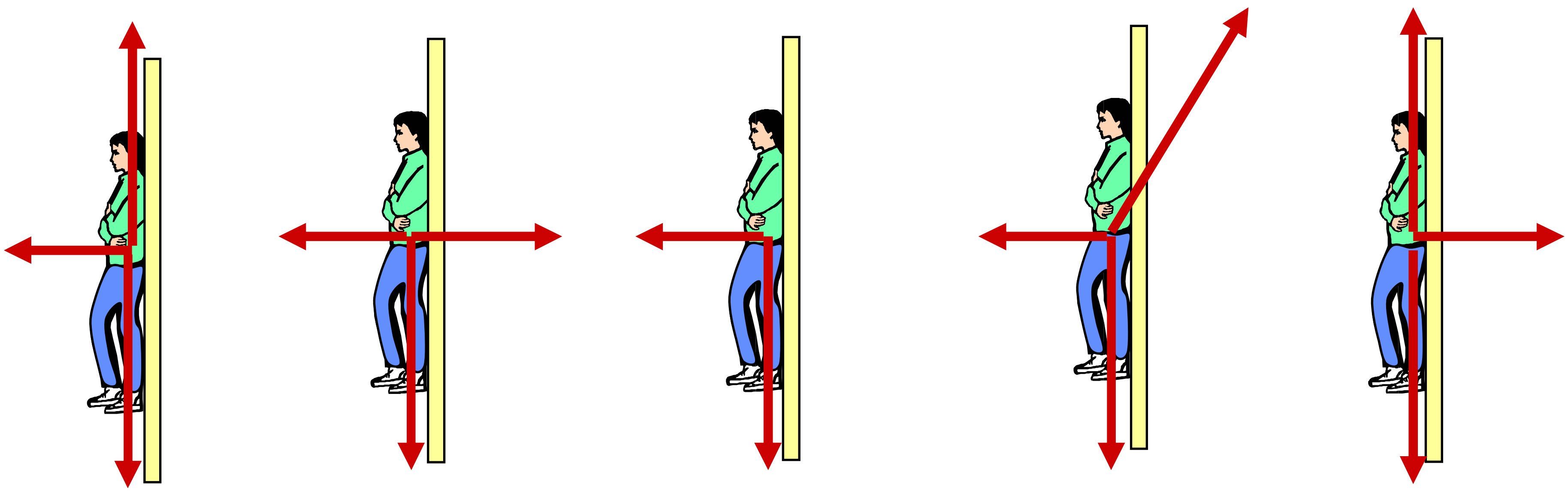


Problem: You have been hired to serve as a technical consultant for a new James Bond film. One scene calls for 007 to chase a villain onto a merry-go-round. An accomplice starts the merry-go-round rotating in an effort to toss 007 into an adjacent pool filled with hungry sharks. You measure the radius of the merry-go-round as 11 meters, and the maximum rate of rotation to be 1 revolution per 8.2 seconds. The coefficient of static friction between Bond's shoes and the merry-go-round is 0.7 when the merry-go-round is dry. What should happen when the merry-go-round starts to rotate? On the actual day of filming, it is quite cold and the merry-go-round has a small layer of ice on it. Would it be wise to film on this day?

Interactive Question

A rider in an amusement park ride, the "barrel of fun" finds herself stuck with her back to the wall. Which diagram correctly shows the forces acting on her?





A)   B)   C)   D)   E)

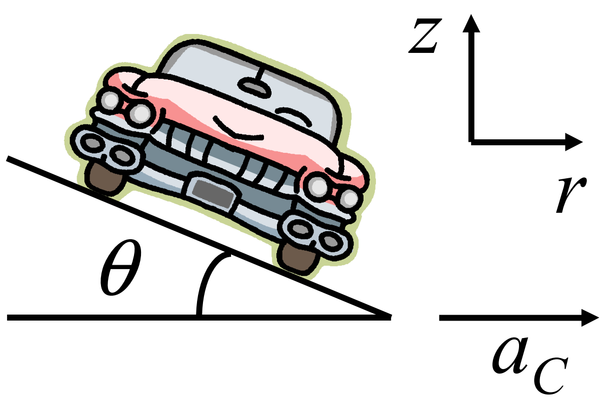
Problem: A road designer wants to design a curve so that a car can turn even if there is no friction between the tires and the road. What should be the angle of the banked curve? First do this problem for the general case. Then find the banking angle for a curve with a radius of 50 m and a speed of 15 m/s.

Interactive Question

A car approaches a curve with a radius of 50 m and a banking angle of 25º. The car is *not* traveling 15 m/s. If there is no friction between the tires and the car, what will happen to the car?

A) It will negotiate the curve just fine
B) It will slide down the bank
C) It will slide up the bank
D) There is not enough information to answer

Problem: A car approaches a curve with a banking angle of 15º. The coefficient of static friction between the car tires and the road is 0.90. How fast can the car safely go around the curve?

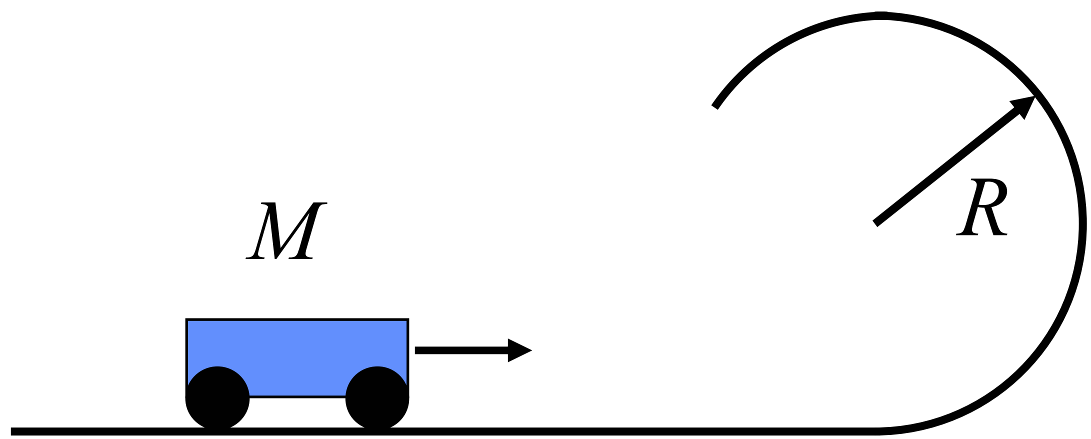


Problem: What is the minimum velocity you can spin a can filled with water attached to a 1.0 m long string in a vertical direction without the water falling out?

Problem: If you are spinning a can as in the previous problem, what is the normal force at the bottom of the circle?

Interactive Question

A cart of mass M travels along a straight horizontal track. As suggested in the figure, the track then bends into a vertical circle of radius R. Which expression determines the minimum speed that the car must have at the top of the track if it is to remain in contact with the track?



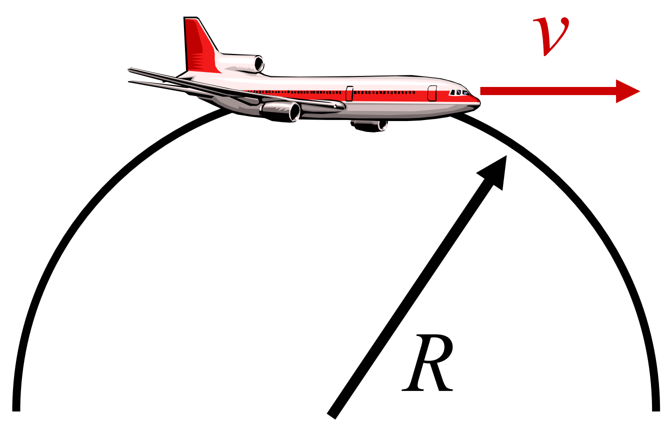
A) $v = MgR$ B) $v^2 = 2gR$ C) $v = gR$

D) $v = 2gR$ E) $v^2 = gR$

Interactive Question

An airplane is traveling at 200 m/s following the arc of a vertical circle of radius *R*. At the top of its path, the passengers experience "weightlessness". To one significant figure, what is the value of *R*?

A) 200 m
B) 1,000 m
C) 2,000 m
D) 4,000 m
E) 40,000 m



Problem: You tie a ball to a string and rotate the ball in a horizontal circle that makes an an angle of θ with the vertical direction.

(a) Find an expression for the centripetal acceleration of the ball.

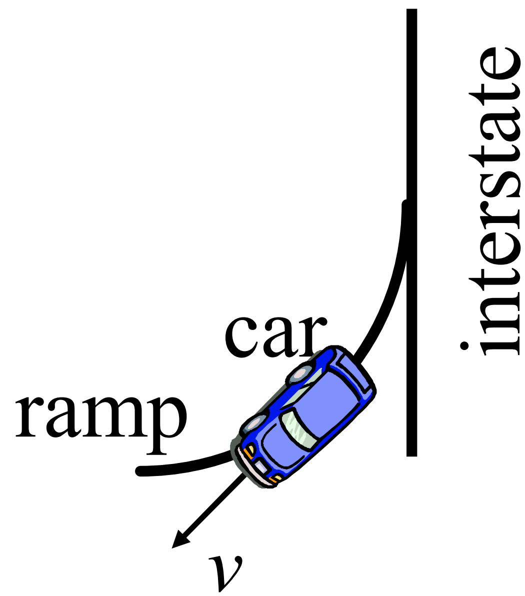
(b) If the string is 0.8 meters long and θ=20°, how fast is the ball rotating?

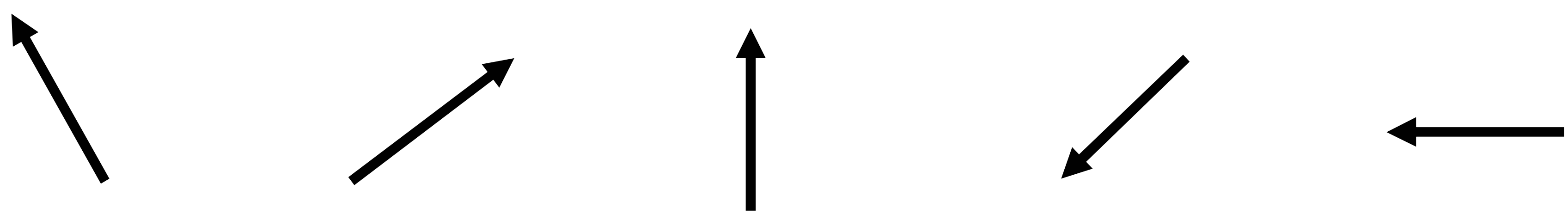
Forces for Non-Uniform Circular Motion

$\sum \mathbf{F} = m\mathbf{a}$ is, of course, a vector equation. This means that the magnitude *and* direction on each side of the equation must be equal. So the net force on an object points in the direction of acceleration. When an object is turning and changing speed, it has both a radial and tangential acceleration, as we have discussed. Consequently, it will have components of force in both the radial and tangential directions.

Interactive Question

A car is slowing down as it exits the interstate on a circular exit ramp as shown in the figure at right. What is the direction of the net force acting on the car when it is at the point indicated?

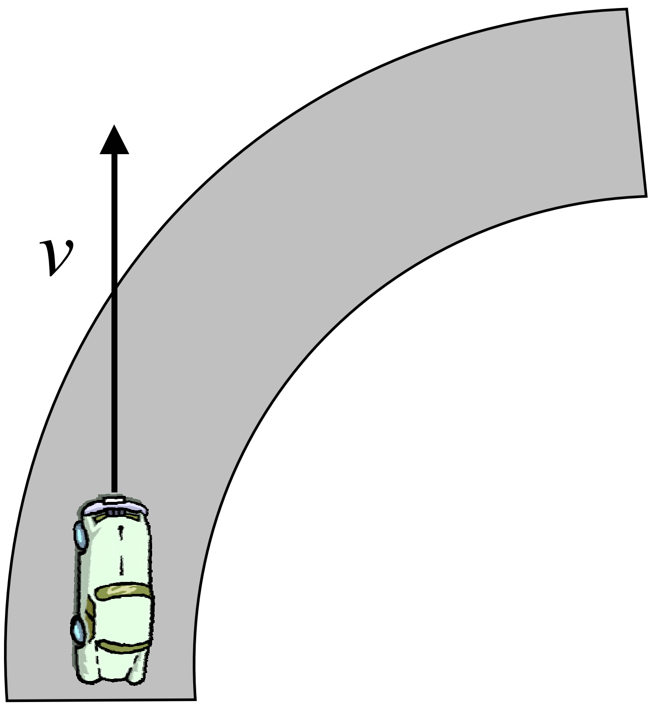




A)   B)   C)   D)   E)

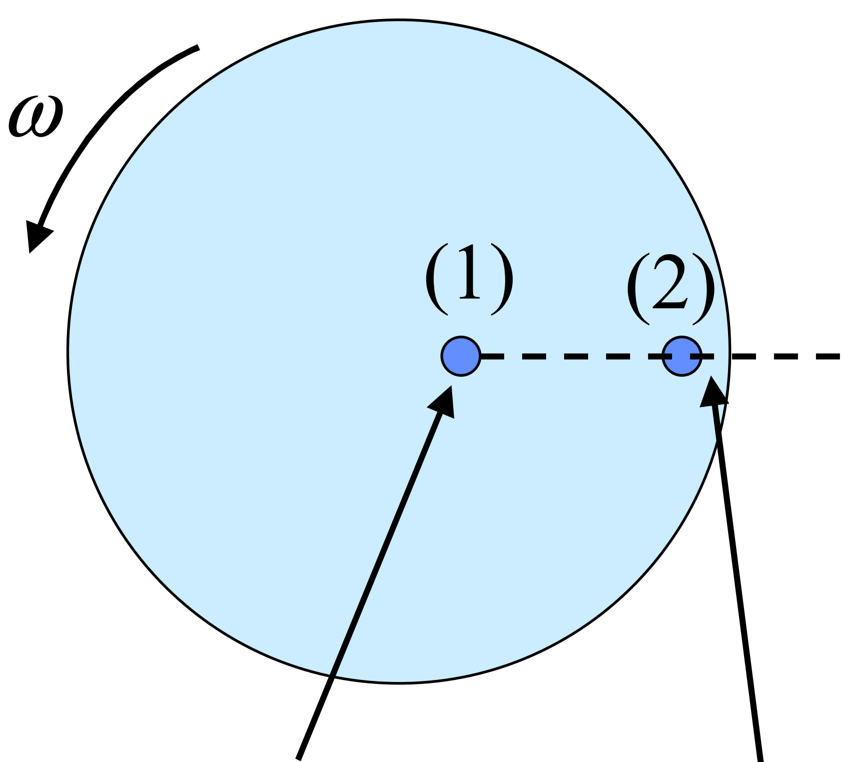
Centripetal Force and "Centrifugal" Force

Centripetal: Center Seeking
Centrifugal: Center Fleeing

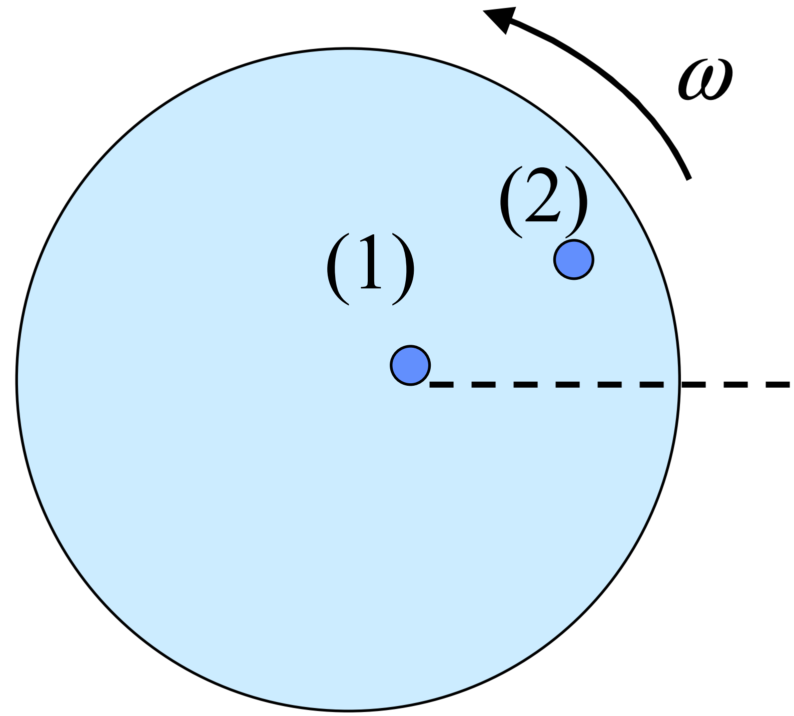


While driving the car around the corner, you think you are trying to "fly outward," but you are really just trying to go straight, while the car is turning.

We "invent" a pretend force that we think is making us fly outward and call it "centrifugal" force, but it is a pseudo-force that exists only because we are in a "non-inertial" reference frame, (i.e. an accelerating reference frame).



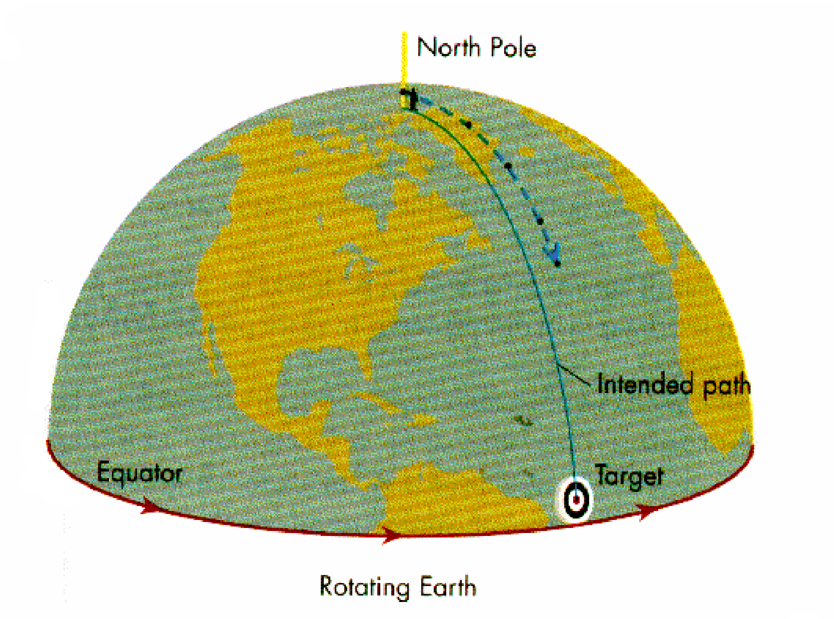
Person here (1) throws ball to person here (2) and the ball goes straight

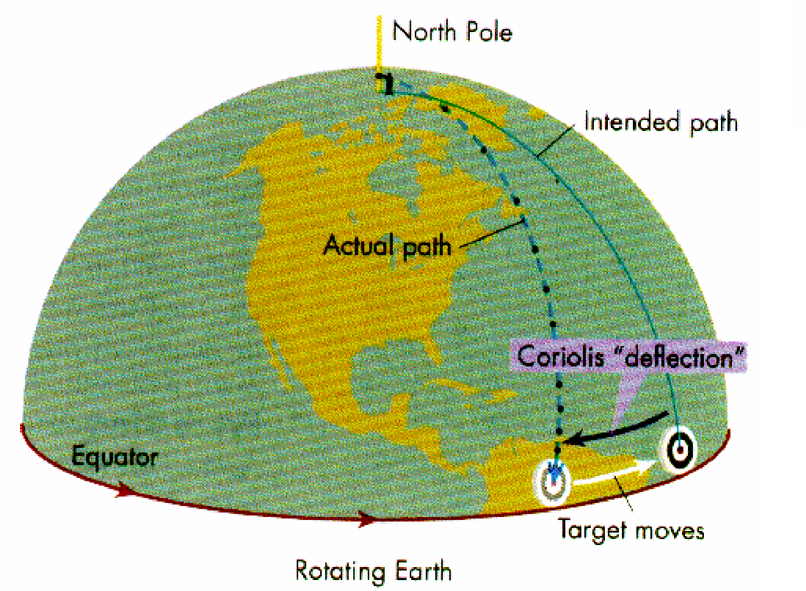


Because person (2) is moving faster than person (1), by the time the ball reaches person (2), it ends up behind person (2)

Person (2) thinks the ball has curved, but it hasn’t

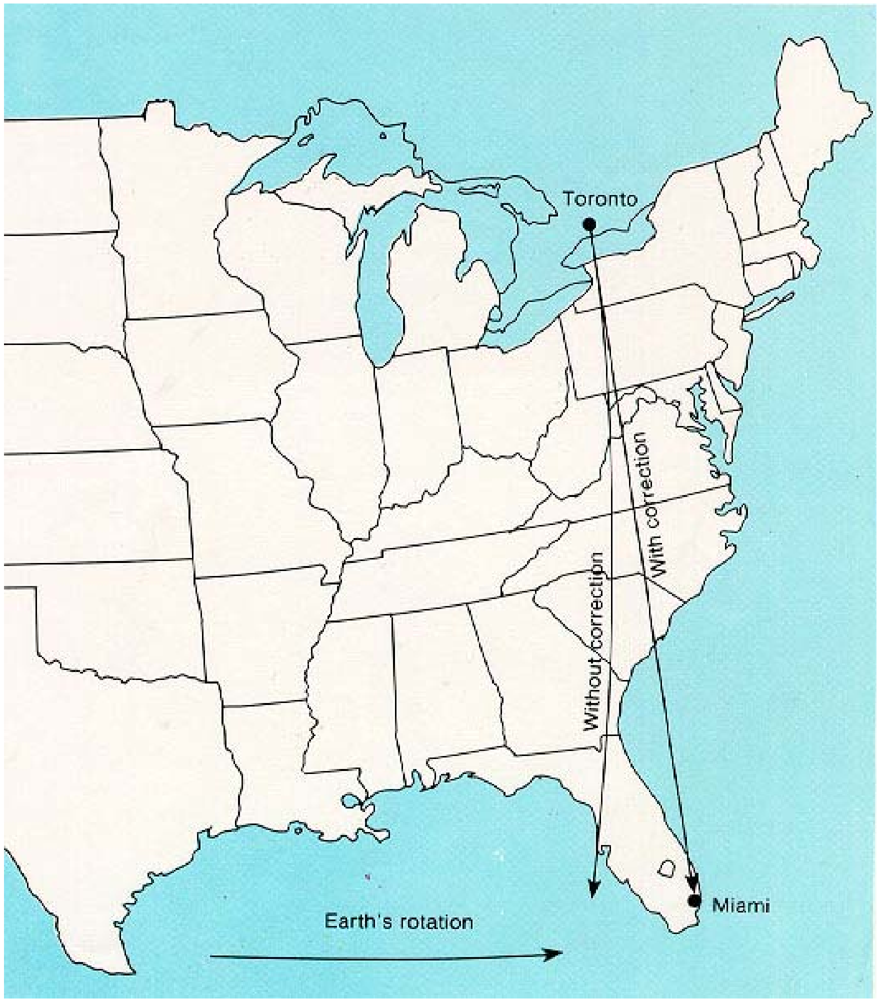
Inertial and Non Inertial Frames:
The Coriolis "Force"

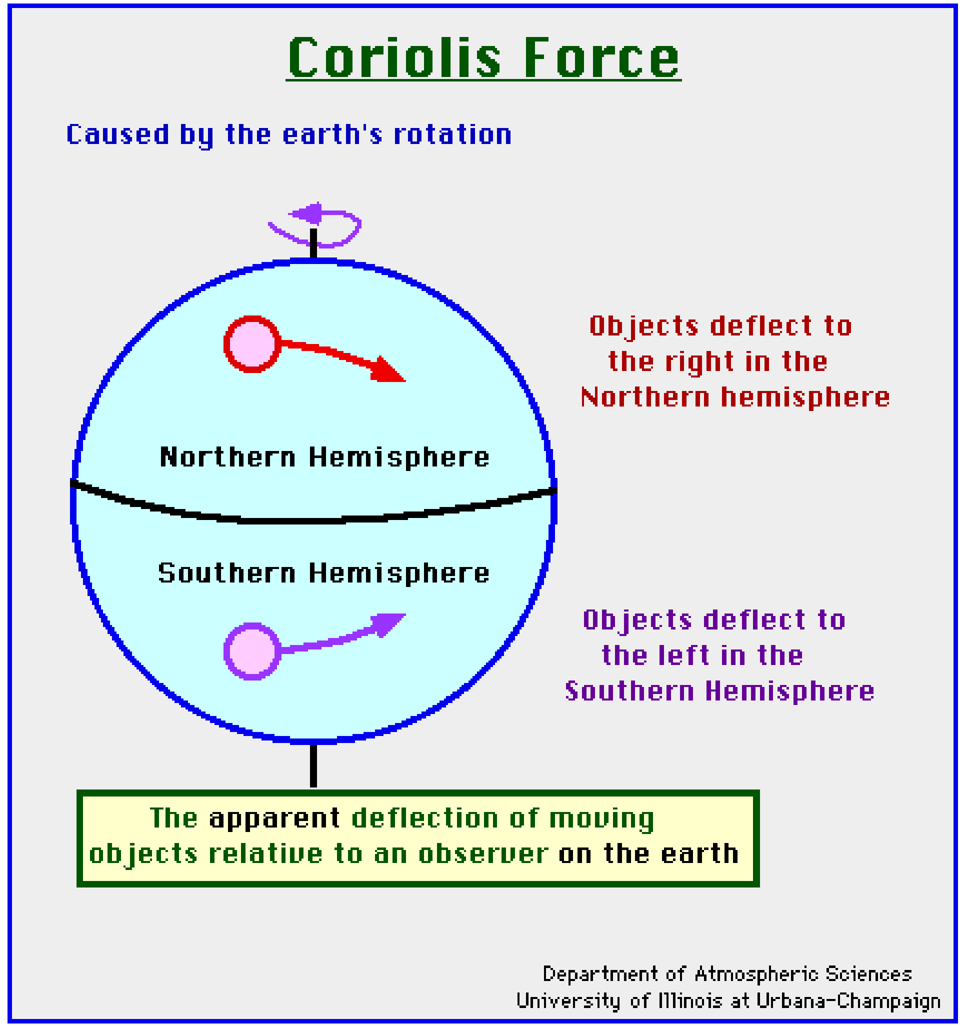




Points farther north have less tangential velocity than points farther south.

A projectile directed south toward the equator will appear to "curve" to the west.


Toronto
Without correction
With correction
Miami
Earth's rotation


Coriolis Force
Caused by the earth's rotation
Objects deflect to the right in the Northern hemisphere
Northern Hemisphere
Southern Hemisphere
Objects deflect to the left in the Southern Hemisphere
The apparent deflection of moving objects relative to an observer on the earth
Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign