

# PHYSICS

FOR SCIENTISTS AND ENGINEERS A STRATEGIC APPROACH 4/E

## Chapter 5 Lecture

RANDALL D. KNIGHT

# Chapter 5 Force and Motion



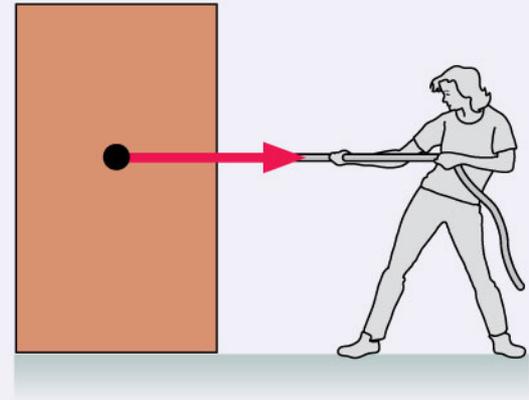
**IN THIS CHAPTER**, you will learn about the connection between force and motion.

# Chapter 5 Preview

## What is a force?

The fundamental concept of **mechanics** is **force**.

- A force is a **push** or a **pull**.
- A force acts on an object.
- A force requires an **agent**.
- A force is a **vector**.

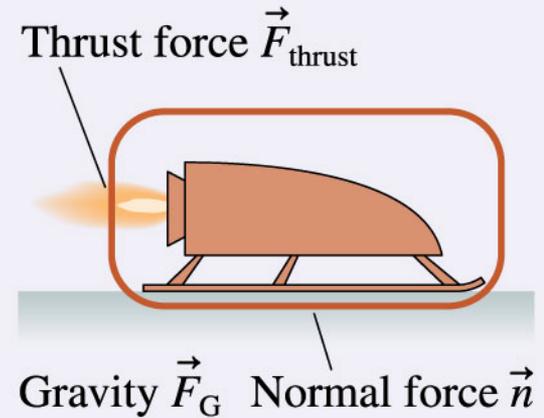


# Chapter 5 Preview

## How do we identify forces?

A force can be a **contact force** or a **long-range force**.

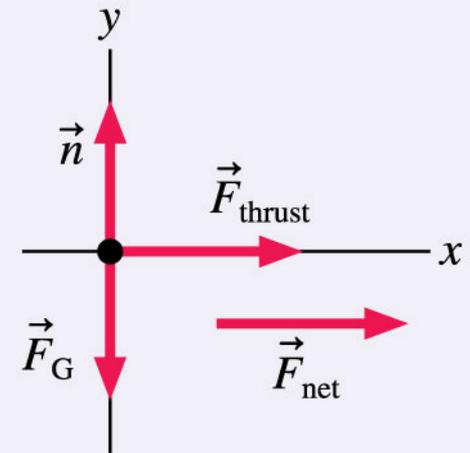
- Contact forces occur at points where the environment touches the object.
- Contact forces disappear the instant contact is lost. Forces have no memory.
- Long-range forces include gravity and magnetism.



# Chapter 5 Preview

## How do we show forces?

Forces can be displayed on a **free-body diagram**. You'll draw all forces—both pushes and pulls—as vectors with their tails on the particle. A well-drawn free-body diagram is an essential step in solving problems, as you'll see in the next chapter.



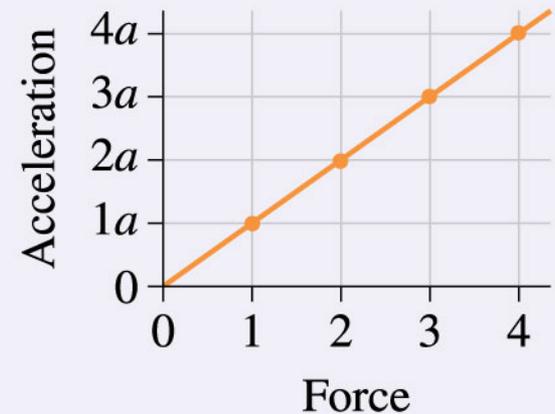
# Chapter 5 Preview

## What do forces do?

A **net force** causes an object to **accelerate** with an acceleration directly proportional to the size of the force. This is **Newton's second law**, the most important statement in mechanics. For a particle of mass  $m$ ,

$$\vec{a} = \frac{1}{m} \vec{F}_{\text{net}}$$

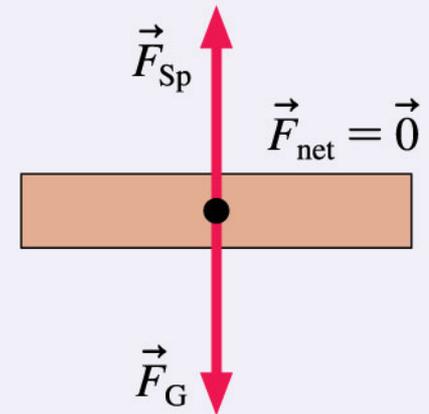
◀◀ **LOOKING BACK** Sections 1.4, 2.4, and 3.2  
Acceleration and vector addition



# Chapter 5 Preview

## What is Newton's first law?

**Newton's first law**—an object at rest stays at rest and an object in motion continues moving at constant speed in a straight line if and only if the **net force** on the object is zero—helps us define what a force *is*. It is also the basis for identifying the reference frames—called **inertial reference frames**—in which Newton's laws are valid.



## What good are forces?

Kinematics describes *how* an object moves. For the more important tasks of knowing *why* an object moves and being able to predict its position and orientation at a future time, we have to know the forces acting on the object. **Relating force to motion** is the subject of **dynamics**, and it is one of the most important underpinnings of all science and engineering.

# Chapter 5 Reading Questions

# Reading Question 5.1

What is a “net force?”

- A. The weight excluding the container.
- B. The vector sum of all forces in a problem.
- C. The vector sum of all forces acting on an object.
- D. The vector force applied by a net.
- E. The vector sum of all forces that add up to zero.

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-  C. **The vector sum of all forces acting on an object.**
- D. The vector force applied by a net.
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## Reading Question 5.2

Which of the following are steps used to identify the forces acting on an object?

- A. Draw a closed curve around the system.
- B. Identify “the system” and “the environment.”
- C. Draw a picture of the situation.
- D. All of the above.
- E. None of the above.

## Reading Question 5.2

Which of the following are steps used to identify the forces acting on an object?

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- B. Identify “the system” and “the environment.”
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-  **D. All of the above.**
- E. None of the above.

## Reading Question 5.3

Which of these is *not* a force discussed in this chapter?

- A. The tension force.
- B. The orthogonal force.
- C. The normal force.
- D. The thrust force.
- E. None of the above.

## Reading Question 5.3

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# Reading Question 5.4

What is the name of a diagram used to show **all** forces acting on an object?

- A. Motion diagram.
- B. Interaction diagram.
- C. Free-body diagram.
- D. Second-law diagram.

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# Chapter 5 Content, Examples, and QuickCheck Questions

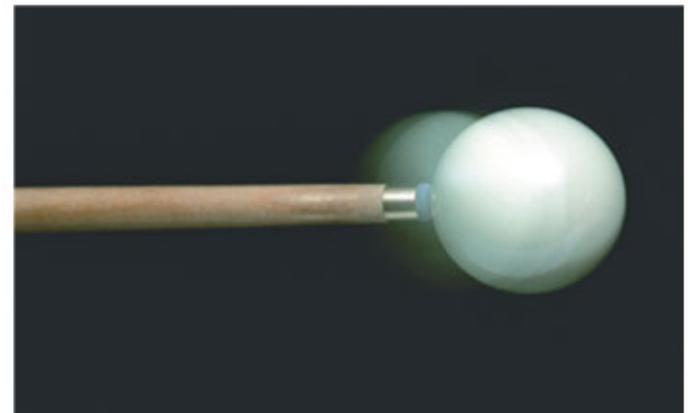
# What Is a Force?

- A force is a *push* or a *pull*.
- A force acts on an object.
- Pushes and pulls are applied *to* something.
- From the object's perspective, it has a force *exerted* on it.



# What Is a Force?

- A force requires an **agent**, something that acts or exerts power.
- If you throw a ball, your hand is the agent or cause of the force exerted on the ball.
- A force is a vector.
- To quantify a push or pull, we need to specify both magnitude and a direction.



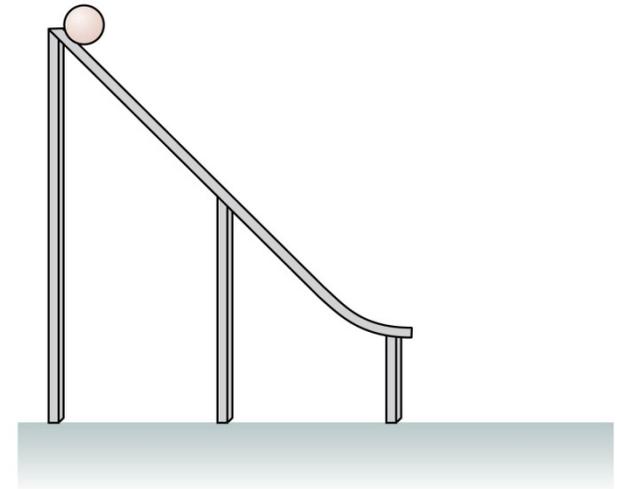
# What Is a Force?

- **Contact forces** are forces that act on an object by touching it at a point of contact.
- The bat must touch the ball to hit it.
  
- **Long-range forces** are forces that act on an object without physical contact.
- A coffee cup released from your hand is pulled to the earth by the long-range force of gravity.



# QuickCheck 5.1

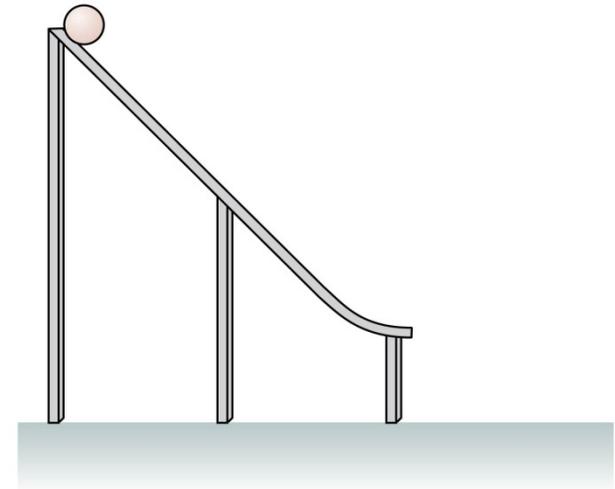
A ball rolls down an incline and off a horizontal ramp. Ignoring air resistance, what force or forces act on the ball as it moves through the air just after leaving the horizontal ramp?



- A. The weight of the ball acting vertically down.
- B. A horizontal force that maintains the motion.
- C. A force whose direction changes as the direction of motion changes.
- D. The weight of the ball and a horizontal force.
- E. The weight of the ball and a force in the direction of motion.

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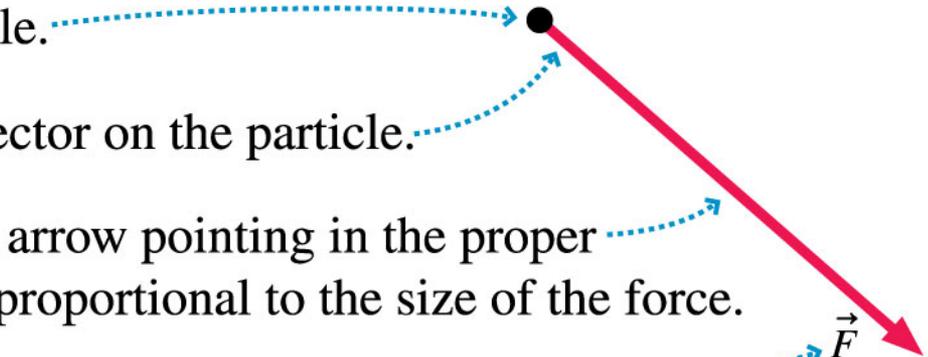
**The answer will be deferred until later.**

# Tactics: Drawing Force Vectors

## TACTICS BOX 5.1

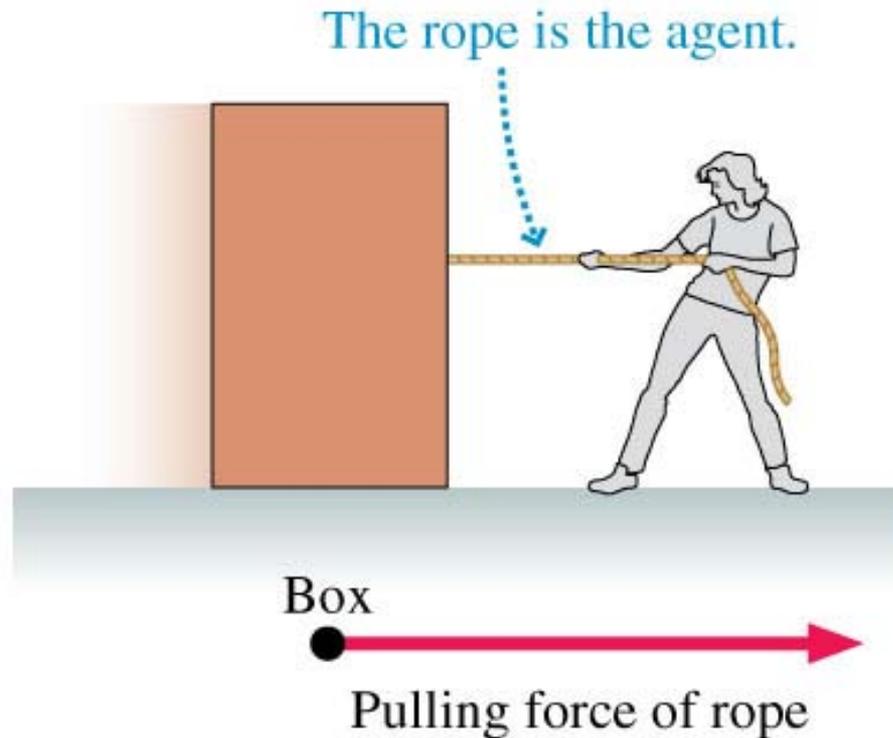


### Drawing force vectors

- 1 Model 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.
- 
- A diagram illustrating the steps for drawing a force vector. A black dot represents the particle. A red arrow points downwards and to the right from this dot. The arrow is labeled with a vector symbol
- $\vec{F}$
- at its tip. Four blue dotted arrows with arrowheads point from the numbered steps to the corresponding parts of the diagram: step 1 points to the black dot, step 2 points to the tail of the red arrow, step 3 points to the red arrow itself, and step 4 points to the label
- $\vec{F}$
- .

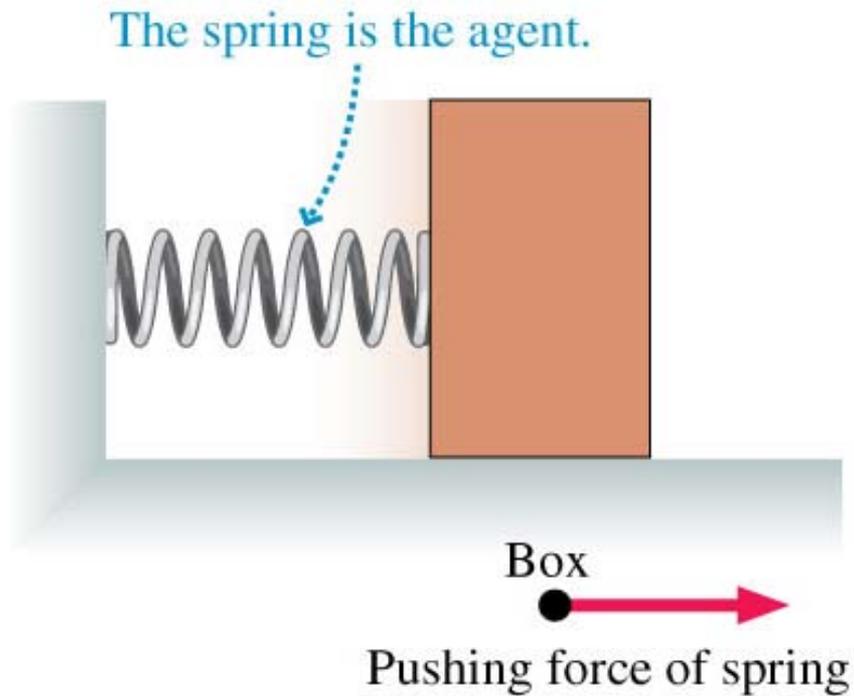
# Example: Drawing a Force Vector

A box is pulled to the right by a rope.



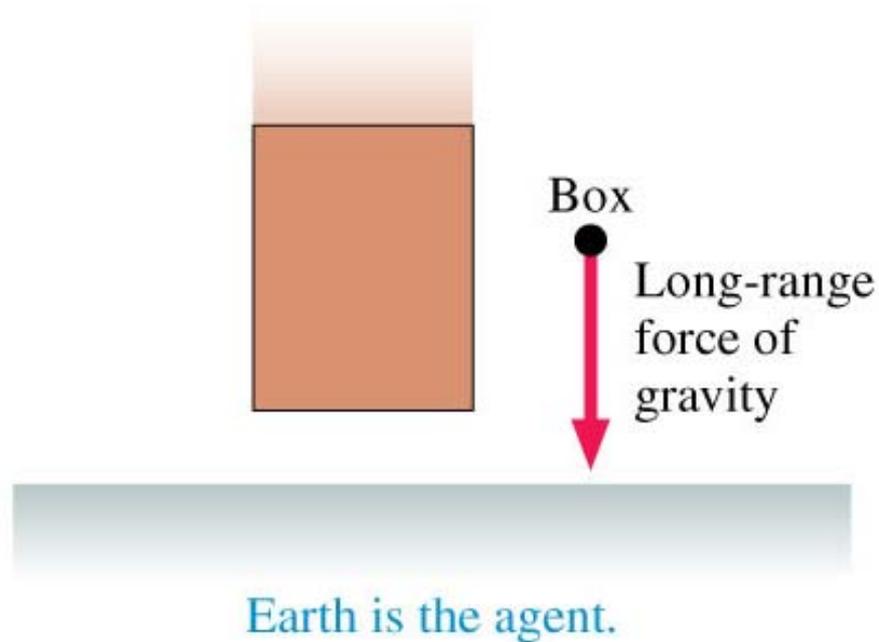
# Example: Drawing a Force Vector

A box is pushed to the right by a spring.



# Example: Drawing a Force Vector

A box is pulled down by gravity.



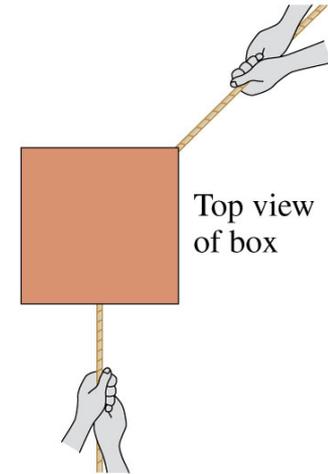
# Combining Forces

- A box is pulled by two ropes, as shown.
- When several forces are exerted on an object, they combine to form a **net force** given by the *vector sum* of *all* the forces:

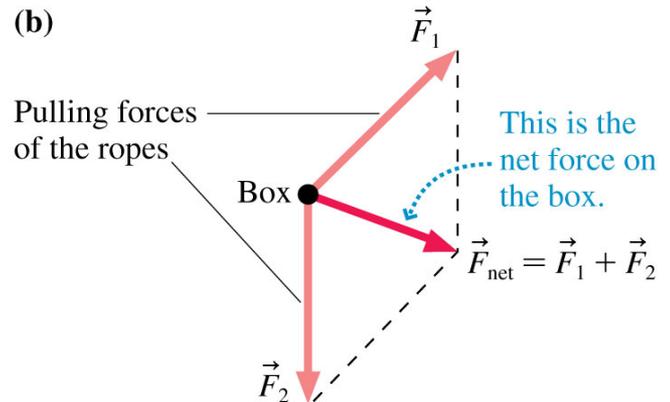
$$\vec{F}_{\text{net}} \equiv \sum_{i=1}^N \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \cdots + \vec{F}_N$$

- This is called a **superposition of forces**.

(a)

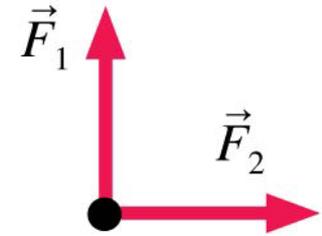


(b)

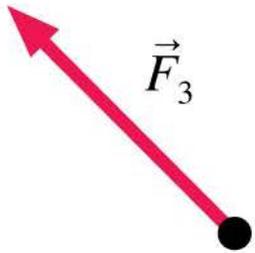


# QuickCheck 5.2

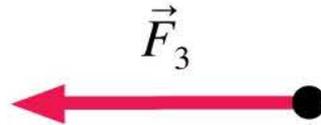
The net force on an object points to the left. Two of three forces are shown. Which is the missing third force?



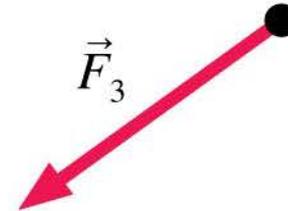
Two of the three forces exerted on an object



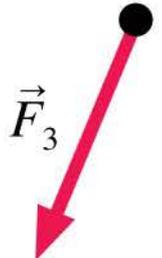
A.



B.



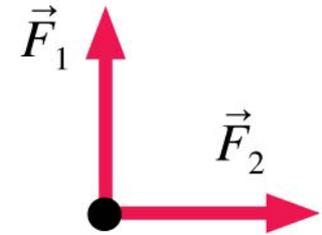
C.



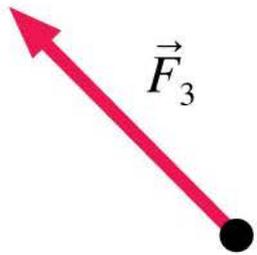
D.

# QuickCheck 5.2

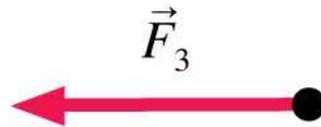
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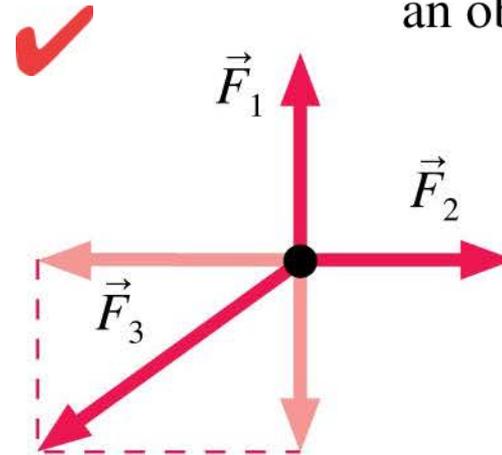
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A.

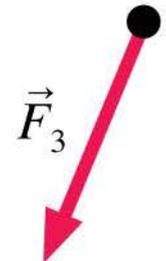


B.



C.

Vertical components cancel

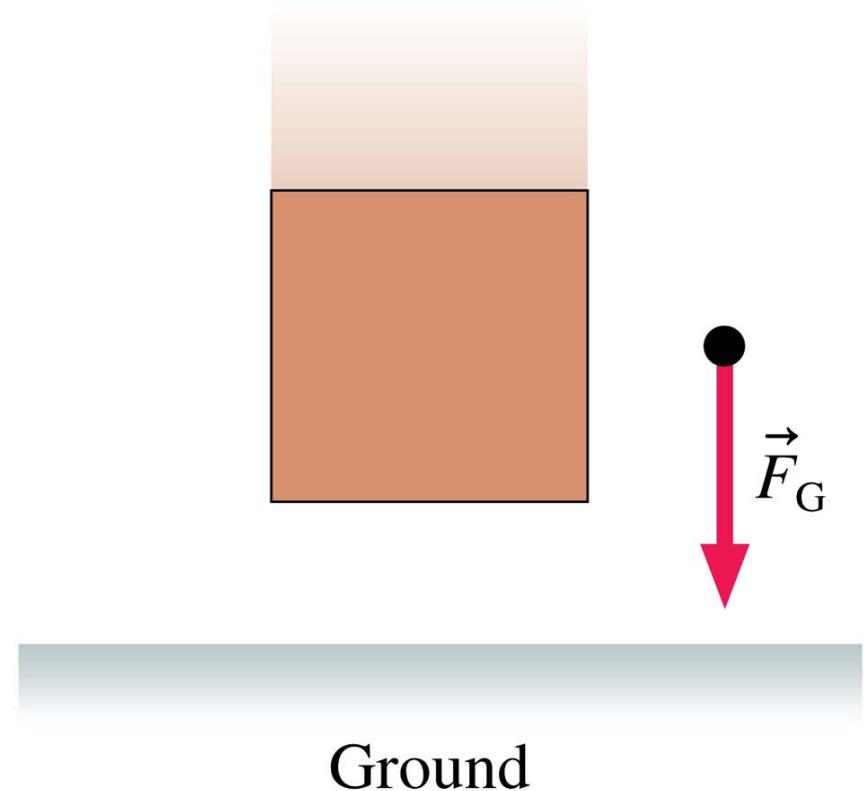


D.

# Gravity

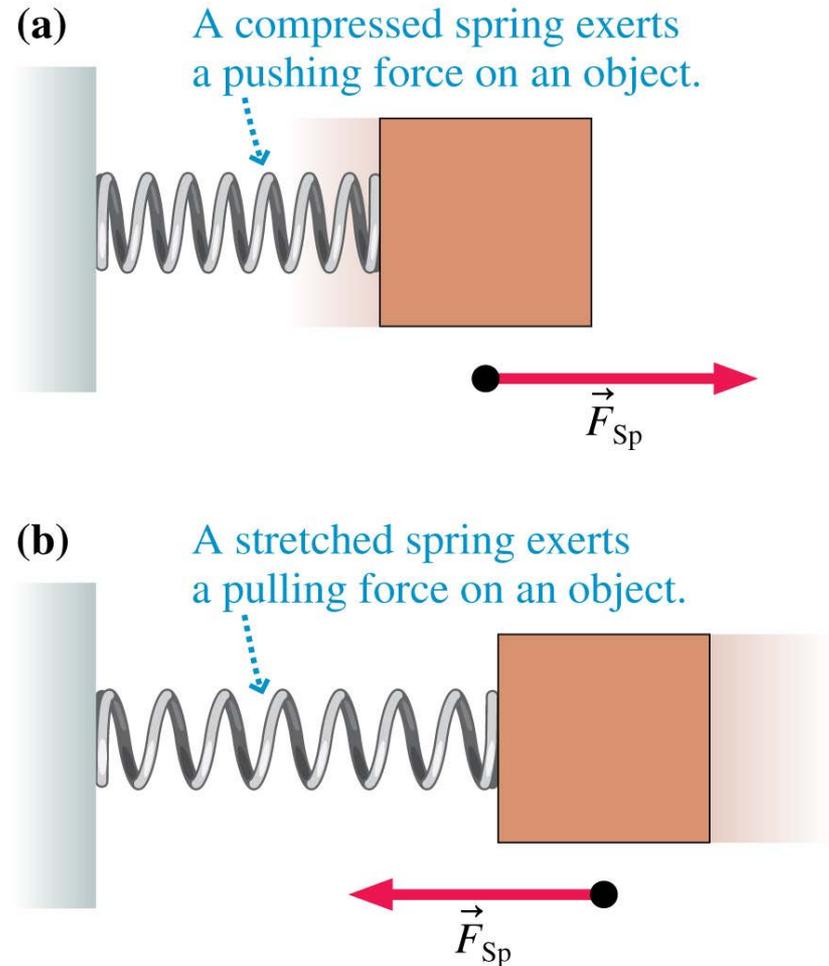
- The pull of a planet on an object near the surface is called the **gravitational force**.
- The agent for the gravitational force is the *entire planet*.
- Gravity acts on *all* objects, whether moving or at rest.
- The gravitational force vector always points vertically downward.

The gravitational force pulls the box down.



# Spring Force

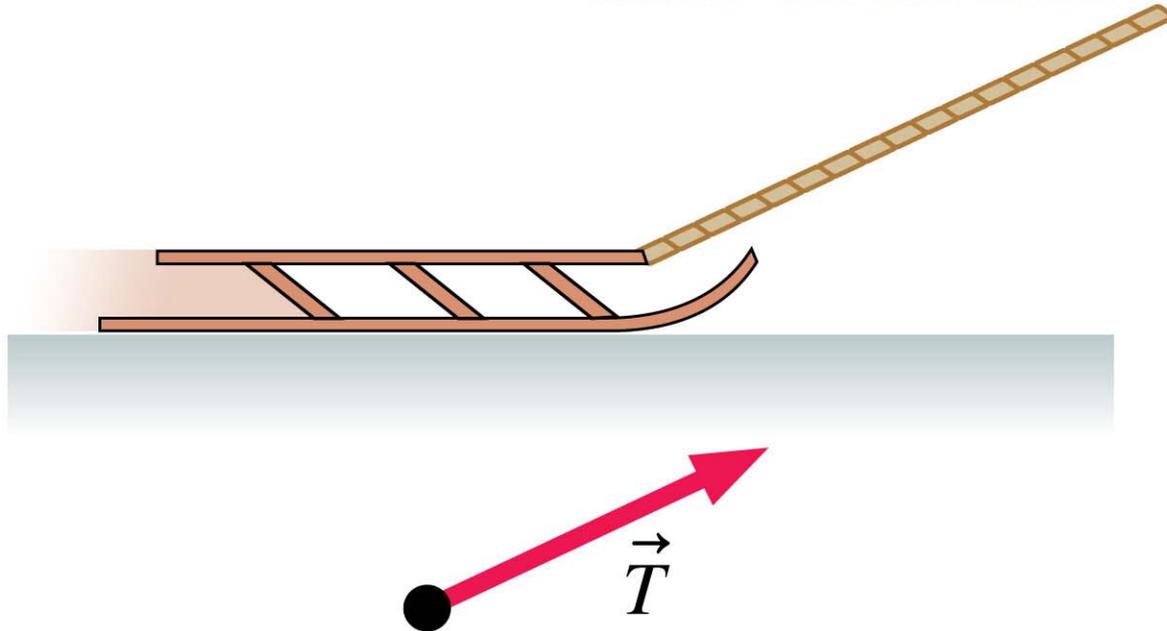
- A spring can either push (when compressed) or pull (when stretched).
- Not all springs are metal coils.
- Whenever an elastic object is flexed or deformed in some way, and then “springs” back to its original shape when you let it go, this is a **spring force**.



# Tension Force

- When a string or rope or wire pulls on an object, it exerts a contact force called the **tension force**.
- The tension force is in the direction of the string or rope.

The rope exerts a tension force on the sled.



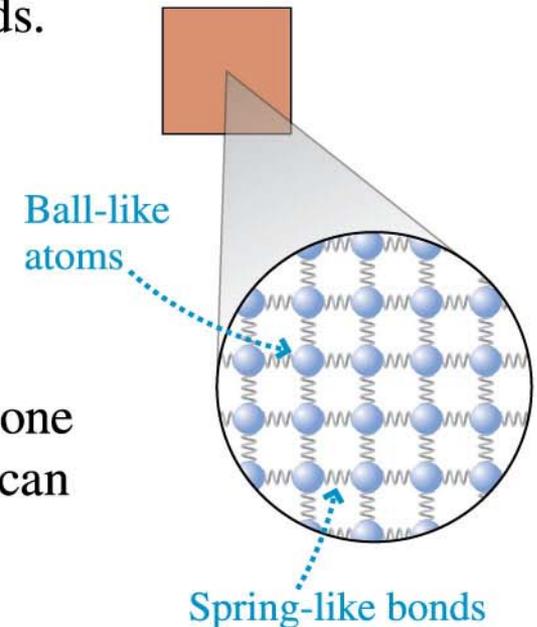
# Ball-and-Spring Model of Solids

## MODEL 5.1

### Ball-and-spring model of solids

Solids consist of atoms held together by molecular bonds.

- Represent the solid as **an array of balls connected by springs**.
- Pulling on or pushing on a solid causes the bonds to be stretched or compressed. **Stretched or compressed bonds exert spring forces**.
- There are an immense number of bonds. The force of one bond is very tiny, but the combined force of all bonds can be very large.
- Limitations: Model fails for liquids and gases.



## QuickCheck 5.3

A steel beam hangs from a cable as a crane lifts the beam. What forces act on the beam?

- A. Gravity.
- B. Gravity and tension in the cable.
- C. Gravity and a force of motion.
- D. Gravity and tension and a force of motion.

## QuickCheck 5.3

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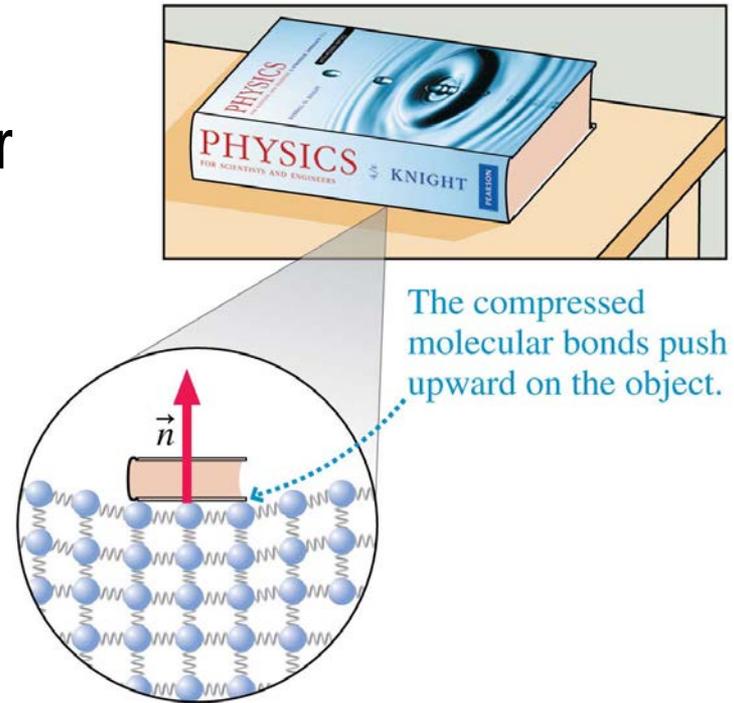
## QuickCheck 5.4

A book rests on a horizontal table. Gravity pulls down on the book. You may have learned something in a previous physics class about an upward force called the “normal force.” Deep in your heart, do you really believe the table is exerting an upward force on the book?

- A. Yes, I'm quite confident the table exerts an upward force on the book.
- B. No, I don't see how the table can exert such a force.
- C. I really don't know.

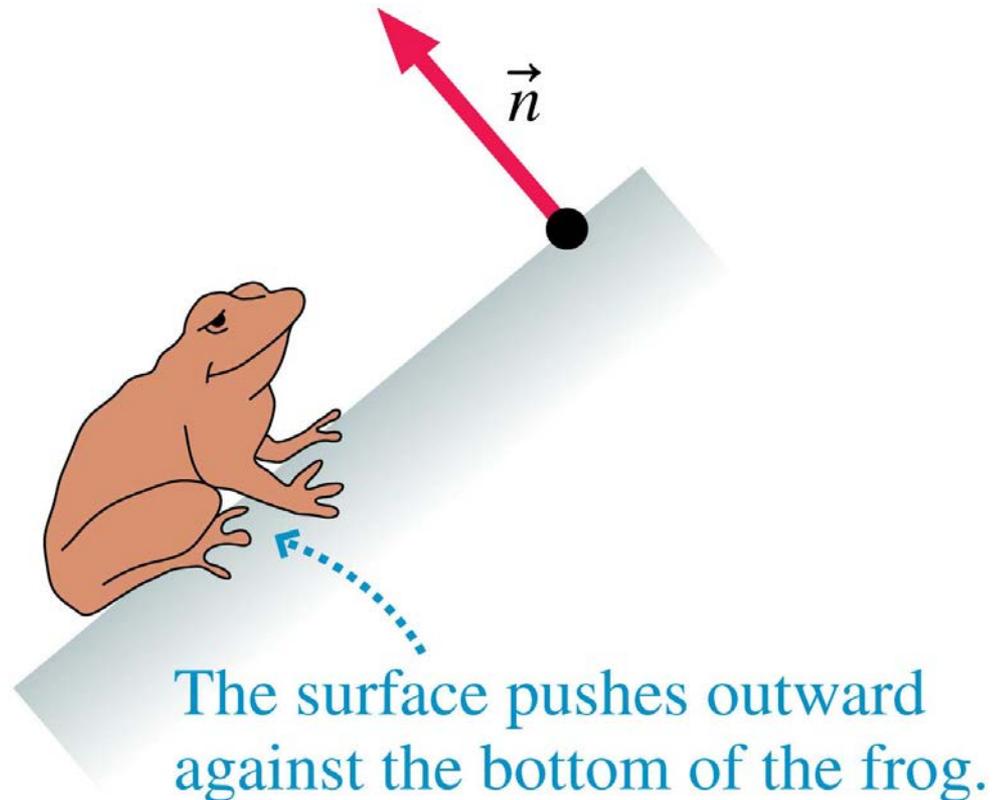
# Normal Force

- When an object sits on a table, the table surface exerts an upward contact force on the object.
- This pushing force is directed *perpendicular* to the surface, and thus is called the **normal force**.
- A table is made of *atoms* joined together by *molecular bonds* which can be modeled as springs.
- Normal force is a result of many molecular springs being compressed ever so slightly.



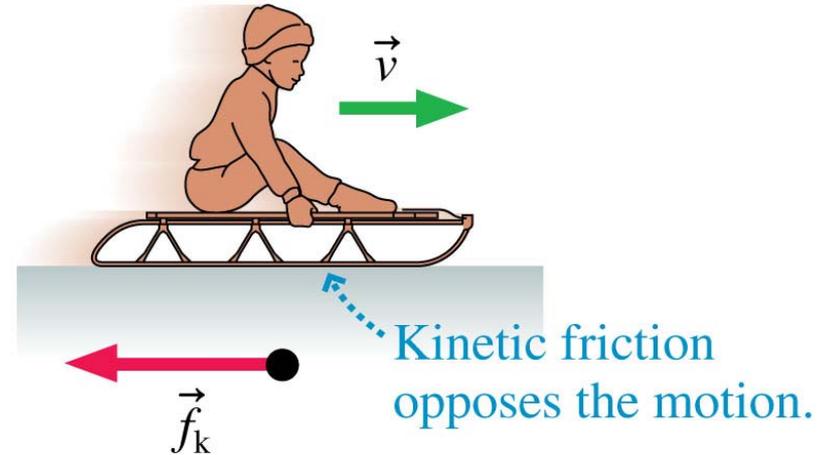
# Examples of Normal Force

- Suppose you place your hand on a wall and lean against it.
- The wall exerts a horizontal **normal force** on your hand.
- Suppose a frog sits on an inclined surface.
- The surface exerts a tilted **normal force** on the frog.



# Kinetic Friction

- When an object slides along a surface, the surface can exert a contact force which opposes the motion.
- This is called sliding friction or **kinetic friction**.
- The kinetic friction force is directed *tangent* to the surface, and opposite to the velocity of the object relative to the surface.
- Kinetic friction tends to slow down the sliding motion of an object in contact with a surface.



## QuickCheck 5.5

A bobsledder pushes her sled across horizontal snow to get it going, then jumps in. After she jumps in, the sled gradually slows to a halt. What forces act on the sled just after she's jumped in?

- A. Gravity and kinetic friction.
- B. Gravity and a normal force.
- C. Gravity and the force of the push.
- D. Gravity, a normal force, and kinetic friction.
- E. Gravity, a normal force, kinetic friction, and the force of the push.

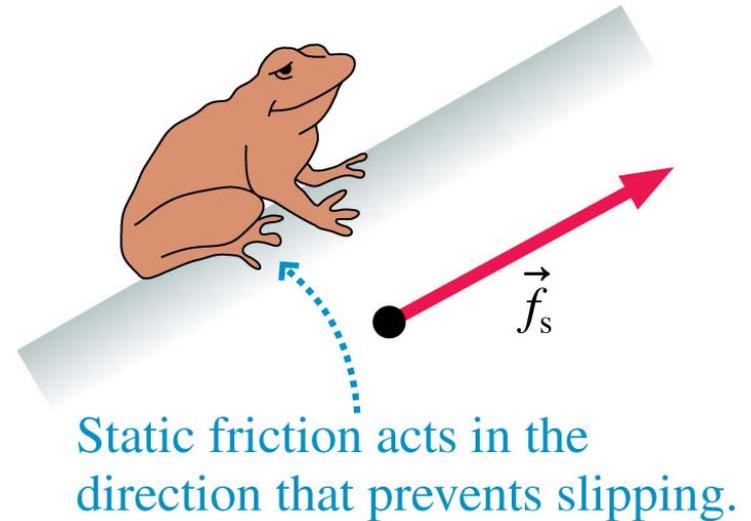
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# Static Friction

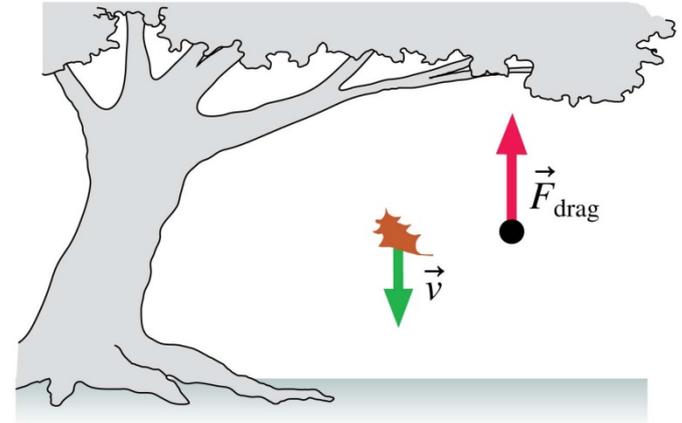
- **Static friction** is the contact force that keeps an object “stuck” on a surface, and prevents relative motion.
- The static friction force is directed *tangent* to the surface.
- Static friction points opposite the direction in which the object *would* move if there were no static friction.



# Drag

- Kinetic friction is a *resistive force*, which opposes or resists motion.
- Resistive forces are also experienced by objects moving through fluids.
- The resistive force of a fluid is called **drag**.
- Drag points opposite the direction of motion.
- For heavy and compact objects in air, drag force is fairly small.
- **You can neglect air resistance in all problems unless a problem explicitly asks you to include it.**

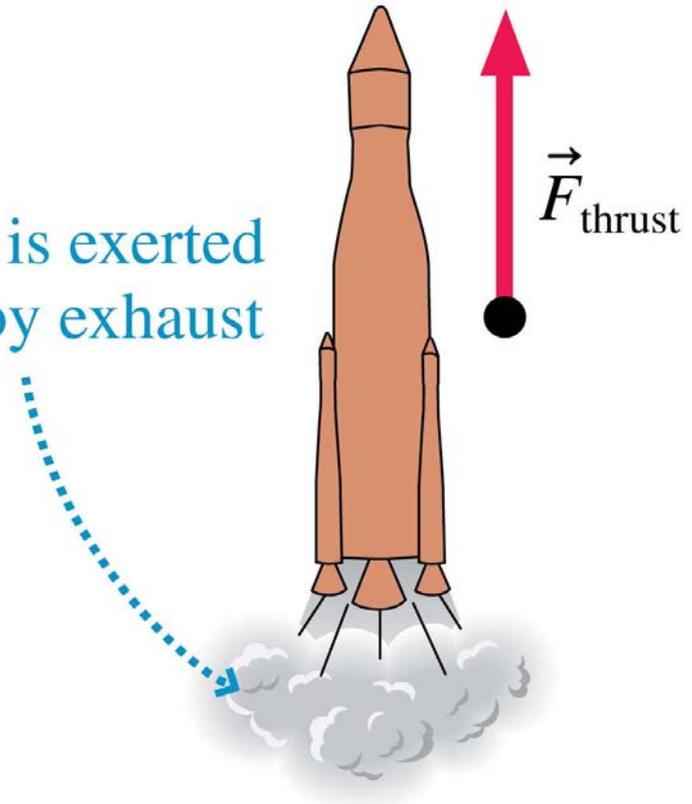
Air resistance points opposite the direction of motion.



# Thrust

- A jet airplane or a rocket has a **thrust** force pushing it forward during takeoff.
- Thrust occurs when an engine expels gas molecules at high speed.
- This exhaust gas exerts a contact force on the engine.
- The direction of thrust is opposite the direction in which the exhaust gas is expelled.

Thrust force is exerted on a rocket by exhaust gases.



# Electric and Magnetic Forces

- Electricity and magnetism, like gravity, exert long-range forces.
- We will study electric and magnetic forces in detail in Part VI.
- Atoms and molecules are made of charged particles (electrons and protons) and what we call a molecular bond is really an **electric force** between these particles.
- Forces such as the normal force, tension force, and friction are, at the most fundamental level, actually **electric** forces between the charged particles in the atoms.

# Symbols for Forces

<b>Force</b>	<b>Notation</b>
General force	$\vec{F}$
Gravitational force	$\vec{F}_G$
Spring force	$\vec{F}_{\text{sp}}$
Tension	$\vec{T}$
Normal force	$\vec{n}$
Static friction	$\vec{f}_s$
Kinetic friction	$\vec{f}_k$
Drag	$\vec{F}_{\text{drag}}$
Thrust	$\vec{F}_{\text{thrust}}$

# Tactics: Identifying Forces

## TACTICS BOX 5.2

MP

### Identifying forces

- 1 **Identify the object of interest.** This is the object 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.

Exercises 3–8



# EXAMPLE 5.1 Forces on a Bungee Jumper

## EXAMPLE 5.1 | Forces on a bungee jumper

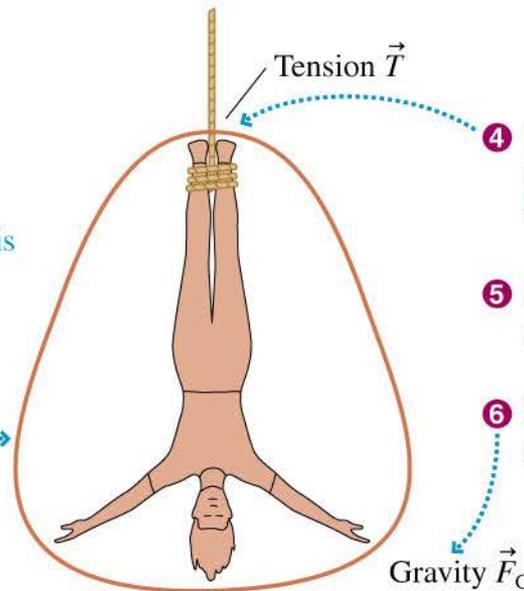
A bungee jumper has leapt off a bridge and is nearing the bottom of her fall. What forces are being exerted on the jumper?

### VISUALIZE

1 Identify the object of interest. Here the object is the bungee jumper.

2 Draw a picture of the situation.

3 Draw a closed curve around the object.



4 Locate the points where other objects touch the object of interest. Here the only point of contact is where the cord attaches to her ankles.

5 Name and label each contact force. The force exerted by the cord is a tension force.

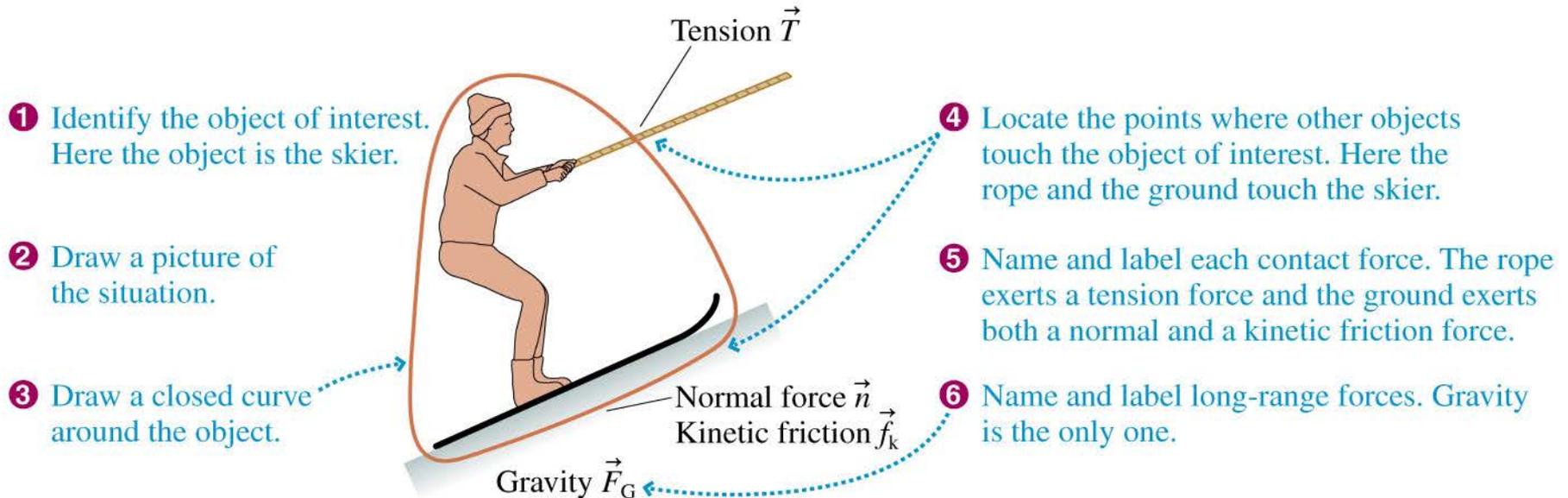
6 Name and label long-range forces. Gravity is the only one.

# EXAMPLE 5.2 Forces on a Skier

## EXAMPLE 5.2 | Forces on a skier

A skier is being towed up a snow-covered hill by a tow rope. What forces are being exerted on the skier?

### VISUALIZE

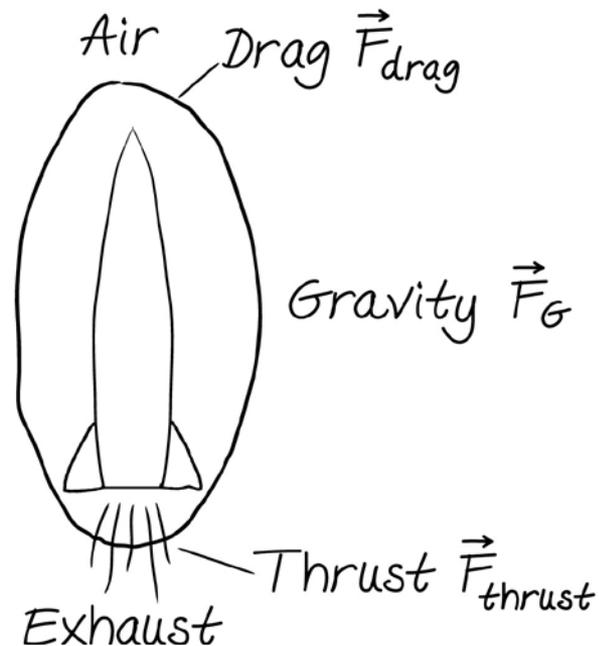


# EXAMPLE 5.3 Forces on a Rocket

## EXAMPLE 5.3 | Forces on a rocket

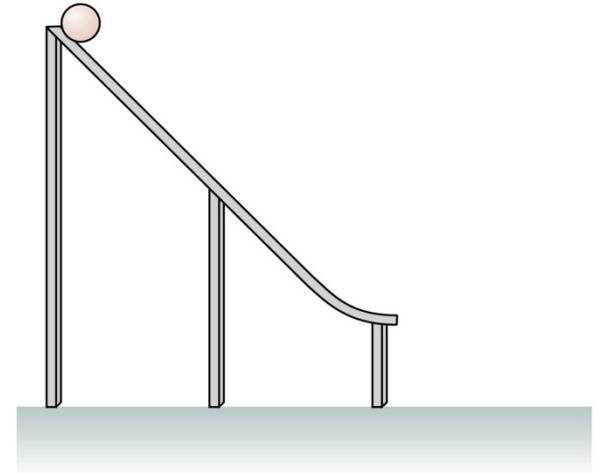
A rocket is being launched to place a new satellite in orbit. Air resistance is not negligible. What forces are being exerted on the rocket?

**VISUALIZE** This drawing is much more like the sketch you would make when identifying forces as part of solving a problem.



# QuickCheck 5.1 (revisited)

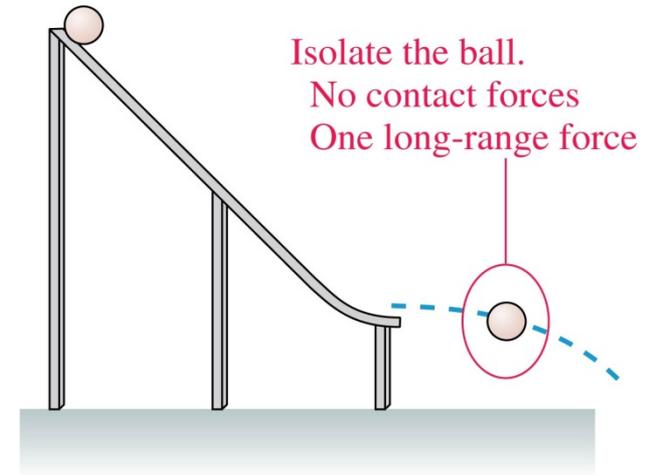
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- C. A force whose direction changes as the direction of motion changes.
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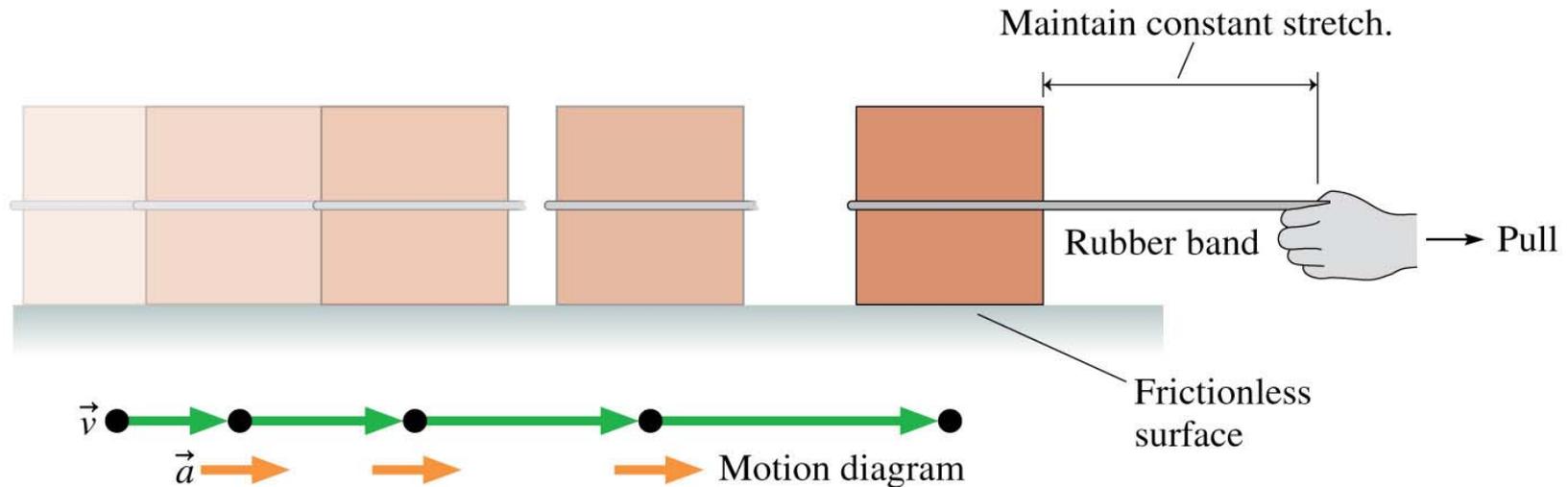
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- E. The weight of the ball and a force in the direction of motion.

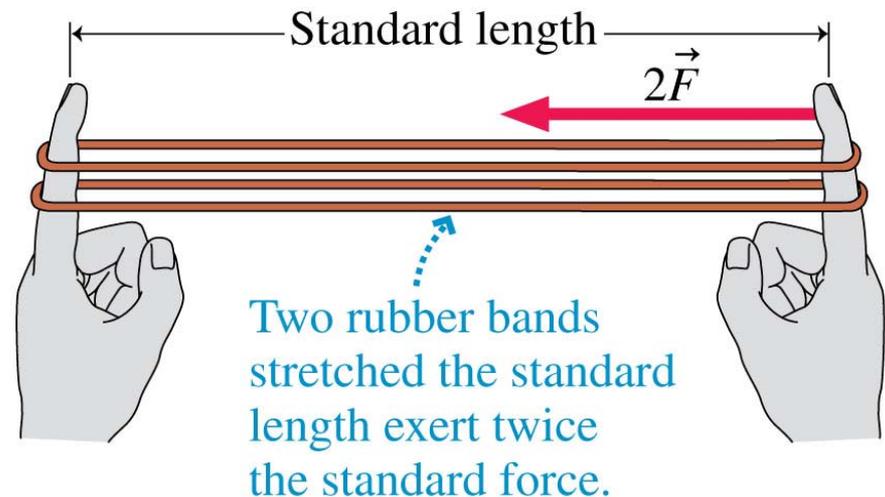
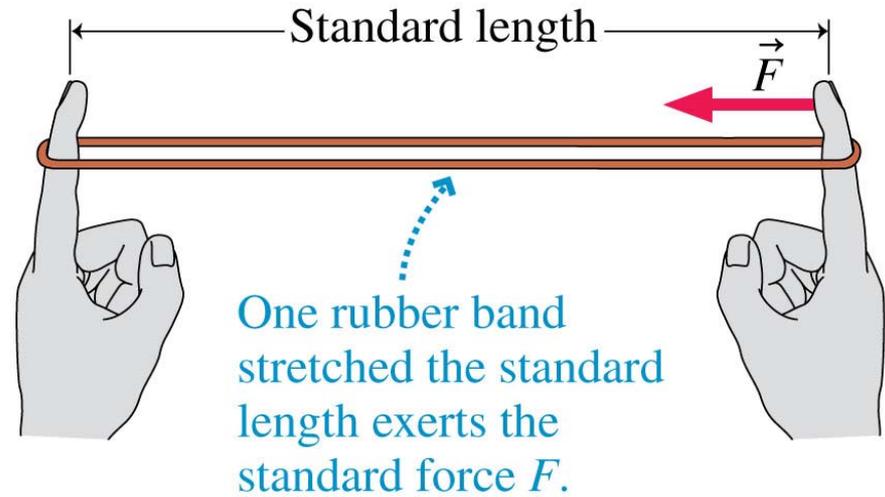
# What Do Forces Do? A Virtual Experiment

- Attach a stretched rubber band to a 1 kg block.
- Use the rubber band to pull the block across a horizontal, frictionless table.
- Keep the rubber band stretched by a fixed amount.
- We find that the block moves with a **constant acceleration**.



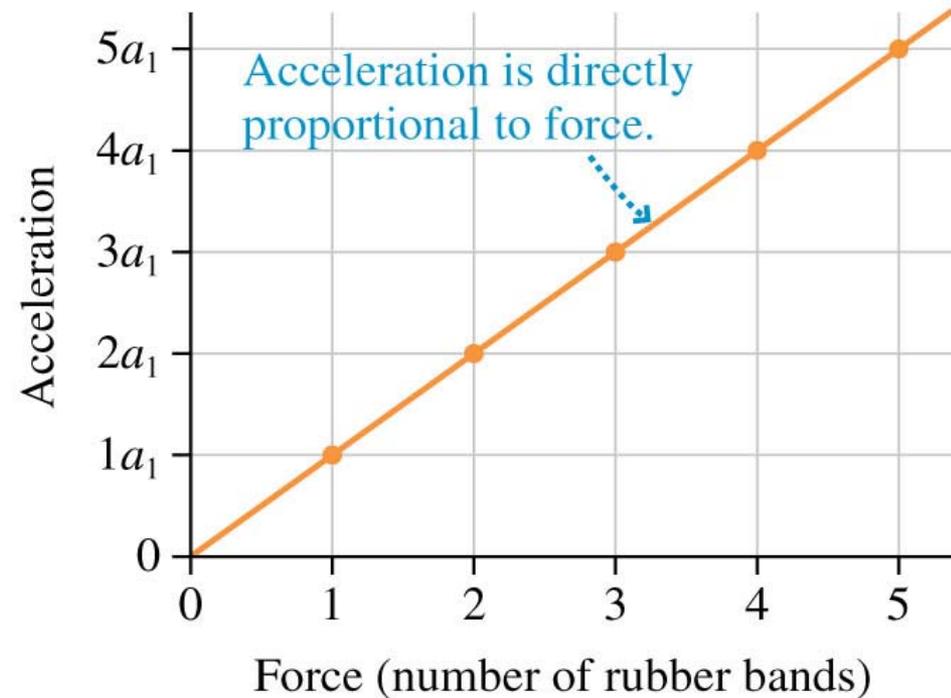
# What Do Forces Do? A Virtual Experiment

- A standard rubber band can be stretched to some standard length.
- This will exert a reproducible spring force of magnitude  $F$  on whatever it is attached to.
- $N$  side-by-side rubber bands exert  $N$  times the standard force:  $F_{\text{net}} = NF$



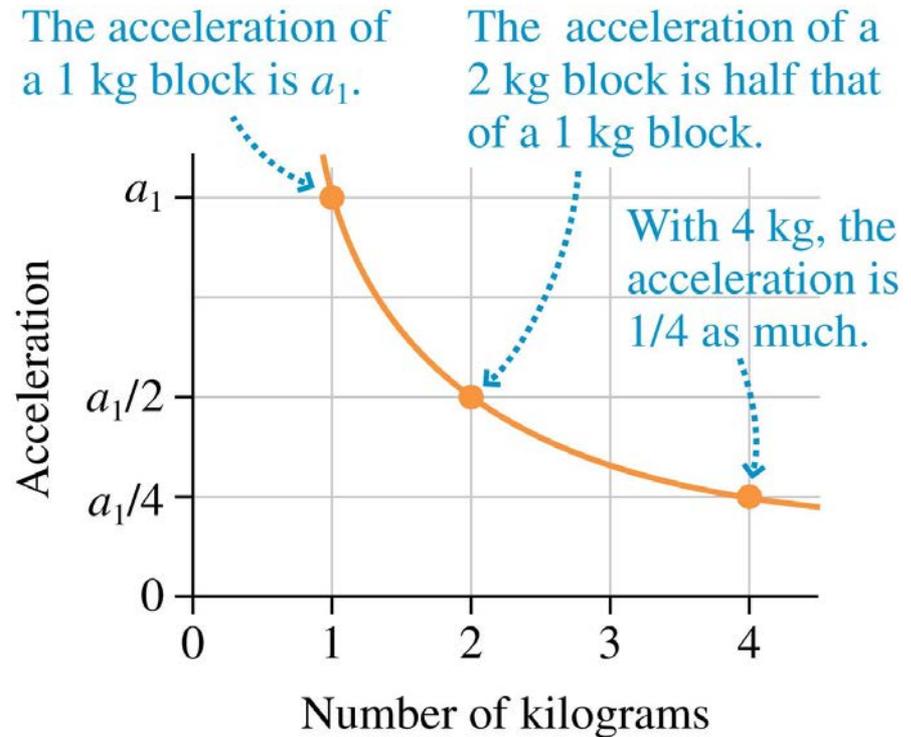
# What Do Forces Do? A Virtual Experiment

- When a 1 kg block is pulled on a frictionless surface by a single elastic band stretched to the standard length, it accelerates with *constant acceleration*  $a_1$ .
- Repeat the experiment with 2, 3, 4, and 5 rubber bands attached side-by-side.
- **The acceleration is directly proportional to the force.**



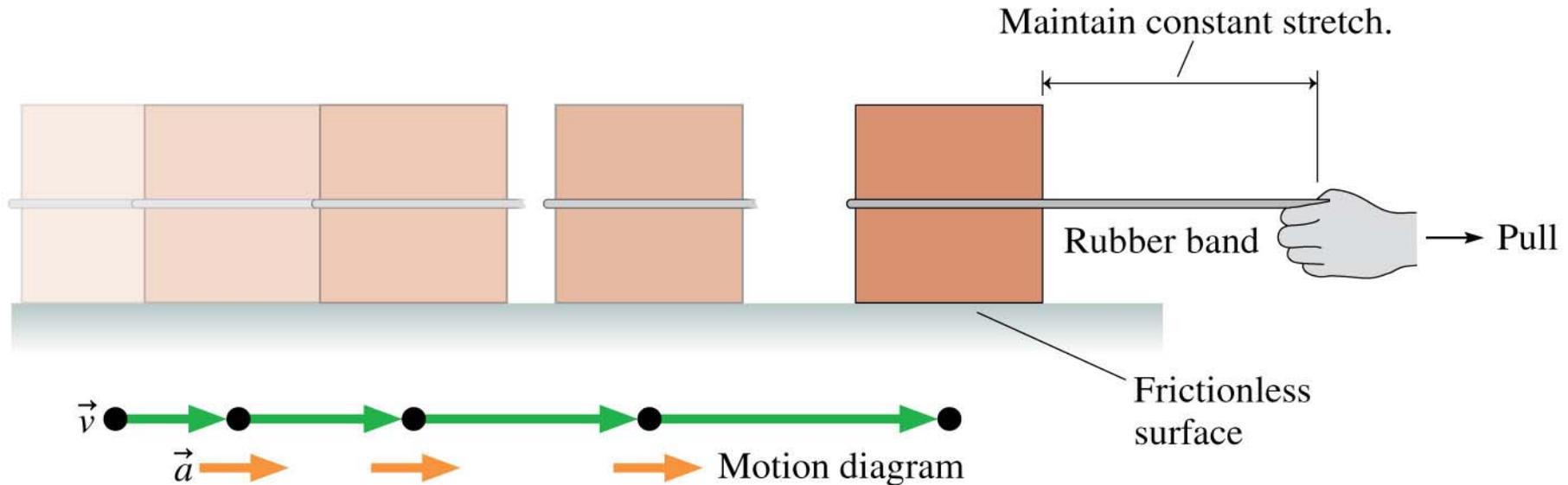
# What Do Forces Do? A Virtual Experiment

- When a 1 kg block is pulled on a frictionless surface by a single elastic band stretched to the standard length, it accelerates with constant acceleration  $a_1$ .
- Repeat the experiment with a 2 kg, 3 kg and 4 kg block.
- **The acceleration is inversely proportional to the mass.**



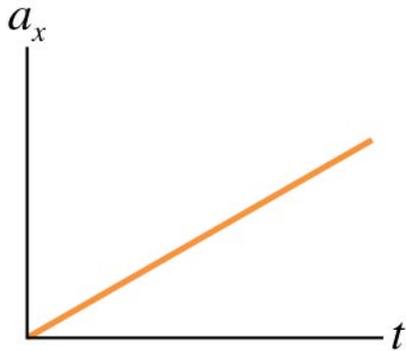
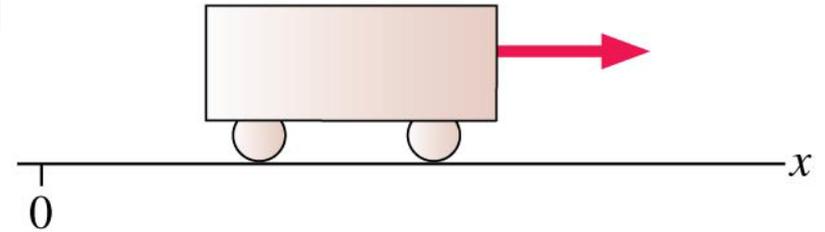
# What Do Forces Do? A Virtual Experiment

- Force causes an object to *accelerate!*
- The result of the experiment is  $a = \frac{F}{m}$
- The basic unit of force is the **newton** (N).
- $1 \text{ N} = 1 \text{ kg m/s}^2$

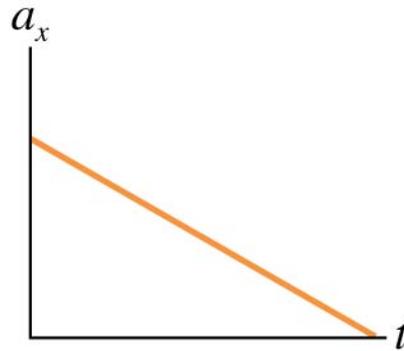


# QuickCheck 5.6

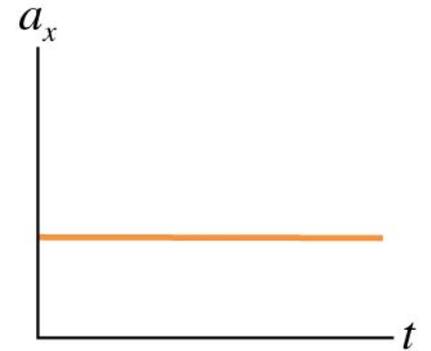
A cart is pulled to the right with a constant, steady force. How will its acceleration graph look?



A.



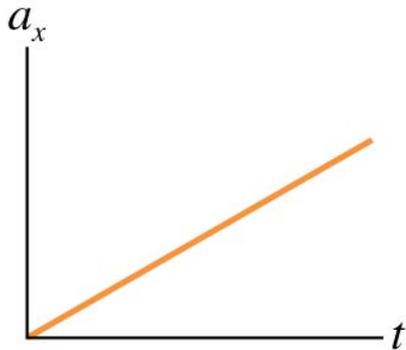
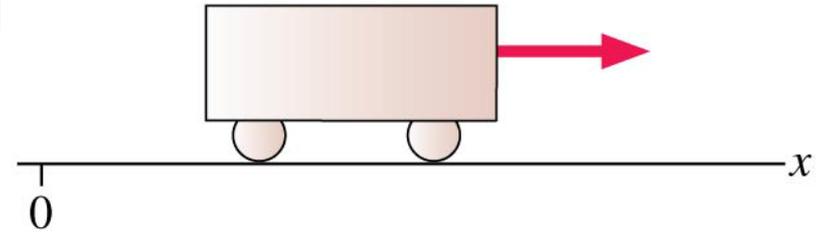
B.



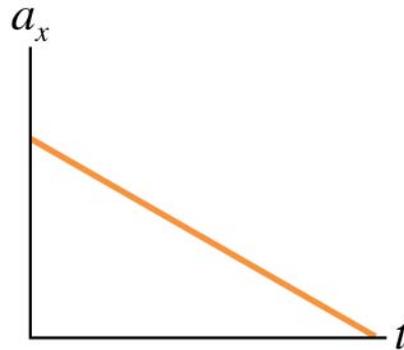
C.

# QuickCheck 5.6

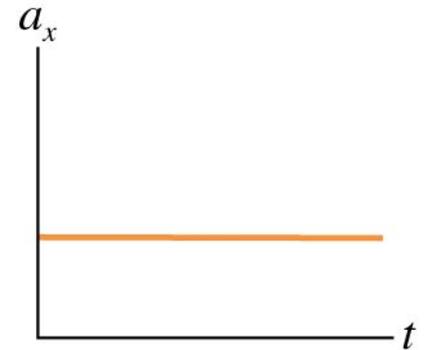
A cart is pulled to the right with a constant, steady force. How will its acceleration graph look?



A.



B.



C.

**A constant force produces a constant acceleration.**

# Approximate Magnitude of Some Typical Forces

**TABLE 5.1** Approximate magnitude of some typical forces

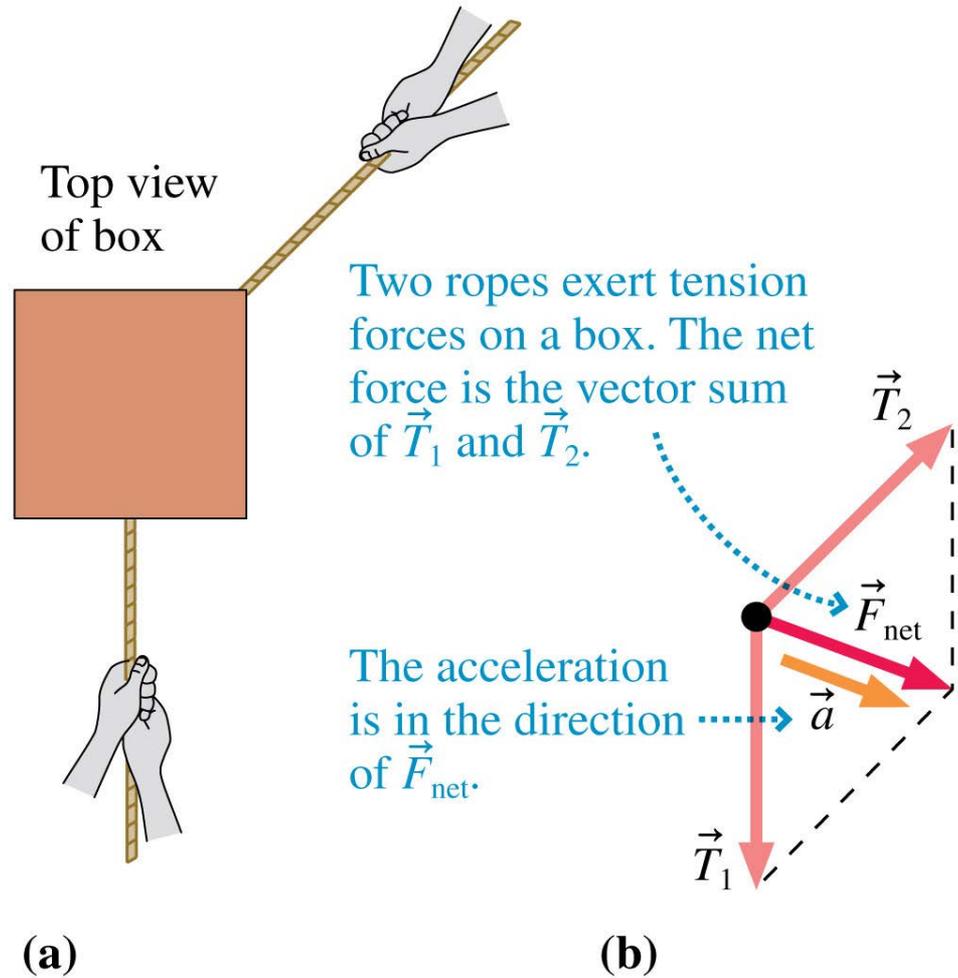
<b>Force</b>	<b>Approximate magnitude (newtons)</b>
Weight of a U.S. quarter	0.05
Weight of 1/4 cup sugar	0.5
Weight of a 1 pound object	5
Weight of a house cat	50
Weight of a 110 pound person	500
Propulsion force of a car	5,000
Thrust force of a small jet engine	50,000

# Inertial Mass

- An object with twice the amount of matter accelerates only half as much in response to the same force.
- The more matter an object has, the more it *resists* accelerating in response to the same force.
- The tendency of an object to resist a *change* in its velocity is called **inertia**.
- The mass used in  $a = F/m$  is called **inertial mass**.

# Newton's Second Law

- When more than one force is acting on an object, the object accelerates in the direction of the net force vector  $\vec{F}_{\text{net}}$ .



# Newton's Second Law

**Newton's second law** An object of mass  $m$  subjected to forces  $\vec{F}_1, \vec{F}_2, \vec{F}_3, \dots$  will undergo an acceleration  $\vec{a}$  given by

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

where the net force  $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots$  is the vector sum of all forces acting on the object. The acceleration vector  $\vec{a}$  points in the same direction as the net force vector  $\vec{F}_{\text{net}}$ .

# Newton's Zeroth Law

- An object responds only to the forces acting on it *at this instant*.
- The object has no memory of forces that may have been exerted at earlier times.
- This idea is sometimes called **Newton's zeroth law**.

## QuickCheck 5.7

A constant force causes an object to accelerate at  $4 \text{ m/s}^2$ . What is the acceleration of an object with twice the mass that experiences the same force?

- A.  $1 \text{ m/s}^2$
- B.  $2 \text{ m/s}^2$
- C.  $4 \text{ m/s}^2$
- D.  $8 \text{ m/s}^2$
- E.  $16 \text{ m/s}^2$

## QuickCheck 5.7

A constant force causes an object to accelerate at  $4 \text{ m/s}^2$ . What is the acceleration of an object with twice the mass that experiences the same force?

A.  $1 \text{ m/s}^2$

 B.  $2 \text{ m/s}^2$

C.  $4 \text{ m/s}^2$

D.  $8 \text{ m/s}^2$

E.  $16 \text{ m/s}^2$

$$a = \frac{F}{m}$$

# Newton's First Law

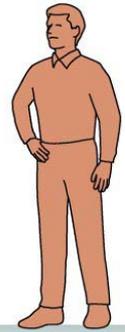
**Newton's first law** An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

- Newton's first law is also known as the *law of inertia*.
- If an object is at rest, it has a tendency to stay at rest.
- If it is moving, it has a tendency to continue moving with the *same velocity*.

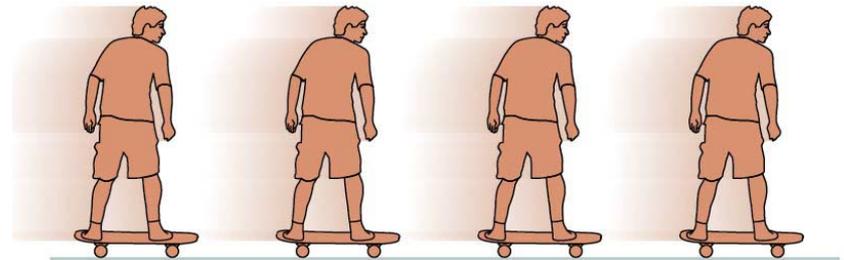
# Newton's First Law

- An object on which the net force is zero—and thus is either at rest or moving in a straight line with constant velocity—is said to be in mechanical equilibrium.
- As the figure shows, objects in mechanical equilibrium have no acceleration.

An object at rest is in equilibrium:  $\vec{F}_{\text{net}} = \vec{0}$ .



$$\vec{v} = \vec{0} \quad \bullet$$
$$\vec{a} = \vec{0}$$

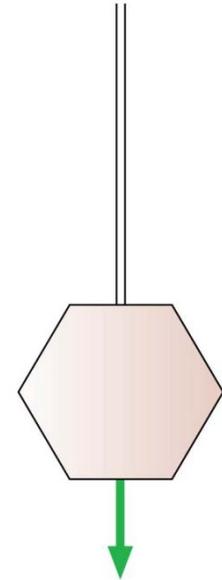


$$\vec{v} \quad \bullet \quad \bullet \quad \bullet \quad \bullet$$
$$\vec{a} = \vec{0}$$

An object moving in a straight line at constant velocity is also in equilibrium:  $\vec{F}_{\text{net}} = \vec{0}$ .

# QuickCheck 5.8

An object on a rope is lowered at constant speed.  
Which is true?

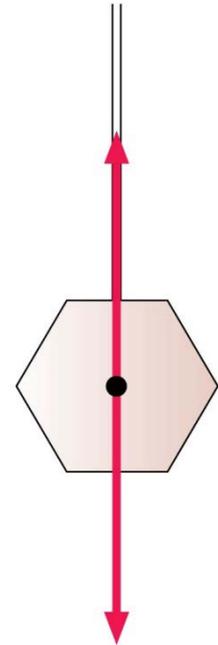


- A. The rope tension is greater than the object's weight.
- B. The rope tension equals the object's weight.
- C. The rope tension is less than the object's weight.
- D. The rope tension can't be compared to the object's weight.

# QuickCheck 5.8

An object on a rope is lowered at constant speed.  
Which is true?

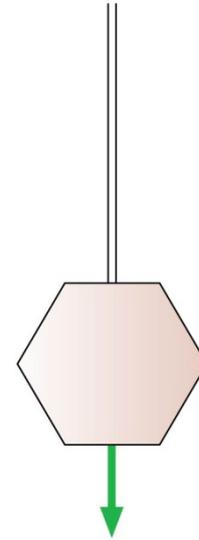
Constant velocity  
Zero acceleration  
 $\vec{F}_{\text{net}} = \vec{0}$



- A. The rope tension is greater than the object's weight.
- ✓ **B. The rope tension equals the object's weight.**
- C. The rope tension is less than the object's weight.
- D. The rope tension can't be compared to the object's weight.

# QuickCheck 5.9

An object on a rope is lowered at a steadily decreasing speed. Which is true?

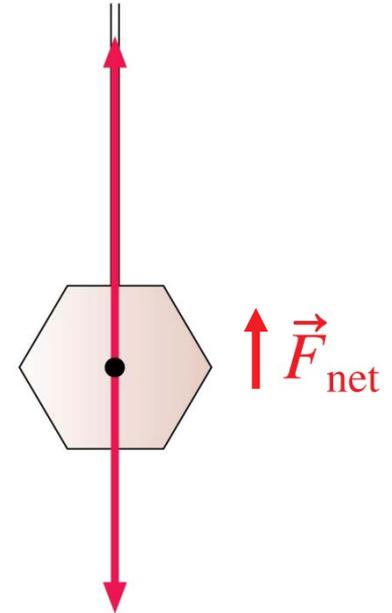


- A. The rope tension is greater than the object's weight.
- B. The rope tension equals the object's weight.
- C. The rope tension is less than the object's weight.
- D. The rope tension can't be compared to the object's weight.

# QuickCheck 5.9

An object on a rope is lowered at a steadily decreasing speed. Which is true?

Decreasing downward velocity  
Acceleration vector points up  
 $\vec{F}_{\text{net}}$  points up



- ✓ **A. The rope tension is greater than the object's weight.**
- B. The rope tension equals the object's weight.
- C. The rope tension is less than the object's weight.
- D. The rope tension can't be compared to the object's weight.

# Inertial Reference Frames

- If a car stops suddenly, you may be “thrown” forward.
- You do have a forward acceleration *relative to the car*.
- However, there is no force pushing you forward.

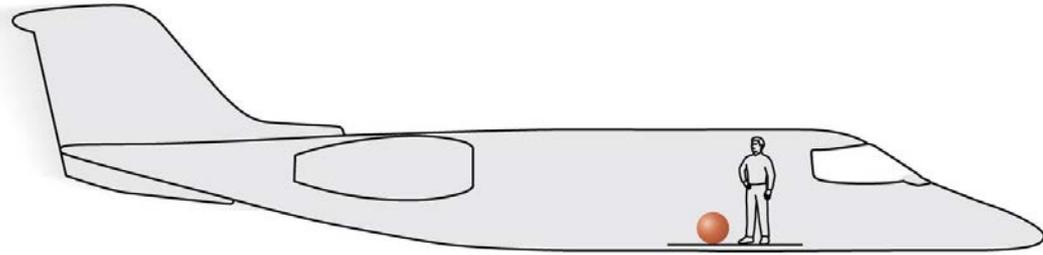


This guy thinks there's a force hurling him into the windshield. What a dummy!

- We define an **inertial reference frame** as one in which Newton's laws are valid.
- The interior of a crashing car is *not* an inertial reference frame!

# Inertial Reference Frames

- A physics student cruises at a constant velocity in an airplane.
- A ball placed on the floor stays at rest relative to the airplane.

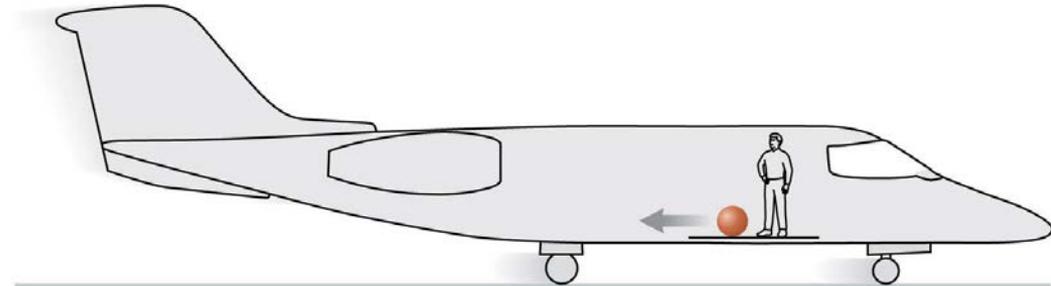


The ball stays in place; the airplane is an inertial reference frame.

- There are no horizontal forces on the ball, so  $\vec{a} = 0$  when  $\vec{F}_{\text{net}} = 0$ .
- Newton's first law is satisfied, so this airplane is an inertial reference frame.

# Inertial Reference Frames

- A physics student is standing up in an airplane during takeoff.
- A ball placed on the floor rolls toward the back of the plane.



The ball accelerates toward the back even though there are no horizontal forces; the airplane is *not* an inertial reference frame.

- There are no horizontal forces on the ball, and yet the ball accelerates *in the plane's reference frame*.
- Newton's first law is violated, therefore this airplane is *not* an inertial reference frame.
- In general, **accelerating reference frames are not inertial reference frames.**

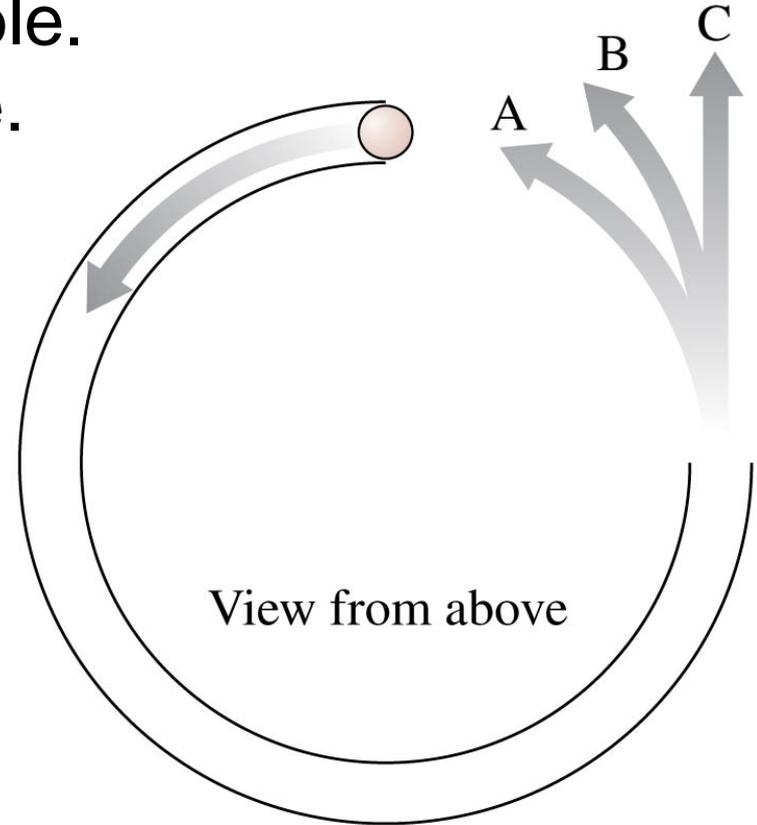
# Thinking About Force

- Every force has an agent which causes the force.
- Forces exist at the point of contact between the agent and the object (except for the few special cases of long-range forces).
- Forces exist due to interactions happening *now*, not due to what happened in the past.
- Consider a flying arrow.
- A pushing force was required to accelerate the *arrow as it was shot*.
- However, *no force* is needed to keep the arrow moving forward as it flies.
- It continues to move because of inertia.



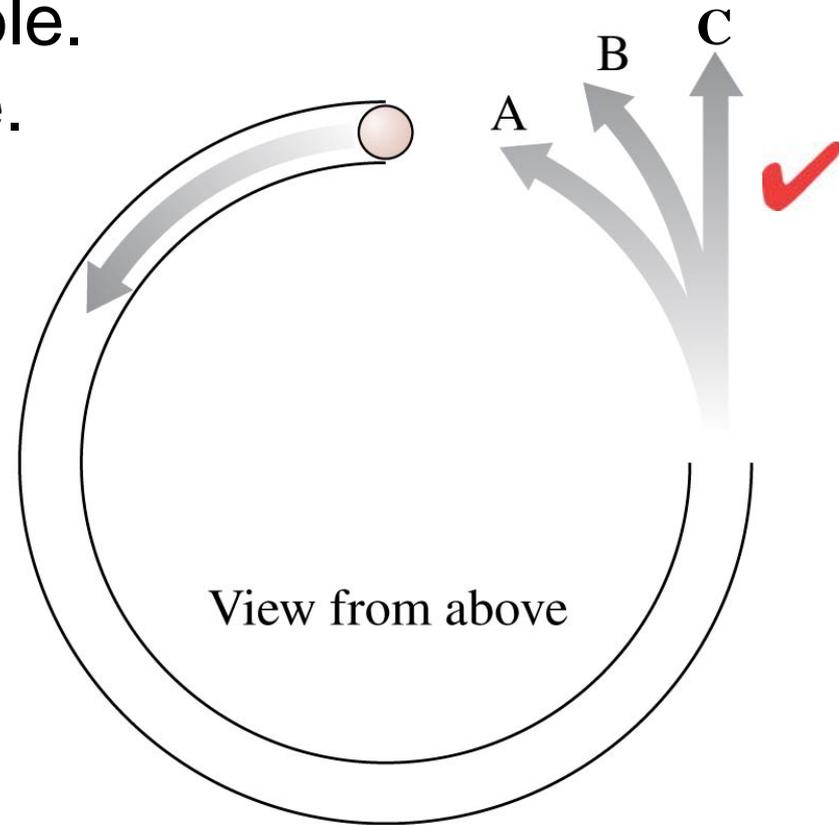
# QuickCheck 5.10

A hollow tube lies flat on a table.  
A ball is shot through the tube.  
As the ball emerges from the other end, which path  
does it follow?



# QuickCheck 5.10

A hollow tube lies flat on a table.  
A ball is shot through the tube.  
As the ball emerges from the other end, which path  
does it follow?



# Tactics: Drawing a Free-body Diagram

## TACTICS BOX 5.3

MP

### Drawing a free-body diagram

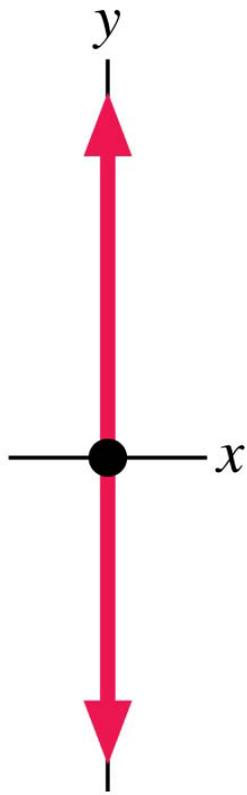
- 1 **Identify all forces acting on the object.** This step was described in Tactics Box 5.2.
- 2 **Draw a coordinate system.** Use the axes defined in your pictorial representation.
- 3 **Represent the object as a dot at the origin of the coordinate axes.** This is the particle model.
- 4 **Draw vectors representing each of the identified forces.** This was described in Tactics Box 5.1. Be sure to label each force vector.
- 5 **Draw and label the *net force* vector  $\vec{F}_{\text{net}}$ .** Draw this vector beside the diagram, not on the particle. Or, if appropriate, write  $\vec{F}_{\text{net}} = \vec{0}$ . Then check that  $\vec{F}_{\text{net}}$  points in the same direction as the acceleration vector  $\vec{a}$  on your motion diagram.

Exercises 24–29

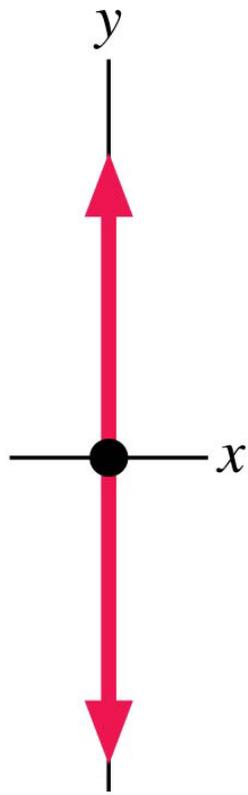


# QuickCheck 5.11

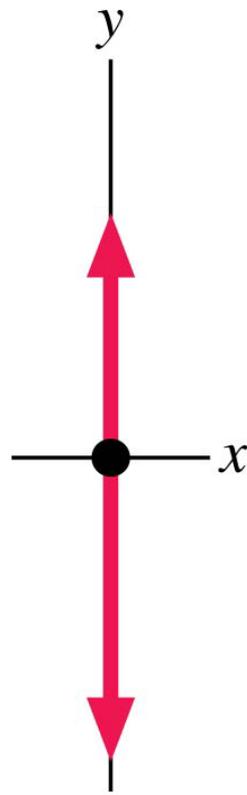
An elevator, lifted by a cable, is moving upward and slowing. Which is the correct free-body diagram?



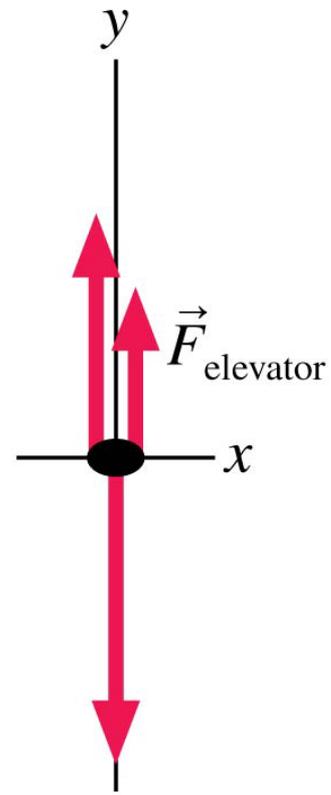
A.



B.



C.



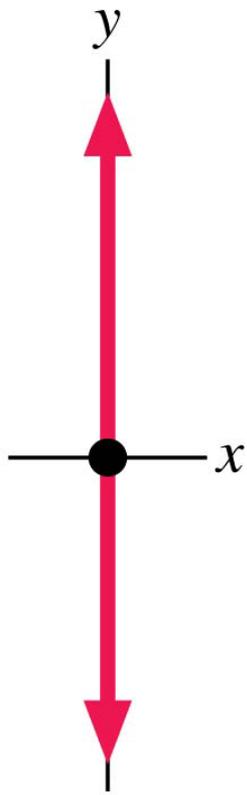
D.

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

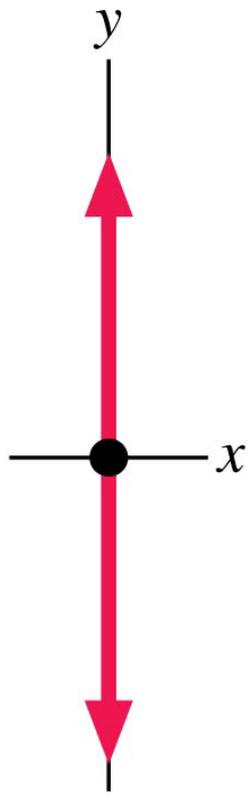
E.

# QuickCheck 5.11

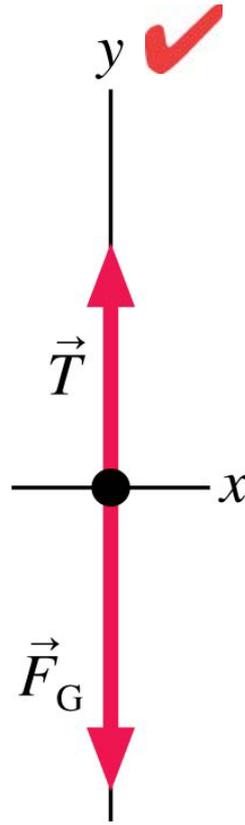
An elevator, lifted by a cable, is moving upward and slowing. Which is the correct free-body diagram?



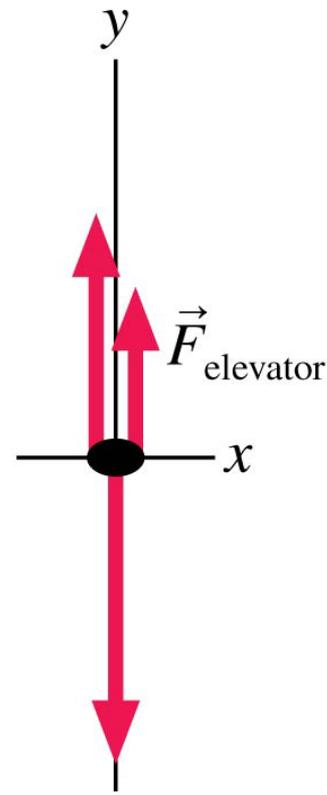
A.



B.



C.



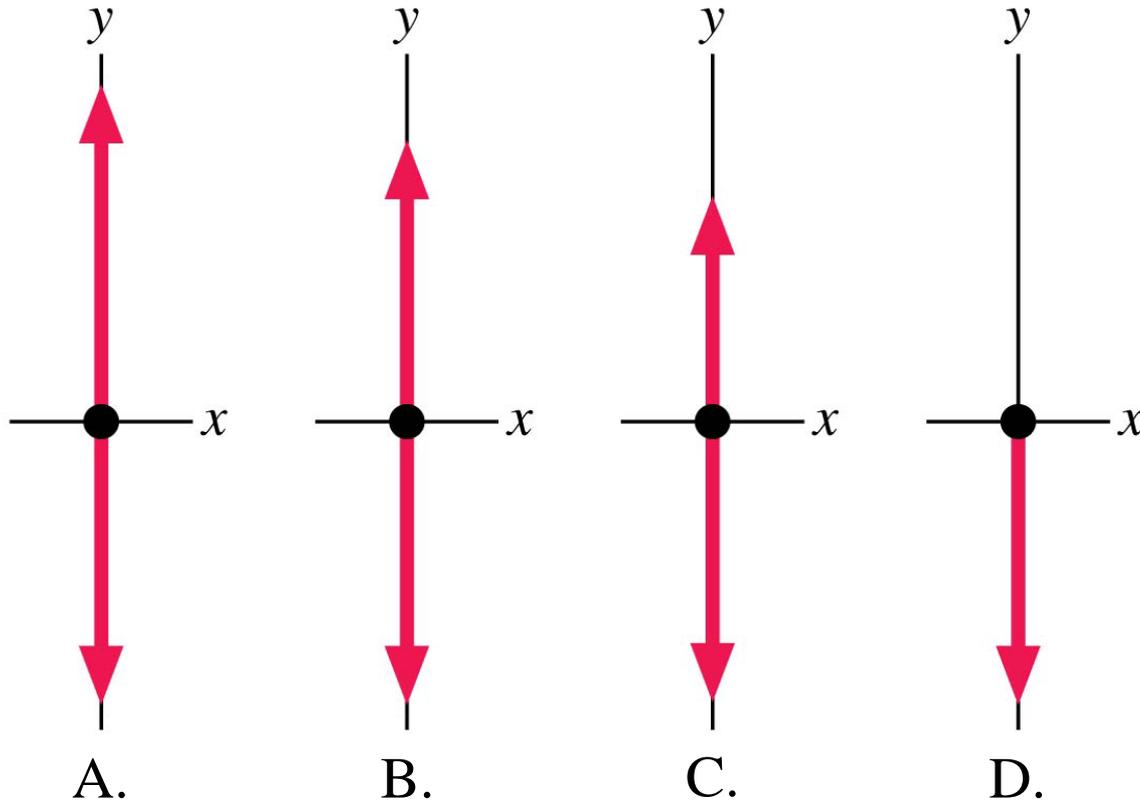
D.

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

E.

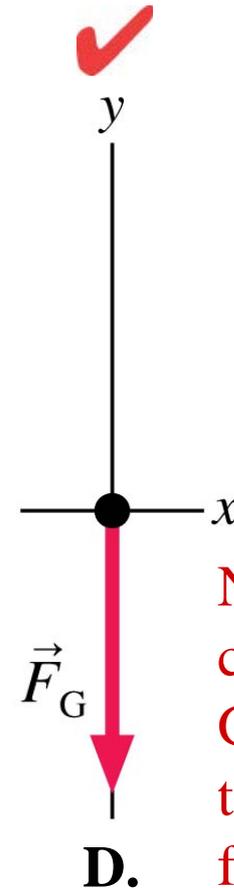
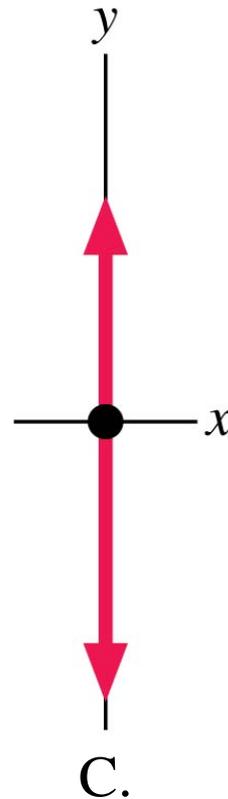
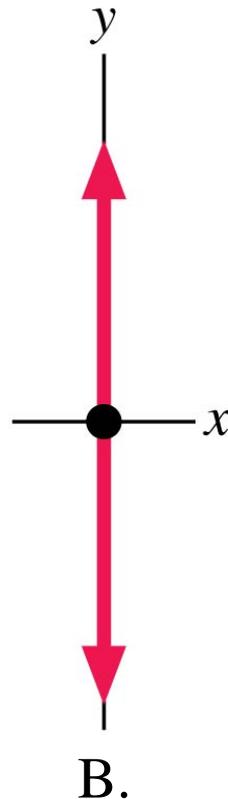
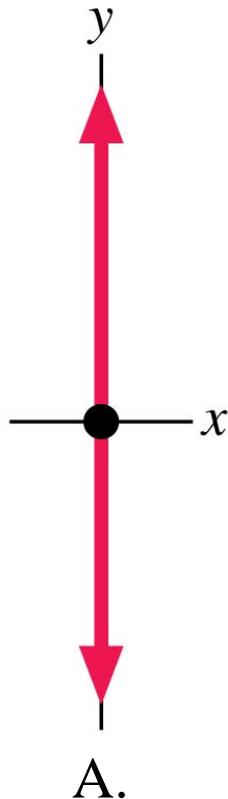
# QuickCheck 5.12

A ball has been tossed straight up. Which is the correct free-body diagram just after the ball has left the hand? Ignore air resistance.



# QuickCheck 5.12

A ball has been tossed straight up. Which is the correct free-body diagram just after the ball has left the hand? Ignore air resistance.



No points of contact.  
Gravity is the only force.

# EXAMPLE 5.4 An Elevator Accelerates Upward

## **EXAMPLE 5.4** | An elevator accelerates upward

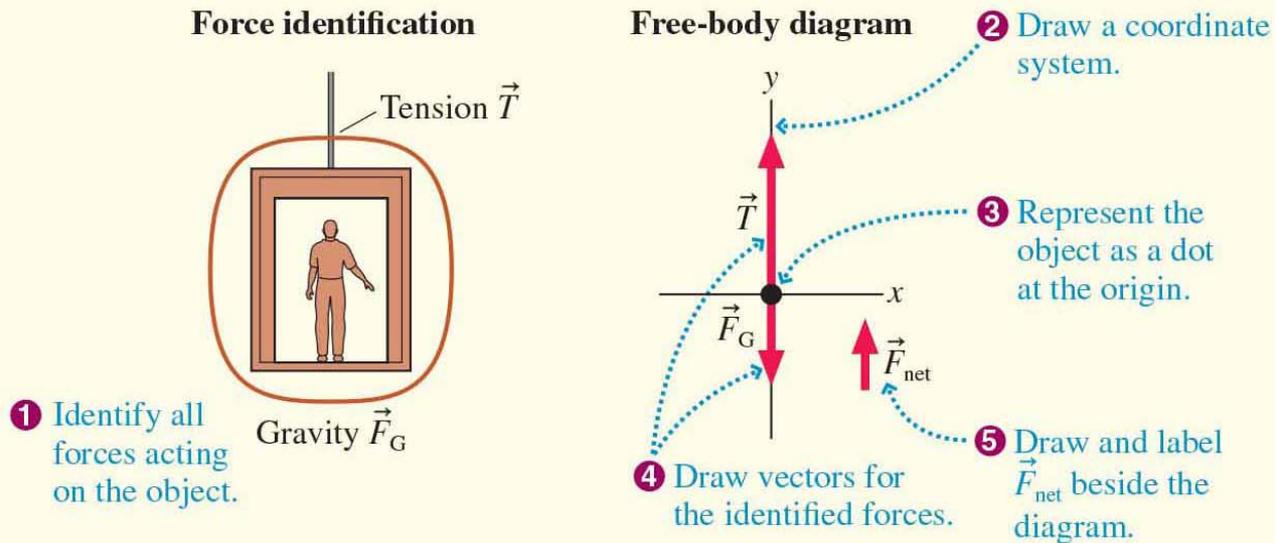
An elevator, suspended by a cable, speeds up as it moves upward from the ground floor. Identify the forces and draw a free-body diagram of the elevator.

**MODEL** Model the elevator as a particle.

# EXAMPLE 5.4 An Elevator Accelerates Upward

## EXAMPLE 5.4 | An elevator accelerates upward

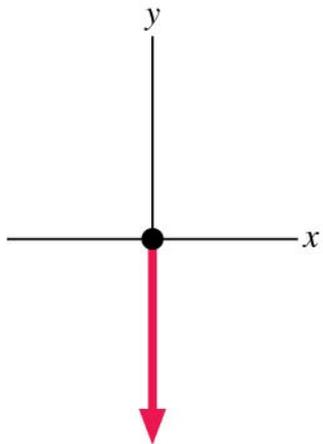
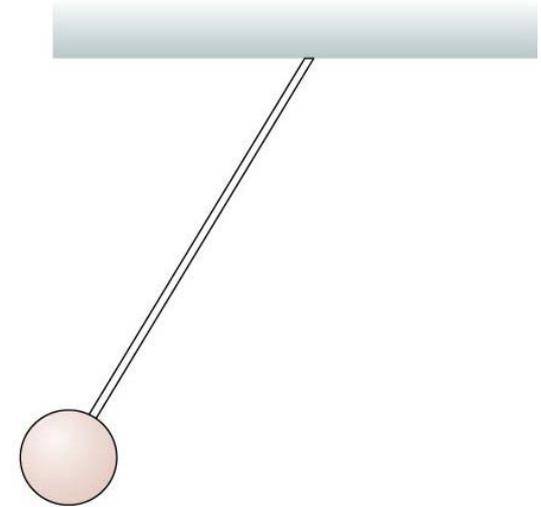
### VISUALIZE



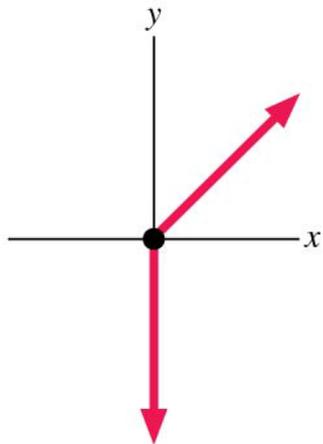
**ASSESS** The coordinate axes, with a vertical  $y$ -axis, are the ones we would use in a pictorial representation of the motion. The elevator is accelerating upward, so  $\vec{F}_{\text{net}}$  must point upward. For this to be true, the magnitude of  $\vec{T}$  must be larger than the magnitude of  $\vec{F}_G$ . The diagram has been drawn accordingly.

# QuickCheck 5.13

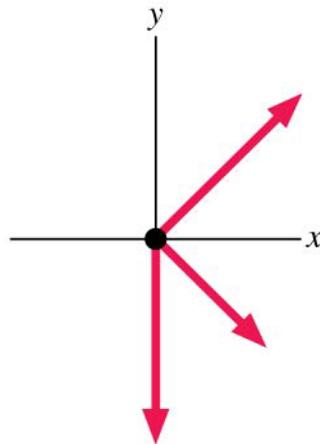
A ball, hanging from the ceiling by a string, is pulled back and released. Which is the correct free-body diagram just after its release?



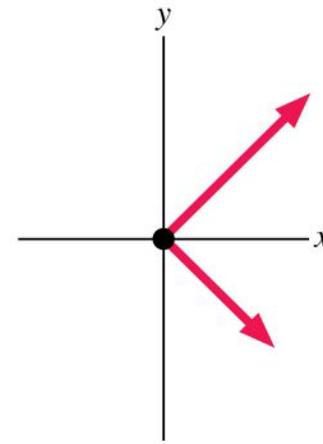
A.



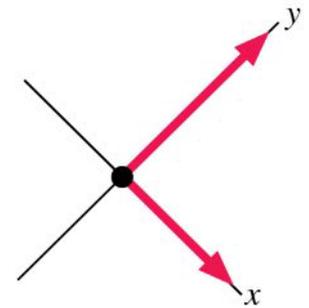
B.



C.



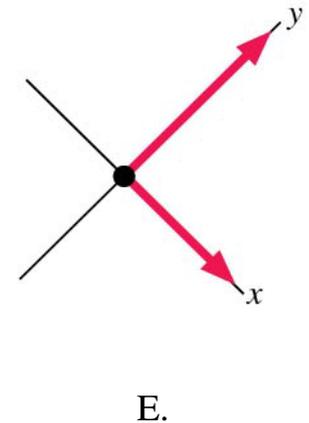
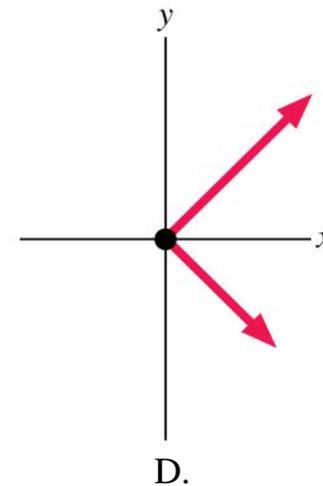
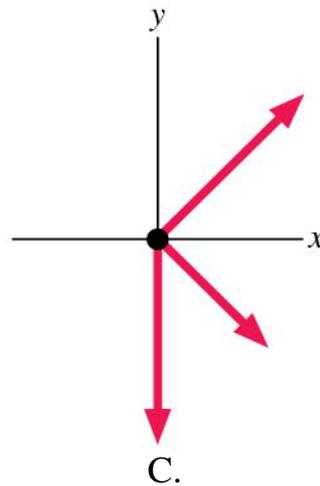
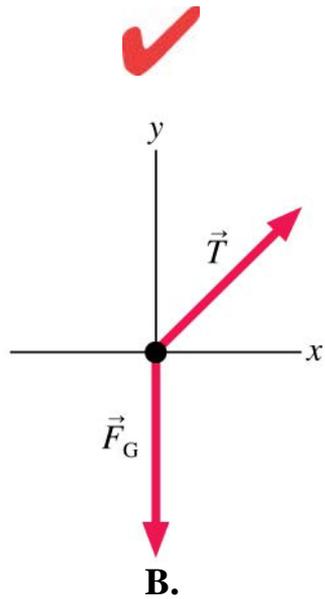
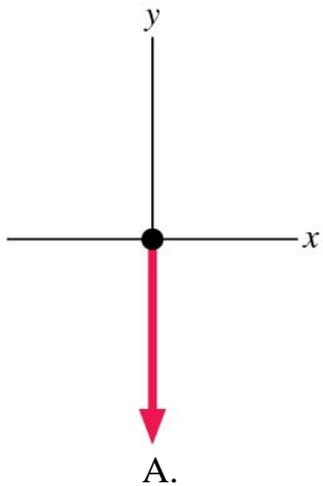
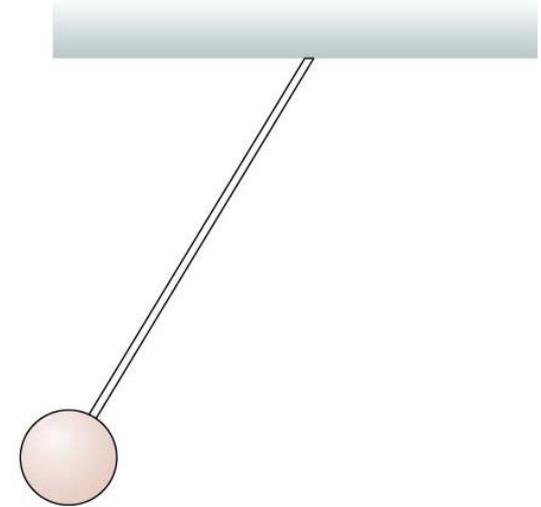
D.



E.

# QuickCheck 5.13

A ball, hanging from the ceiling by a string, is pulled back and released. Which is the correct free-body diagram just after its release?



# EXAMPLE 5.6 A Skier Is Pulled up a Hill

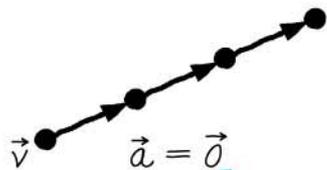
## EXAMPLE 5.6 A skier is pulled up a hill

A tow rope pulls a skier up a snow-covered hill at a constant speed. Draw a pictorial representation of the skier.

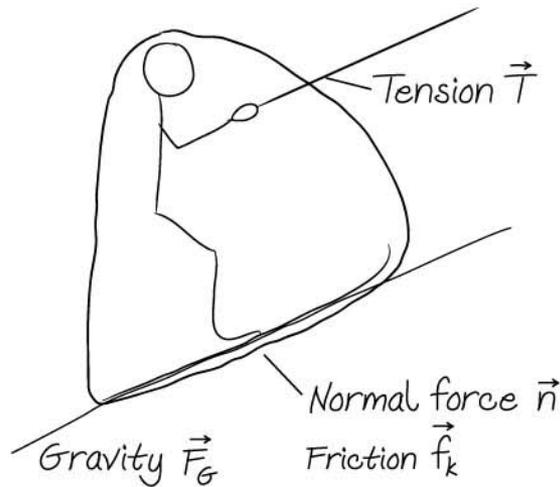
**MODEL** This is Example 5.2 again with the additional information that the skier is moving at constant speed. The skier will be

modeled as a particle in *mechanical equilibrium*. If we were doing a kinematics problem, the pictorial representation would use a tilted coordinate system with the  $x$ -axis parallel to the slope, so we use these same tilted coordinate axes for the free-body diagram.

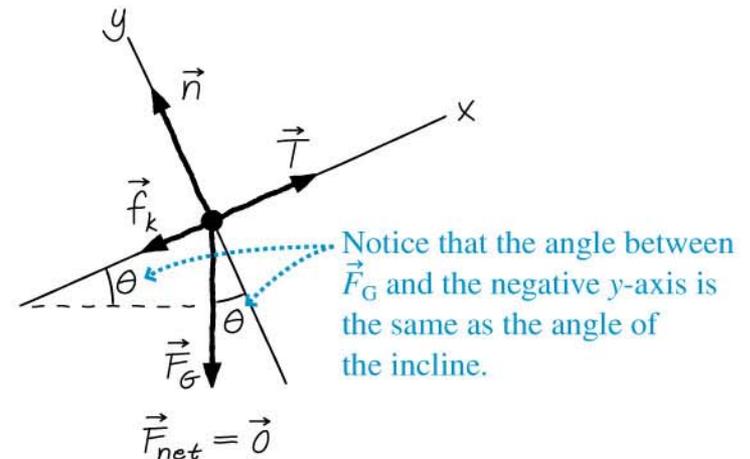
Motion diagram



Force identification



Free-body diagram



Check that  $\vec{F}_{net}$  points in the same direction as  $\vec{a}$ .

# EXAMPLE 5.6 A Skier Is Pulled up a Hill

## EXAMPLE 5.6 | A skier is pulled up a hill

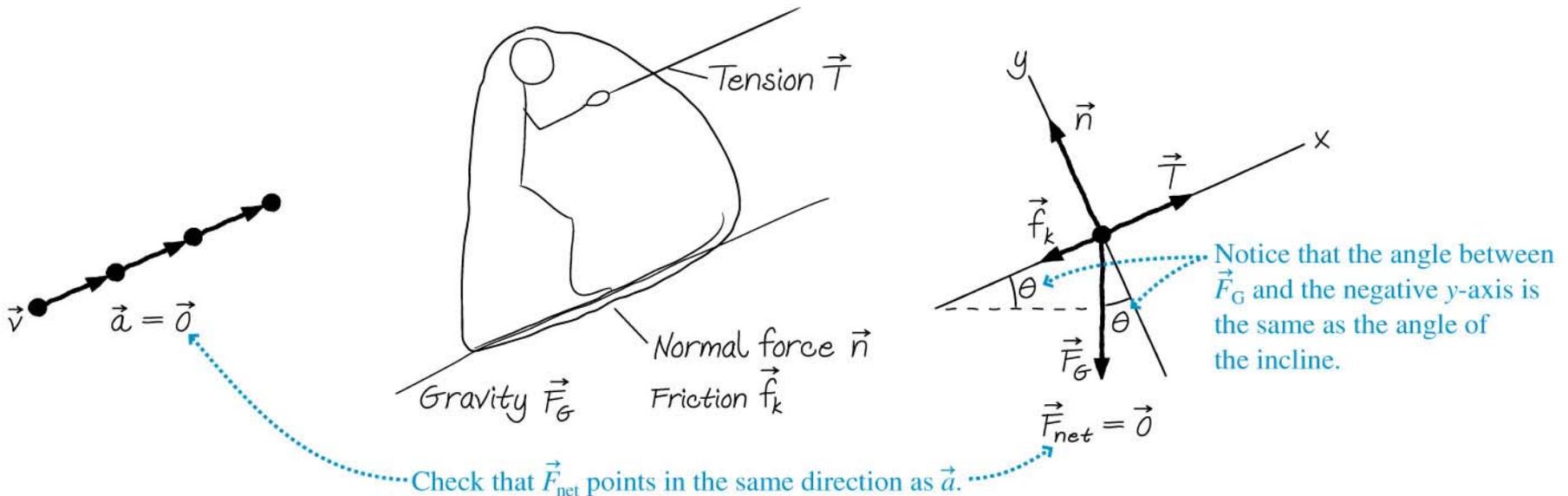
**ASSESS** We have shown  $\vec{T}$  pulling parallel to the slope and  $\vec{f}_k$ , which opposes the direction of motion, pointing down the slope.  $\vec{n}$  is perpendicular to the surface and thus along the y-axis. Finally, and this is important, the gravitational force  $\vec{F}_G$  is vertically downward, *not* along the negative y-axis. In fact, you should convince yourself from the geometry that the angle  $\theta$  between the  $\vec{F}_G$  vector

and the negative y-axis is the same as the angle  $\theta$  of the incline above the horizontal. The skier moves in a straight line with constant speed, so  $\vec{a} = \vec{0}$  and, from Newton's first law,  $\vec{F}_{\text{net}} = \vec{0}$ . Thus we have drawn the vectors such that the y-component of  $\vec{F}_G$  is equal in magnitude to  $\vec{n}$ . Similarly,  $\vec{T}$  must be large enough to match the negative x-components of both  $\vec{f}_k$  and  $\vec{F}_G$ .

**Motion diagram**

**Force identification**

**Free-body diagram**

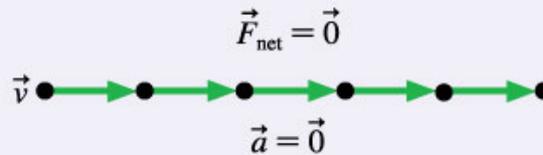


# Chapter 5 Summary Slides

# General Principles

## Newton's First Law

An object at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force on the object is zero.



The first law tells us that no “cause” is needed for motion. Uniform motion is the “natural state” of an object.

# General Principles

## **Newton's Zeroth Law**

An object responds only to forces acting on it *at this instant*.

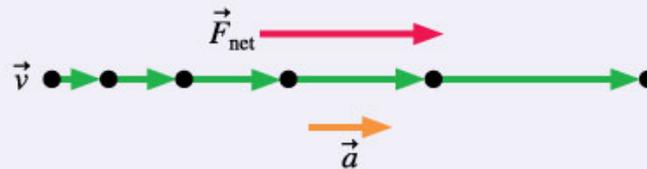
# General Principles

## Newton's Second Law

An object with mass  $m$  has acceleration

$$\vec{a} = \frac{1}{m} \vec{F}_{\text{net}}$$

where  $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots$  is the vector sum of all the individual forces acting on the object.



The second law tells us that a net force causes an object to accelerate. This is the connection between force and motion.

# Important Concepts

**Acceleration** is the link to kinematics.

From  $\vec{F}_{\text{net}}$ , find  $\vec{a}$ .

From  $a$ , find  $v$  and  $x$ .

$\vec{a} = \vec{0}$  is the condition for **equilibrium**.

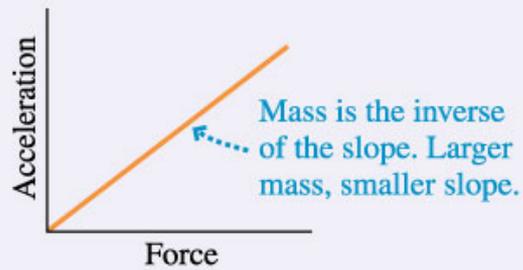
An object **at rest** is in equilibrium.

So is an object with **constant velocity**.

Equilibrium occurs if and only if  $\vec{F}_{\text{net}} = \vec{0}$ .

# Important Concepts

**Mass** is the resistance of an object to acceleration. It is an intrinsic property of an object.



# Important Concepts

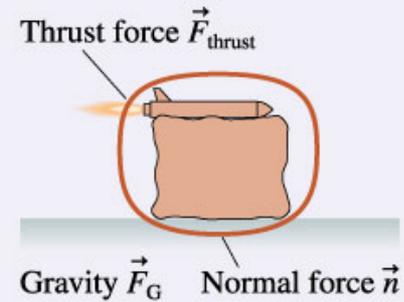
**Force** is a push or a pull on an object.

- Force is a vector, with a magnitude and a direction.
- Force requires an agent.
- Force is either a contact force or a long-range force.

# Key Skills

## Identifying Forces

Forces are identified by locating the points where other objects touch the object of interest. These are points where contact forces are exerted. In addition, objects with mass feel a long-range gravitational force.



# Key Skills

## Free-Body Diagrams

A free-body diagram represents the object as a particle at the origin of a coordinate system. Force vectors are drawn with their tails on the particle. The net force vector is drawn beside the diagram.

