Clerical

- Y'all did well on the Exam. If only I had known earlier that the key to do well was to ask the students to take the Exam at home!
- Done grading Bb exams, almost done with e-mailed exams.
- Assigned participation points for hosting and/or attending study sessions, I would say this was a successful activity.
- I have not assigned participation points for attending Blanca's review sessions, will do that in my meeting with Blanca after this lecture.
- Sent a Bb message to former students requesting bed of nails video, we'll see.

Column
Exam 1 (Assignment)

Points Possible
10

Description

STATISTICS

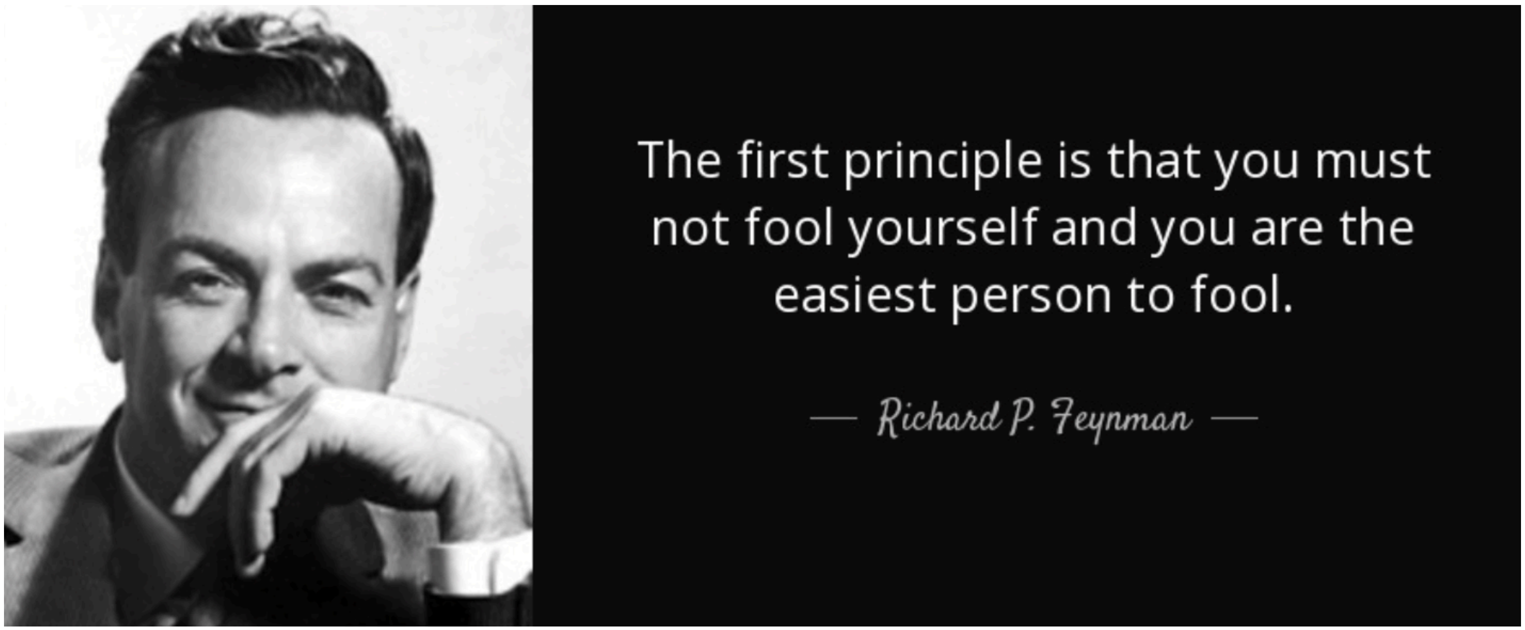
Count	76
Minimum Value	0.00
Maximum Value	10.00
Range	10.00
Average	7.80921
Median	8.50
Standard Deviation	2.24189
Variance	5.02609

STATUS DISTRIBUTION

Null	20
In Progress	0
Needs Grading	0
Exempt	0

GRADE DISTRIBUTION

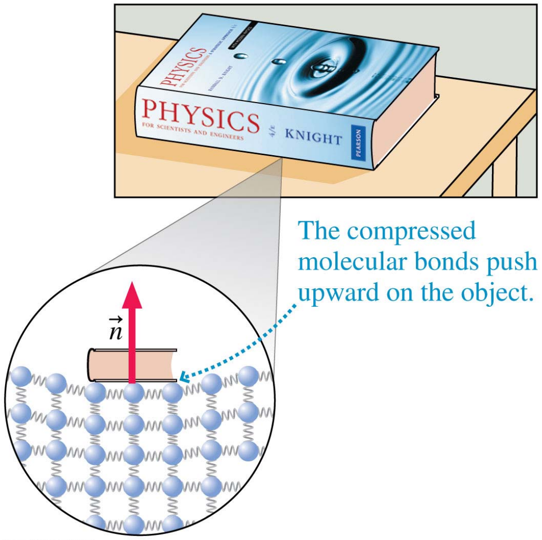
Greater than 100	0
90 - 100	36
80 - 89	15
70 - 79	8
60 - 69	7
50 - 59	3
40 - 49	2
30 - 39	1
20 - 29	1
10 - 19	1
0 - 9	2
Less than 0	0


The first principle is that you must not fool yourself and you are the easiest person to fool.
— Richard P. Feynman —

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.

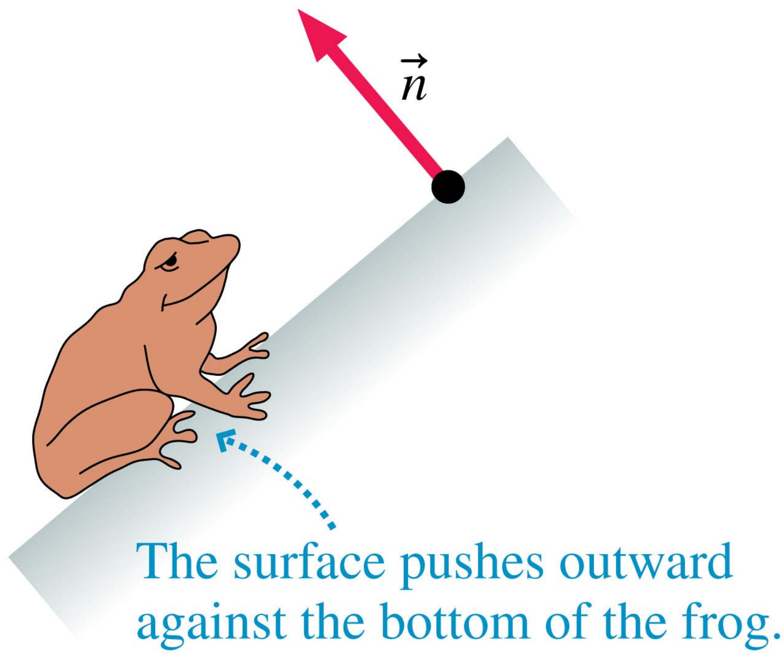
- When an object sits on a table, the table surface exerts an upward contact force on the object.
- This pushing force is directed *perpendicular* to the surface, and thus is called the **normal force**.



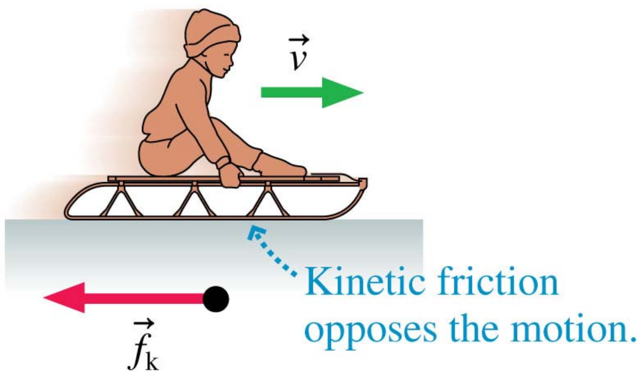
- A table is made of *atoms* joined together by *molecular bonds* which can be modeled as springs.
- Normal force is a result of many molecular springs being compressed ever so slightly.

- 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.



- 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.

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.

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.

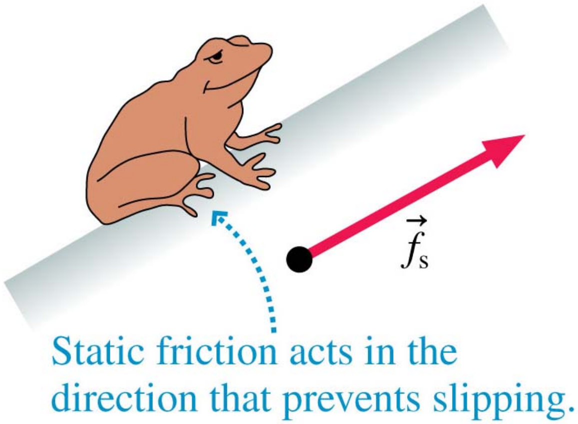
B. Gravity and a normal force.

C. Gravity and the force of the push.

✔ **D. Gravity, a normal force, and kinetic friction.**

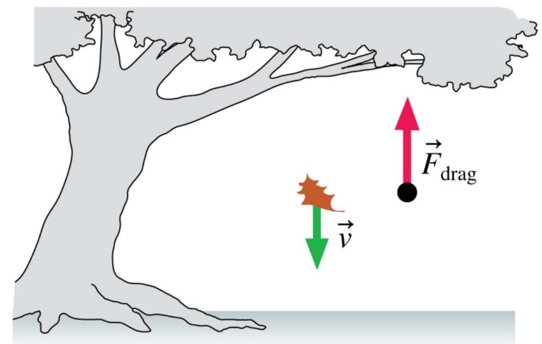
E. Gravity, a normal force, kinetic friction, and the force of the push.

- **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.



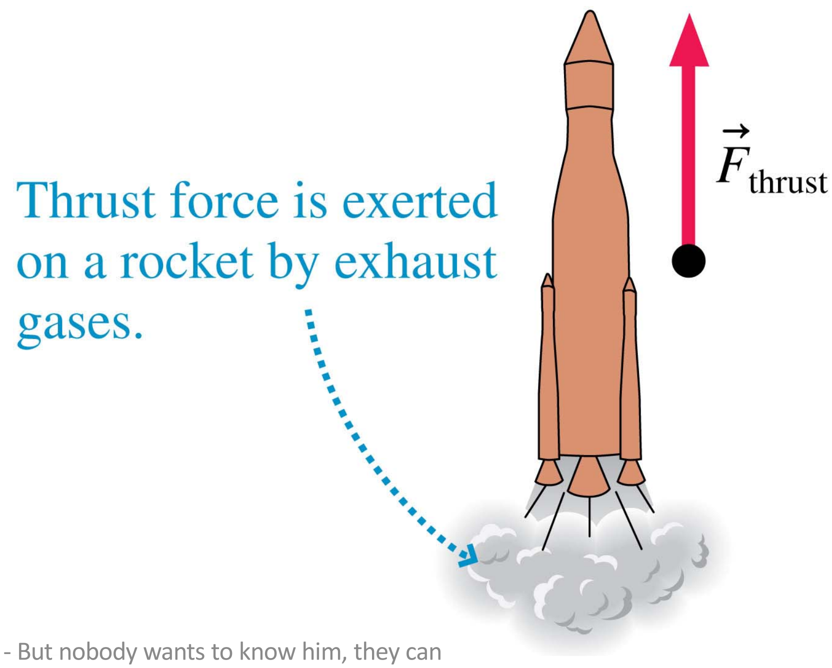
- Kinetic friction is a *resistive force*, which opposes or resists motion.
- Resistive forces are also experienced by objects moving through fluids.

Air resistance points opposite the direction of motion.



- 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**.

- 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.



- Electricity and magnetism, like gravity, exert long-range forces.
- Some of you will study electric and magnetic forces in detail in PHYS 2421.
- 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.

Force	Notation
General force	$\vec{F}$
Gravitational force	$\vec{F}_{\mathrm{G}}$
Spring force	$\vec{F}_{\mathrm{Sp}}$
Tension	$\vec{T}$
Normal force	$\vec{n}$
Static friction	$\vec{f}_{\mathrm{s}}$
Kinetic friction	$\vec{f}_{\mathrm{k}}$
Drag	$\vec{F}_{\mathrm{drag}}$
Thrust	$\vec{F}_{\mathrm{thrust}}$

TACTICS BOX 5.2

Identifying forces

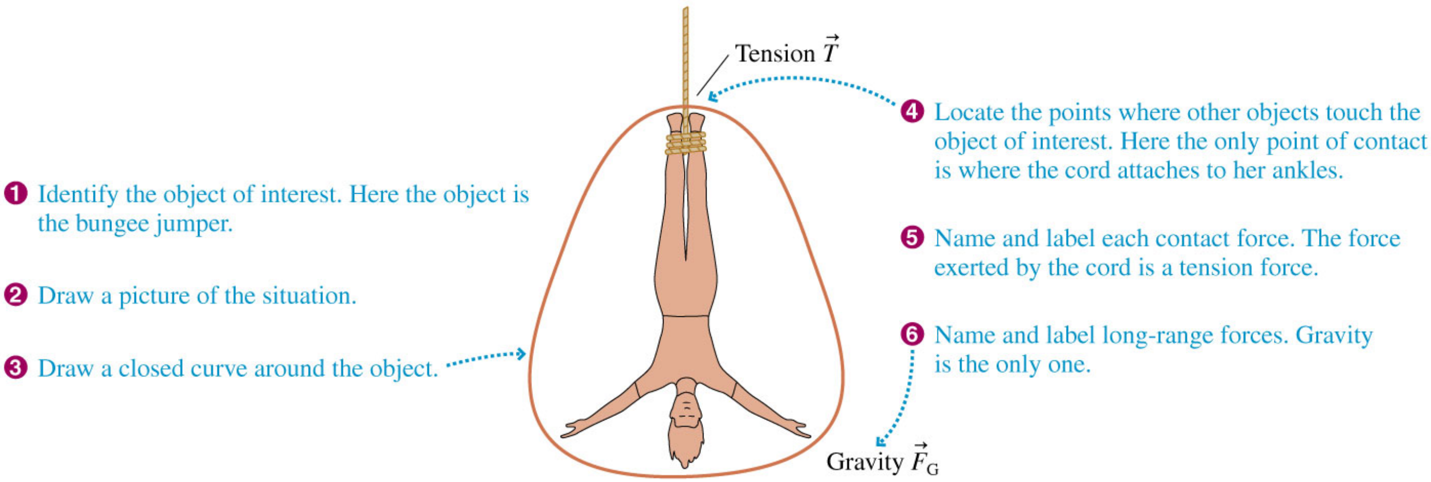
1. **Identify the object of interest.** This is the object you wish to study.
2. **Draw a picture of the situation.** Show the object of interest and all other objects—such as ropes, springs, or surfaces—that touch it.
3. **Draw a closed curve around the object.** Only the object of interest is inside 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**

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

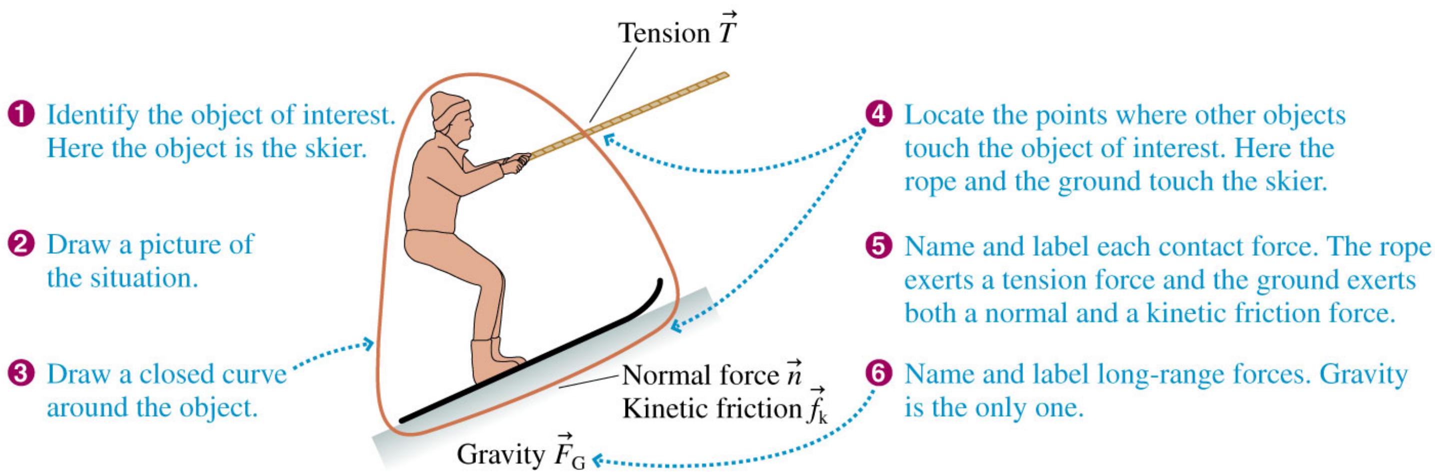
VISUALIZE



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?

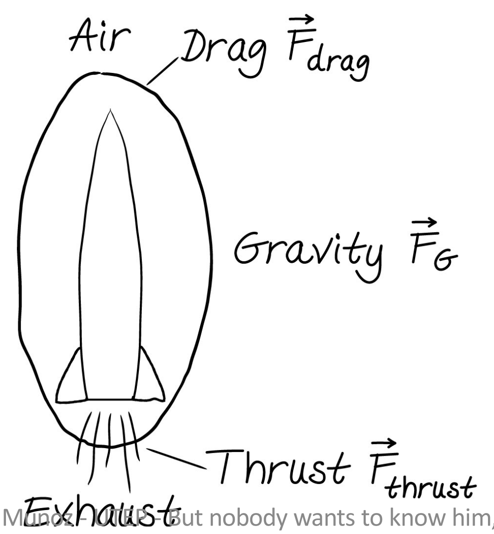
VISUALIZE



EXAMPLE 5.3 | **Forces on a rocket**

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?

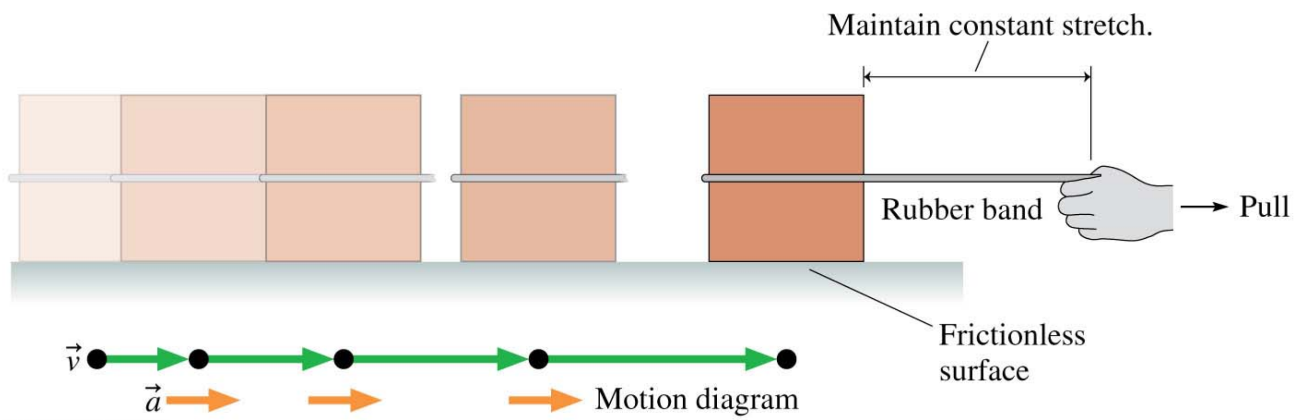
VISUALIZE This drawing is much more like the sketch you would make when identifying forces as part of solving a problem.



- Attach a stretched rubber band to a 1 kg block.
- Use the rubber band to pull the block across a horizontal, frictionless table.

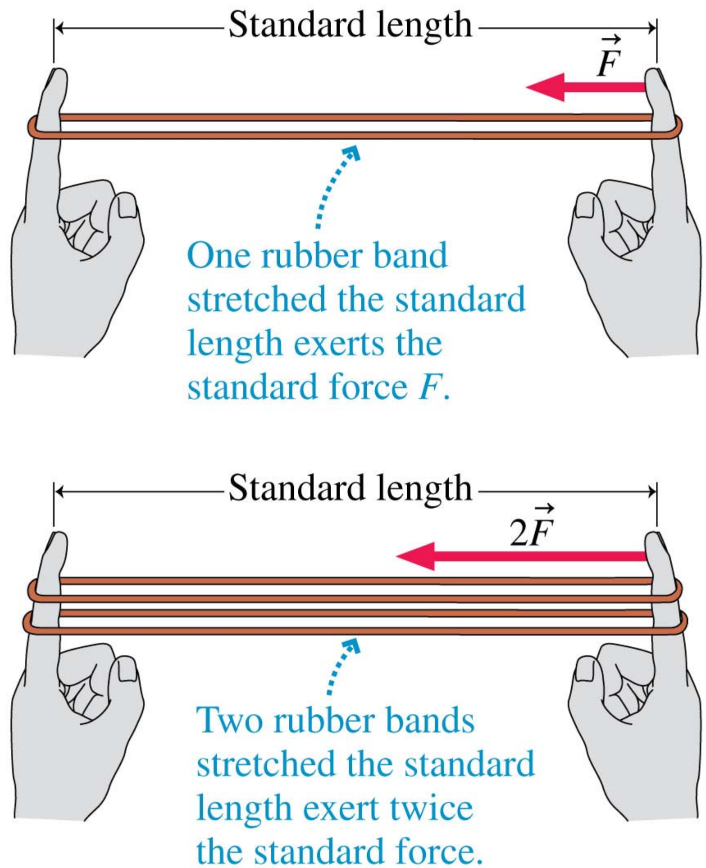
What if not fixed?

- Keep the rubber band stretched by a fixed amount.
- We find that the block moves with a **constant acceleration**.



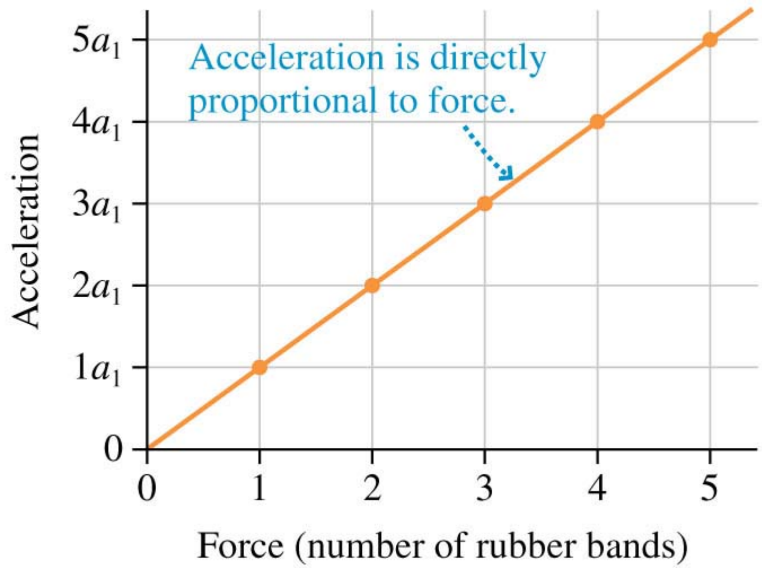
Our friend the motion diagram!

- 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: $F_{\text{net}} = NF$



Ball of rubber bands

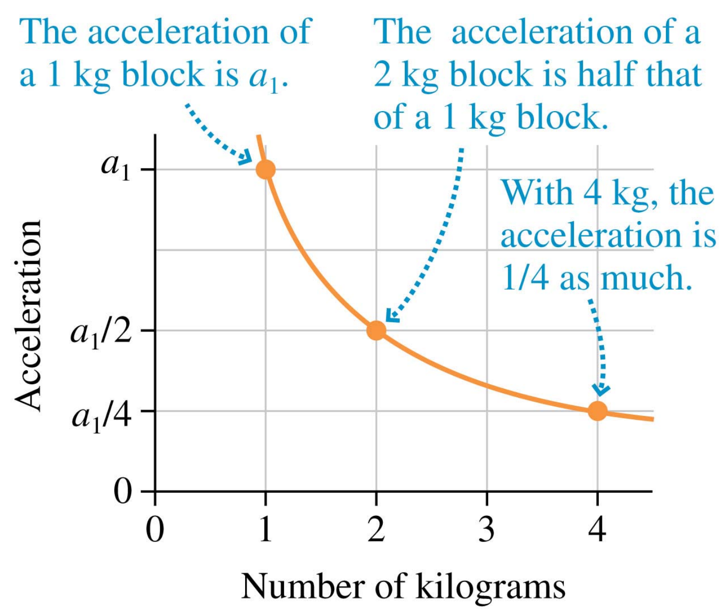
- When a 1 kg block is pulled on a frictionless surface by a single elastic band stretched to the standard length, it accelerates with *constant acceleration* a_1.
- Repeat the experiment with 2, 3, 4, and 5 rubber bands attached side-by-side.



- **The acceleration is directly proportional to the force.**

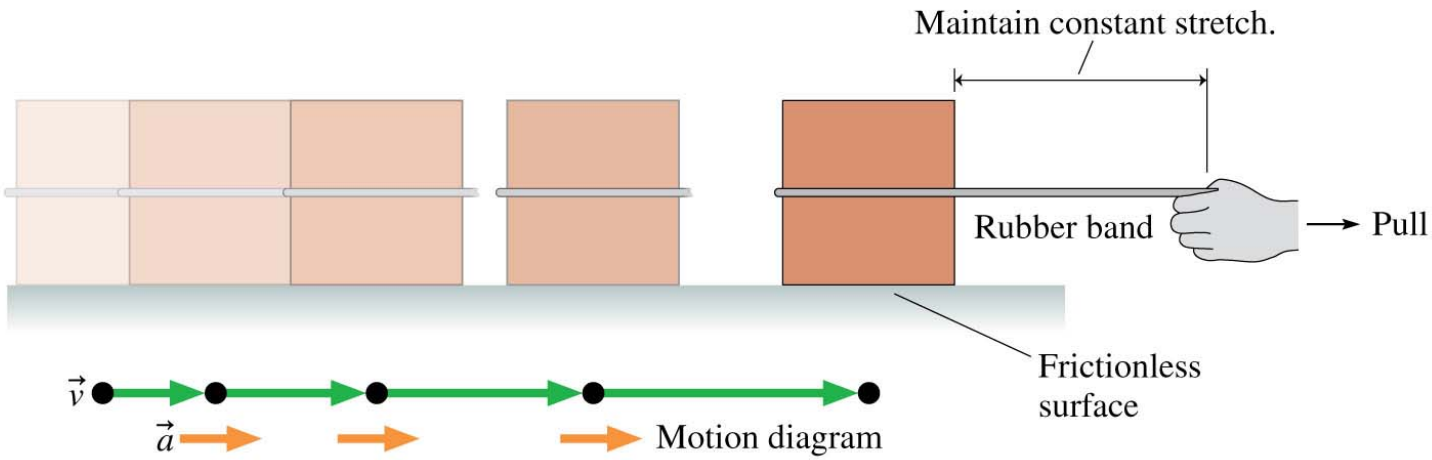
What is the proportionality constant?

- 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.

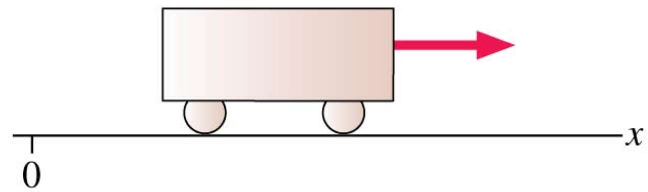


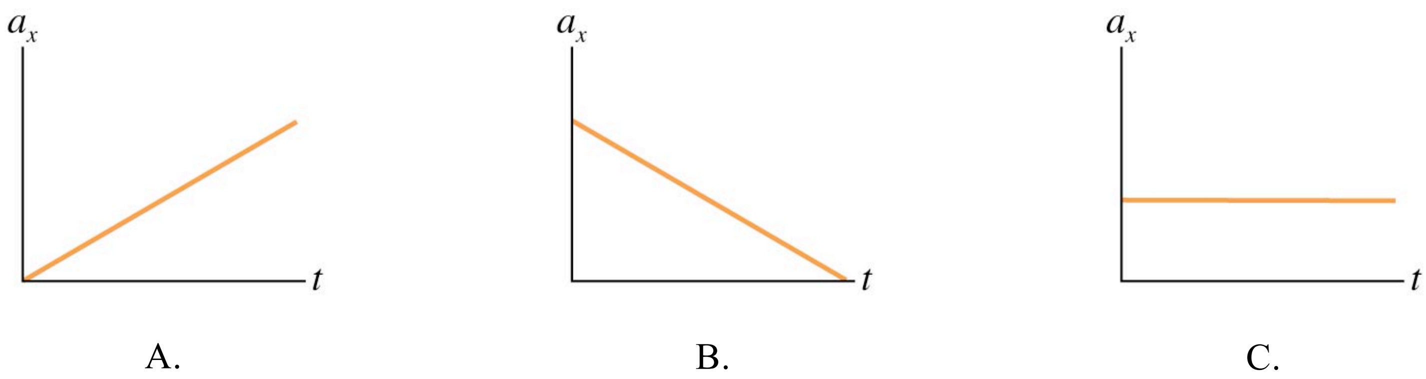
- **The acceleration is inversely proportional to the mass.**

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



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





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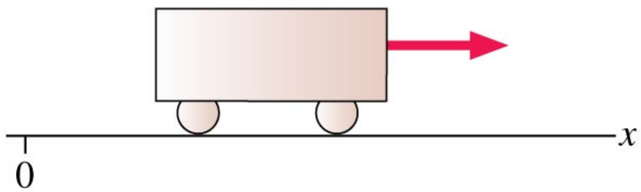
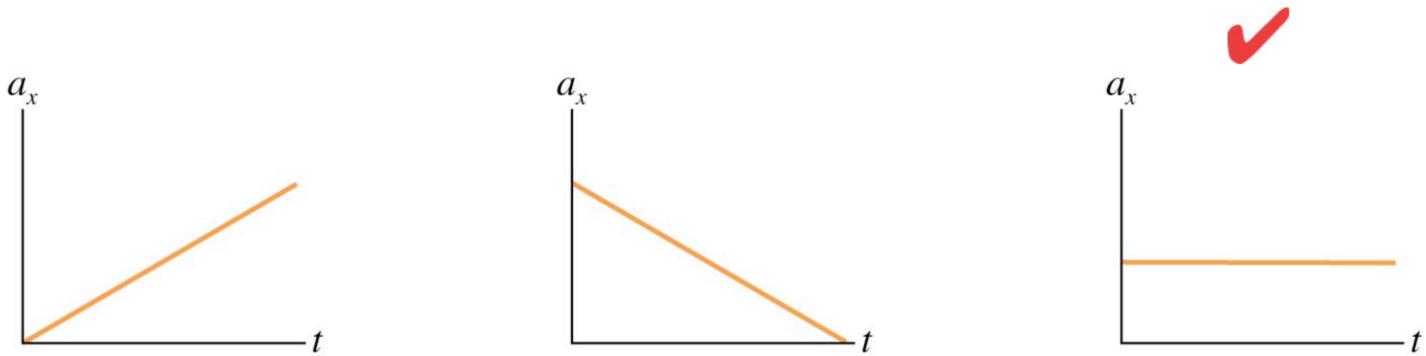




A. B. **C.**

A constant force produces a <u>constant</u> acceleration.

TABLE 5.1 Approximate magnitude of some typical forces

Force	Approximate magnitude (newtons)
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

NASA's Ingenuity is 1.8 kg, so its weight on Earth is 17.6 N, its weight on Mars is 6.7 N since the acceleration due to gravity on that planet is 3.72 m/s^2 as opposed to 9.80 m/s^2 on Earth. The atmosphere of Mars is much thinner, so the rotor speed is 2400 rpm, whereas a large helicopter on Earth has a rotor speed of about 500 rpm.

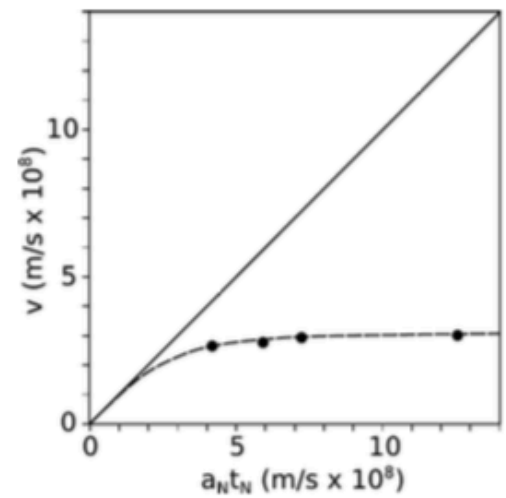
- An object with twice the amount of matter accelerates only half as much in response to the same force.
- The more matter an object has, the more it *resists* accelerating in response to the same force.
- The tendency of an object to resist a *change* in its velocity is called **inertia**.
- The mass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

change means speed up or slow down

A failure of the second law *example 13*

The graph in the figure displays data from a 1964 experiment by Bertozzi that shows how Newton's second law fails if you keep on applying a force to an object indefinitely. Electrons were accelerated by a constant electrical force through a certain distance. Applying Newton's laws gives Newtonian predictions a_N for the acceleration and t_N for the time required. The electrons were then allowed to fly down a pipe for a further distance of 8.4 m without being acted on by any force. The time of flight for this second distance was used to find the final velocity v to which they had actually been accelerated.

According to Newton, an acceleration a_N acting for a time t_N should produce a final velocity $a_N t_N$. The solid line in the graph shows the prediction of Newton's laws, which is that a constant force exerted steadily over time will produce a velocity that rises linearly and without limit.



j / Example 13.

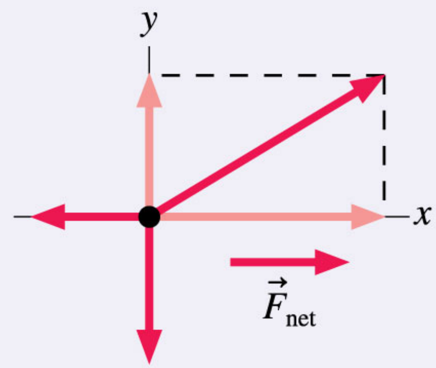
Dynamics in 1-D: Preview

Really important!

How are Newton's laws used to solve problems?

Newton's first and second laws are vector equations. To use them,

- Draw a free-body diagram.
- Read the *x*- and *y*-components of the forces directly off the free-body diagram.
- Use $\sum F_x = ma_x$ and $\sum F_y = ma_y$.



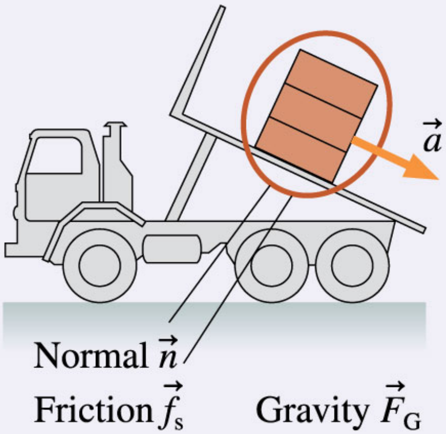
Dynamics in 1-D: Preview

Really important!

How are dynamics problems solved?

A net force on an object causes the object to accelerate.

- Identify the forces and draw a free-body diagram.
- Use Newton's second law to find the object's acceleration.
- Use kinematics for velocity and position.



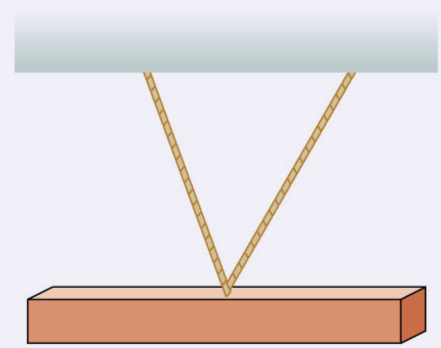
Dynamics in 1-D: Preview

Is it possible that the object is in motion?

How are equilibrium problems solved?

An object at rest or moving with constant velocity is in equilibrium with no net force.

- Identify the forces and draw a free-body diagram.
- Use Newton's second law with $a = 0$ to solve for unknown forces.

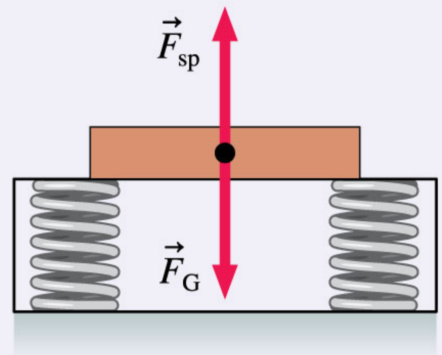


Dynamics in 1-D: Preview

What are mass and weight?

Mass and weight are not the same.

- Mass describes an object's inertia. Loosely speaking, it is the amount of matter in an object. It is the same everywhere.
- Gravity is a force.
- Weight is the result of weighing an object on a scale. It depends on mass, gravity, and acceleration.



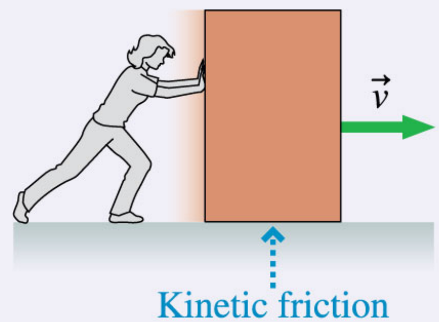
Acceleration?

Dynamics in 1-D: Preview

How do we model friction and drag?

Friction and drag are complex forces, but we will develop simple models of each.

- Static, kinetic, and rolling friction depend on the coefficients of friction but not on the object's speed.
- Drag depends on the *square* of an object's speed and on its cross-section area.
- Falling objects reach terminal speed when drag and gravity are balanced.



Dynamics in 1-D: Preview

Same strategy as before. See a pattern?
For the solve part we now have another tool: Newton's laws

How do we solve problems?

We will develop and use a four-part problem-solving strategy:

- **Model** the problem, using information about objects and forces.
- **Visualize** the situation with a pictorial representation.
- Set up and **solve** the problem with Newton's laws.
- **Assess** the result to see if it is reasonable.

Newton's first law can be applied to

What is each one?

A. Static equilibrium.
B. Newtonian equilibrium.
C. Dynamic equilibrium.
D. Both A and B.
E. Both A and C.

Newton's first law can be applied to

A. Static equilibrium.
B. Newtonian equilibrium.
C. Dynamic equilibrium.
D. Both A and B.
E. Both A and C.

Mass is

A. An intrinsic property.
B. A force.
C. A measurement.

Mass is

✔ **A. An intrinsic property.**

B. A force.

C. A measurement.

Which means?

Gravity is

A. An intrinsic property.
B. A force.
C. A measurement.

Gravity is

A. An intrinsic property.

B. A force.

C. A measurement.

Weight is

A. An intrinsic property.
B. A force.
C. A measurement.

Weight is

A. An intrinsic property.
B. A force.
C. A measurement.

You can’t feel your own weight, and it depends on the mass, acceleration due to gravity, and acceleration due to other forces

The coefficient of static friction is

A. Smaller than the coefficient of kinetic friction.
B. Equal to the coefficient of kinetic friction.
C. Larger than the coefficient of kinetic friction.
D. Depends on the specific situation.

The coefficient of static friction is

A. Smaller than the coefficient of kinetic friction.
B. Equal to the coefficient of kinetic friction.
C. **Larger than the coefficient of kinetic friction.**
D. Depends on the specific situation.

It is easier to continue moving objects when they are already moving than starting from rest. Why?

The force of friction is described by

A. The law of friction.
B. The theory of friction.
C. A model of friction.
D. The friction hypothesis.
E. The friction ultimatum.

What is the definition of law, theory, hypothesis, model?

The force of friction is described by

A. The law of friction.
B. The theory of friction.
C. A model of friction.
D. The friction hypothesis.

When an object moves through the air, the magnitude of the drag force on it

A. Increases as the object’s speed increases.
B. Decreases as the object’s speed increases.
C. Does not depend on the object’s speed.

When an object moves through the air, the magnitude of the drag force on it

A. Increases as the object's speed increases.
B. Decreases as the object's speed increases.
C. Does not depend on the object's speed.

What is a reasonable explanation?

Terminal speed is

A. Equal to the speed of sound.
B. The minimum speed an object needs to escape the earth’s gravity.
C. The speed at which the drag force cancels the gravitational force.
D. The speed at which the drag force reaches a minimum.
E. Any speed that can result in a person’s death.

Terminal speed is

A. Equal to the speed of sound.

B. The minimum speed an object needs to escape the earth's gravity.

C. The speed at which the drag force cancels the gravitational force.

D. The speed at which the drag force reaches a minimum.

E. Any speed that can result in a person's death.

We just looked at the elements that we will be dealing with in this part of the course:

mass, gravity, weight, friction, drag

Now let’s use them for dynamics calculations

The Equilibrium Model

Axes are independent, you can be accelerating in x but not in y

- In the absence of a net force, an object is at rest or moves with constant velocity.
- Its acceleration is zero, and we say that it is **in equilibrium**.

- The concept of equilibrium is essential for the engineering analysis of stationary objects such as bridges.
- When the acceleration is zero, then Newton's second law in two dimensions becomes:

$$(F_{\text{net}})_x = \sum_i (F_i)_x = 0 \quad \text{and} \quad (F_{\text{net}})_y = \sum_i (F_i)_y = 0$$

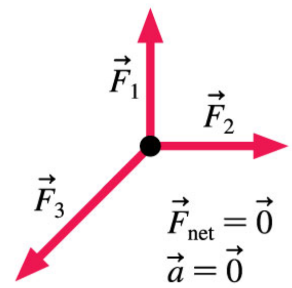
Mechanical Equilibrium

MODEL 6.1

Mechanical equilibrium

For objects on which the net force is zero.

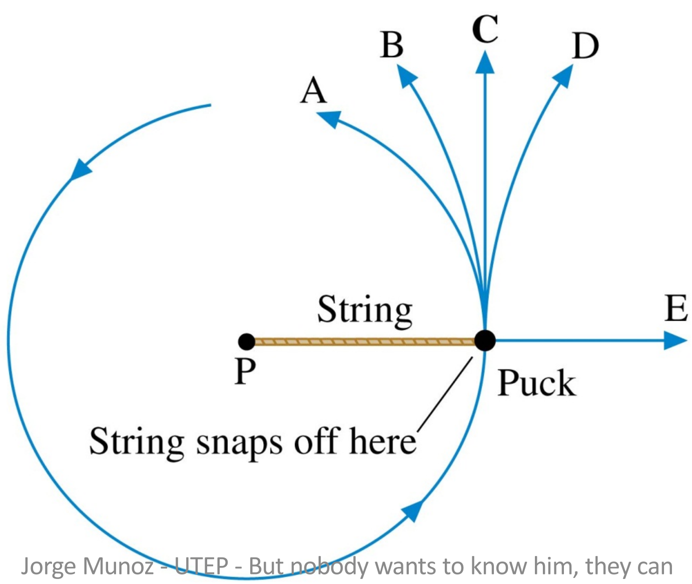
- Model the object as a particle with no acceleration.
  - A particle at rest is in equilibrium.
  - A particle moving in a straight line at constant speed is also in equilibrium.
- Mathematically: $\vec{a} = \vec{0}$ in equilibrium; thus
  - **Newton's second law** is $\vec{F}_{\text{net}} = \sum_i \vec{F}_{\text{i}} = \vec{0}$.
  - The forces are "read" from the free-body diagram,
- Limitations: Model fails if the forces aren't balanced.



The object is at rest or moves with constant velocity.

Quick Check 1

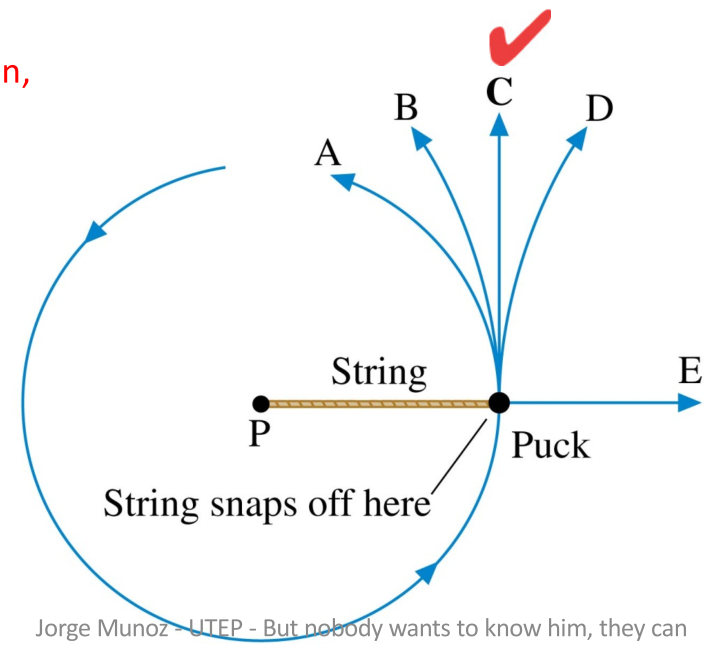
The figure shows the view looking down onto a sheet of frictionless ice. A puck, tied with a string to point P, slides on the ice in the circular path shown and has made many revolutions. If the string suddenly breaks with the puck in the position shown, which path best represents the puck's subsequent motion?



Quick Check 1

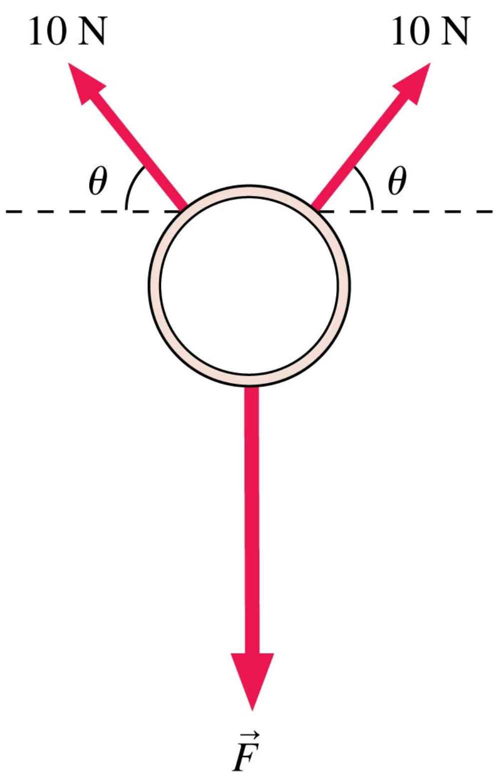
The figure shows the view looking down onto a sheet of frictionless ice. A puck, tied with a string to point P, slides on the ice in the circular path shown and has made many revolutions. If the string suddenly breaks with the puck in the position shown, which path best represents the puck's subsequent motion?

Centripetal acceleration,
Newton's first law



Quick Check 2

A ring, seen from above, is pulled on by three forces. The ring is not moving. How big is the force F?



A. 20 N

B. $10\cos\theta$ N

C. $10\sin\theta$ N

D. $20\cos\theta$ N

E. $20\sin\theta$ N

This is a typical, straightforward, mechanical equilibrium problem: keep in mind that the sum of forces in each individual direction is zero. Let's work it out.

Quick Check 2

A ring, seen from above, is pulled on by three forces. The ring is not moving. How big is the force F?

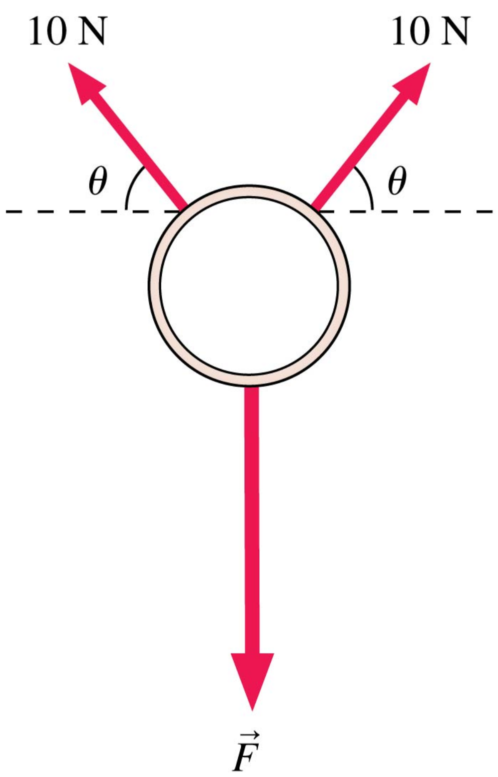
A. 20 N

B. $10\cos\theta$ N

C. $10\sin\theta$ N

D. $20\cos\theta$ N

✔ **E. $20\sin\theta$ N**



Towing a Car up a Hill

EXAMPLE 6.2 | **Towing a car up a hill**

A car with a weight of 15,000 N is being towed up a 20° slope at constant velocity. Friction is negligible. The tow rope is rated at 6000 N maximum tension. Will it break?

MODEL Model the car as a particle in equilibrium.

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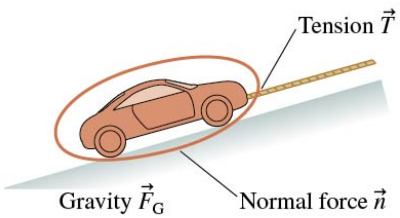
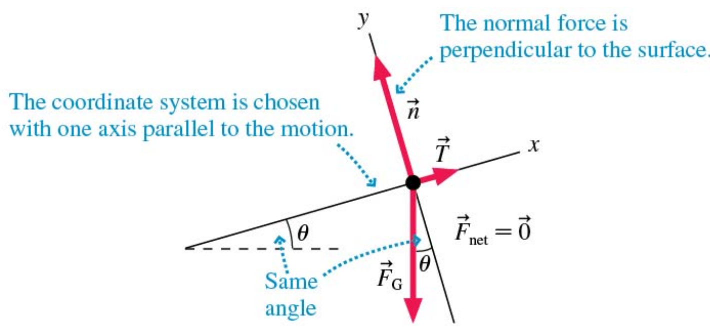
VISUALIZE Part of our analysis of the problem statement is to determine which quantity or quantities allow us to answer the yes-or-no question. In this case, we need to calculate the tension in the rope. **FIGURE 6.2** shows the pictorial representation. Note the similarities to Examples 5.2 and 5.6 in Chapter 5, which you may want to review.

We noted in Chapter 5 that the weight of an object at rest is the magnitude F_G of the gravitational force acting on it, and that information has been listed as known.





Known
$\theta = 20°$
$F_G = 15{,}000$ N

Find
T

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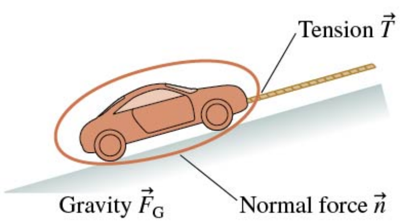
SOLVE The free-body diagram shows forces $\vec{T}$, $\vec{n}$, and $\vec{F}_G$ acting on the car. Newton's second law with $\vec{a} = \vec{0}$ is

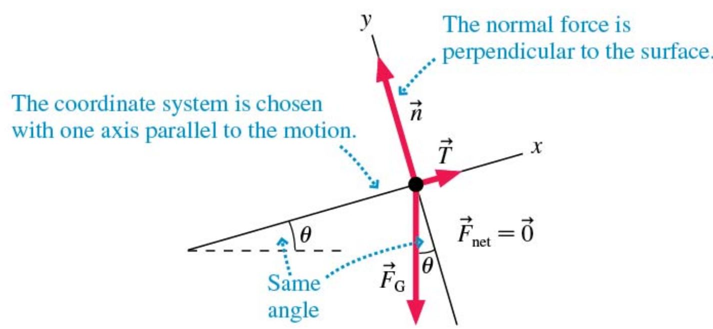
$$(F_{net})_x = \sum F_x = T_x + n_x + (F_G)_x = 0$$
$$(F_{net})_y = \sum F_y = T_y + n_y + (F_G)_y = 0$$

From here on, we'll use $\sum F_x$ and $\sum F_y$, without the label i, as a simple shorthand notation to indicate that we're adding all the x-components and all the y-components of the forces.

We can find the components directly from the free-body diagram:

$$T_x = T \qquad T_y = 0$$
$$n_x = 0 \qquad n_y = n$$
$$(F_G)_x = -F_G \sin\theta \qquad (F_G)_y = -F_G \cos\theta$$





Known
$\theta = 20°$
$F_G = 15{,}000$ N

Find
T

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EXAMPLE 6.2 | **Towing a car up a hill**

NOTE The gravitational force has both x- and y-components in this coordinate system, both of which are negative due to the direction of the vector $\vec{F}_G$. You'll see this situation often, so be sure you understand where $(F_G)_x$ and $(F_G)_y$ come from.

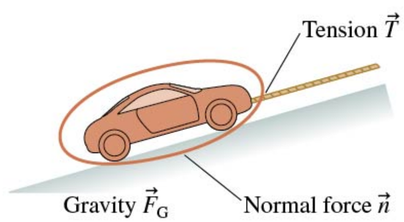
With these components, the second law becomes

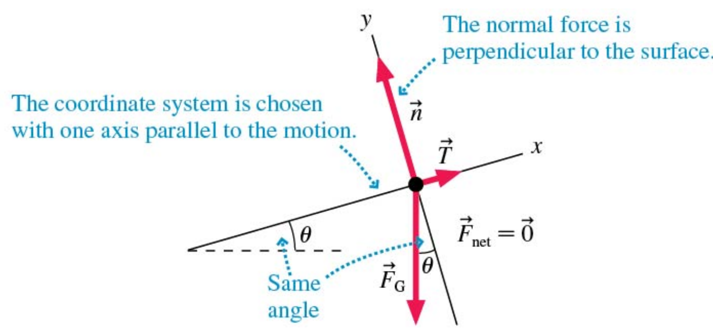
$$T - F_G \sin\theta = 0$$
$$n - F_G \cos\theta = 0$$

The first of these can be rewritten as

$$T = F_G \sin\theta = (15{,}000\ \text{N}) \sin 20^\circ = 5100\ \text{N}$$

Because $T < 6000$ N, we conclude that the rope will *not* break. It turned out that we did not need the y-component equation in this problem.





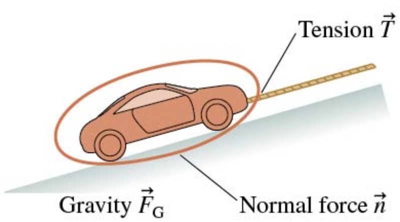
Known
$\theta = 20^\circ$
$F_G = 15{,}000$ N

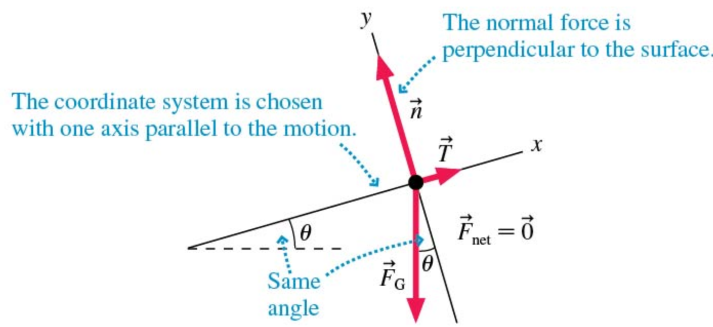
Find
T

Towing a Car up a Hill

EXAMPLE 6.2 **Towing a car up a hill**

ASSESS Because there's no friction, it would not take *any* tension force to keep the car rolling along a horizontal surface ($\theta = 0°$). At the other extreme, $\theta = 90°$, the tension force would need to equal the car's weight ($T = 15{,}000$ N) to lift the car straight up at constant velocity. The tension force for a 20° slope should be somewhere in between, and 5100 N is a little less than half the weight of the car. That our result is reasonable doesn't prove it's right, but we have at least ruled out careless errors that give unreasonable results.



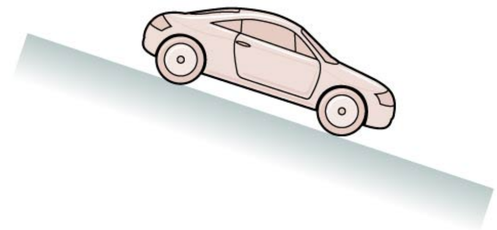


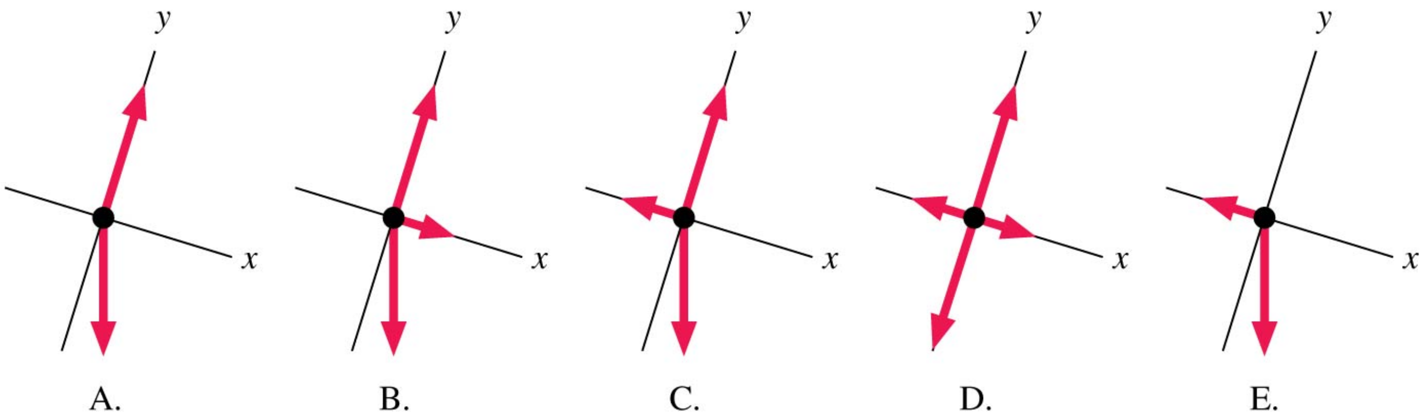
Known
$\theta = 20°$
$F_G = 15{,}000$ N

Find
T

Quick Check 3

A car is parked on a hill. Which is the correct free-body diagram?

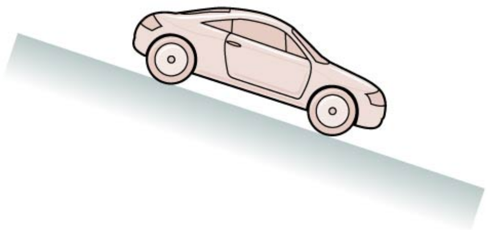


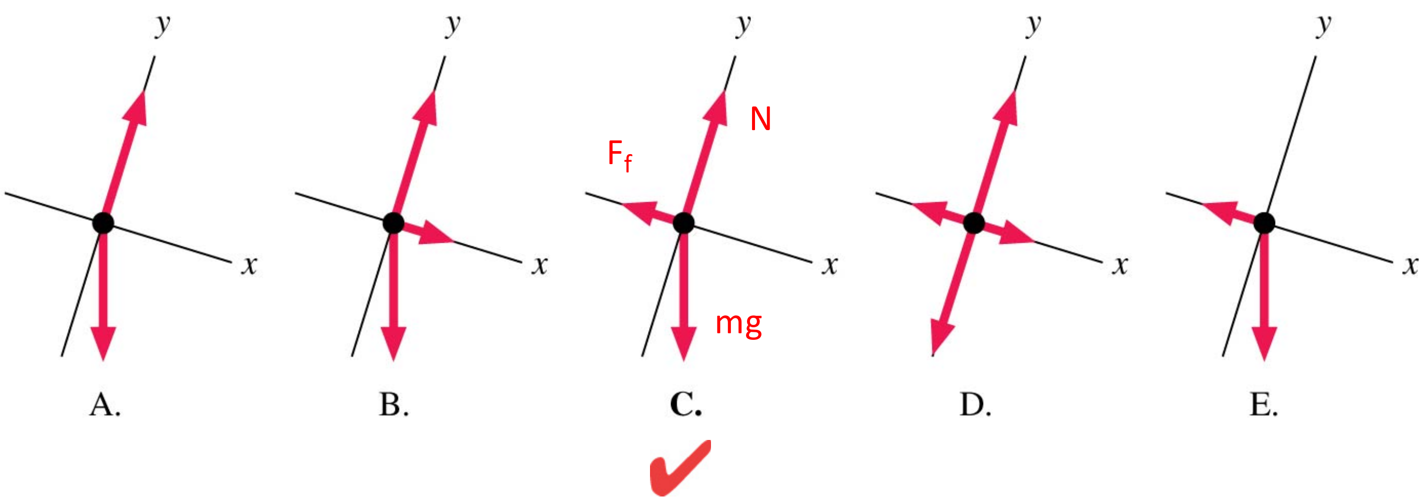


What forces are acting on the car and in which directions?
What is the sum of forces in x? In y?

Quick Check 3

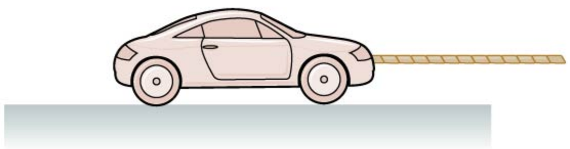
A car is parked on a hill. Which is the correct free-body diagram?

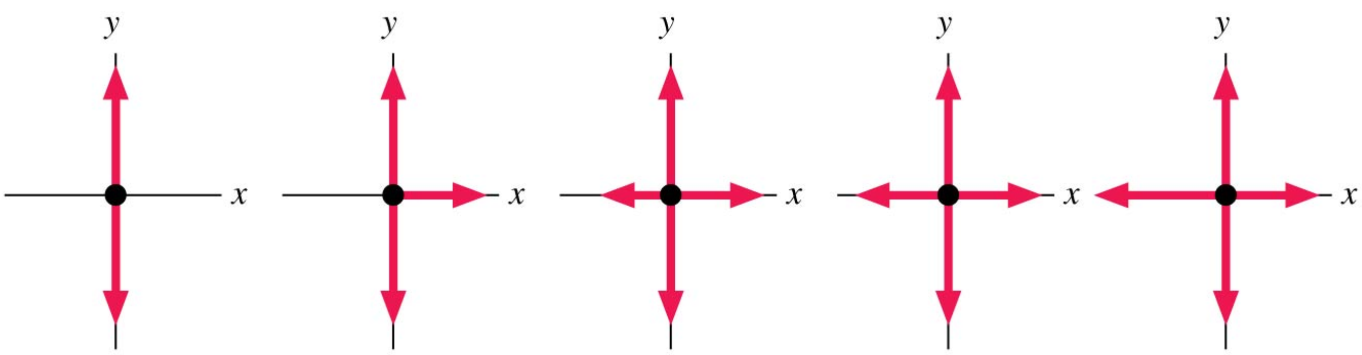




Quick Check 4

A car is towed to the right at constant speed. Which is the correct free-body diagram?



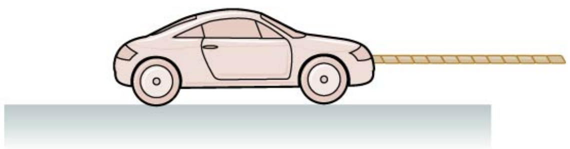


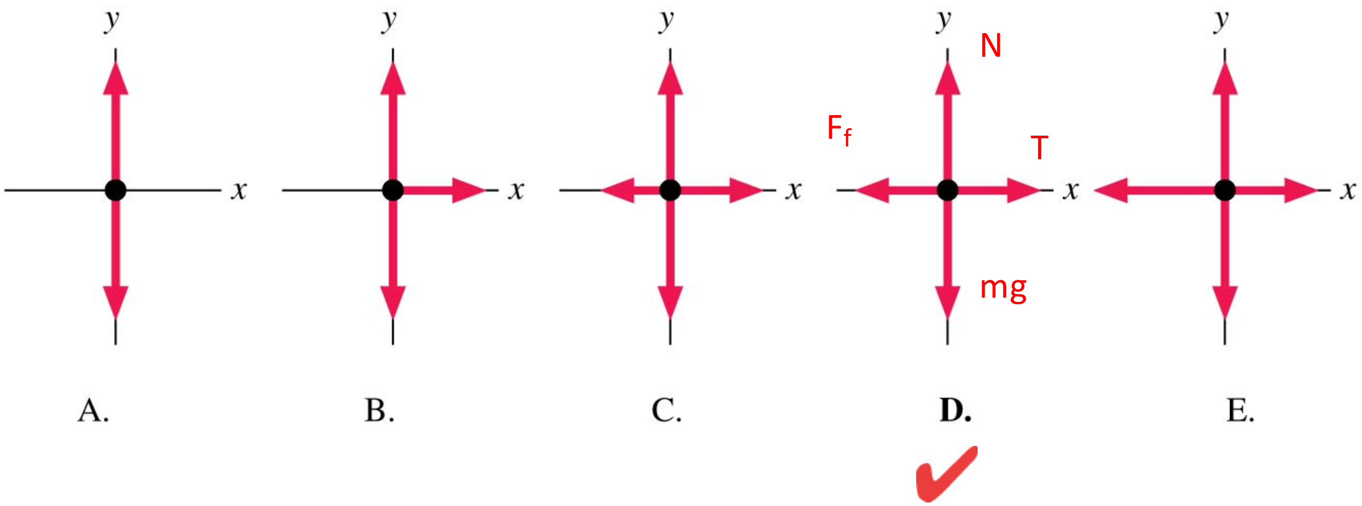
A. B. C. D. E.

What forces are acting on the car and in which directions?
What is the sum of forces in x? In y?

Quick Check 4

A car is towed to the right at constant speed. Which is the correct free-body diagram?





Using Newton's Second Law

- The essence of Newtonian mechanics can be expressed in two steps:
  - The forces on an object determine its acceleration $\vec{a} = \vec{F}_{\text{net}}/m$
  - The object's trajectory can be determined by using $\vec{a}$ in the equations of kinematics.

PROBLEM-SOLVING STRATEGY 6.1

SOLVE The mathematical representation is based on Newton's second law:

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

The forces are "read" directly from the free-body diagram. Depending on the problem, either

- Solve for the acceleration, then use kinematics to find velocities and positions; or
- Use kinematics to determine the acceleration, then solve for unknown forces.

The cart is initially at rest. Force $\vec{F}$ is applied to the cart for time Δt, after which the car has speed v. Suppose the same force is applied for the same time to a second cart with twice the mass. Friction is negligible. Afterward, the second cart's speed will be

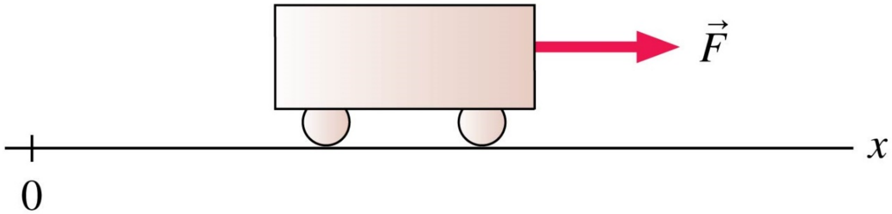
A. $\frac{1}{4}v$

B. $\frac{1}{2}v$

C. v

D. $2v$

E. $4v$



$v = v_0 + a\Delta t$ $\quad a = \frac{F}{m}$ $\quad v_0 = 0$

$v = \frac{F}{m}\Delta t$

The cart is initially at rest. Force $\vec{F}$ is applied to the cart for time Δt, after which the car has speed v. Suppose the same force is applied for the same time to a second cart with twice the mass. Friction is negligible. Afterward, the second cart's speed will be

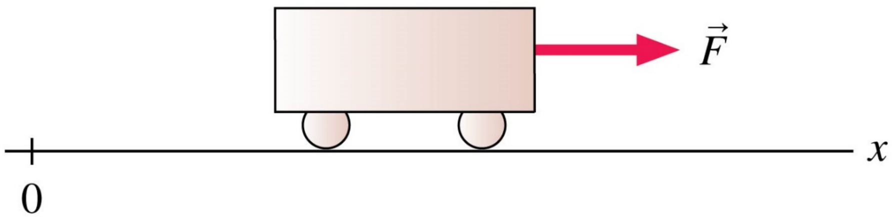
A. $\frac{1}{4}v$

✔ **B.** $\frac{1}{2}v$

C. v

D. $2v$

E. $4v$



$v = v_0 + a\Delta t$ $\quad a = \frac{F}{m}$ $\quad v_0 = 0$

$v = \frac{F}{m}\Delta t$