Richard Feynman @ProfFeynman · Aug 19

Understand, don't memorize. 🧠

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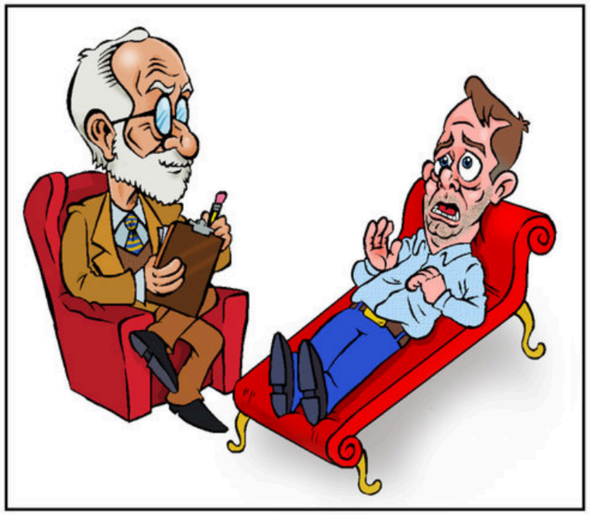
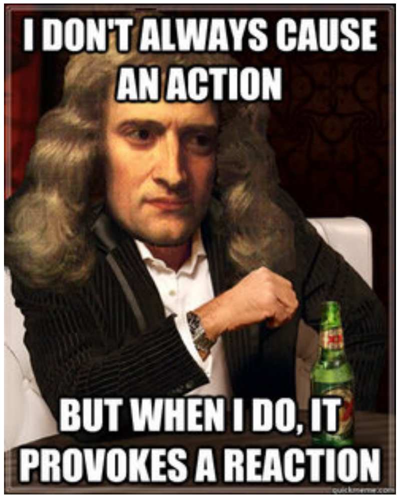
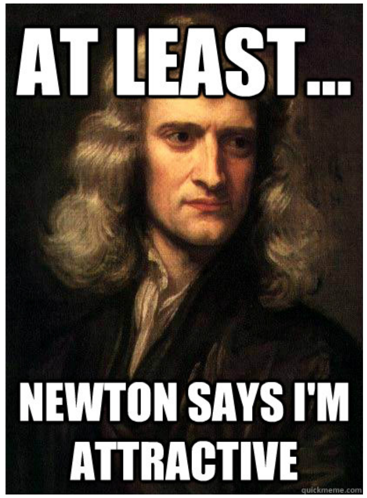
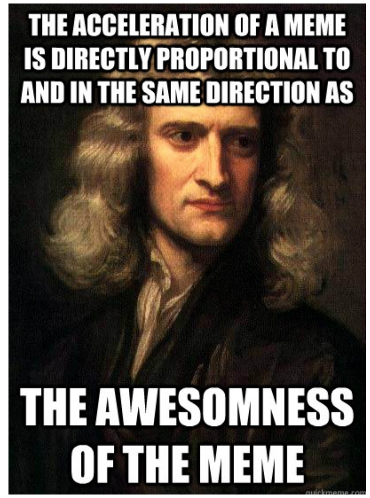
Exam 1 on Thursday February 18th

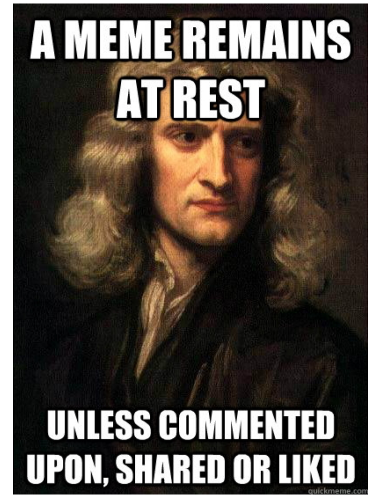
- Questions? Comments? Concerns?

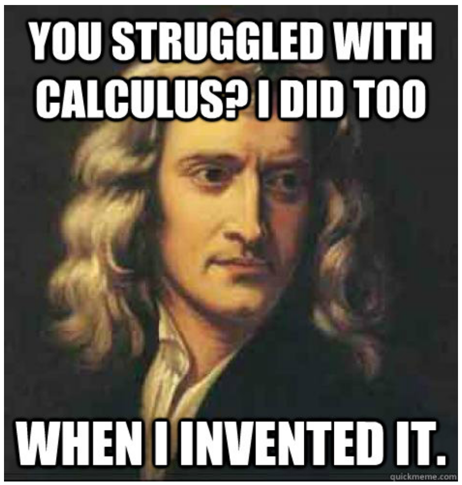


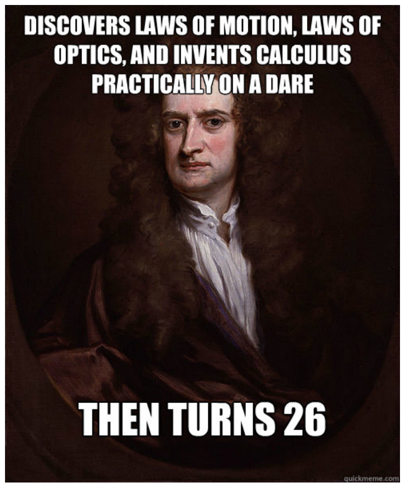


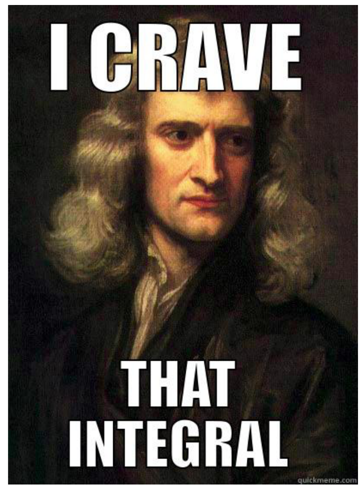


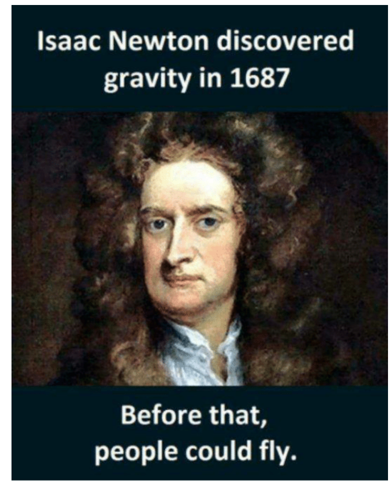




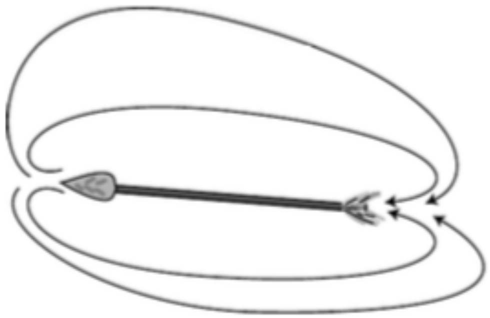




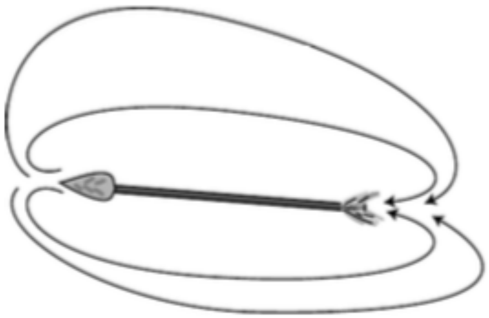




Research suggests there are more memes about his contributions to physics than to math



a / Aristotle said motion had to be caused by a force. To explain why an arrow kept flying after the bowstring was no longer pushing on it, he said the air rushed around behind the arrow and pushed it forward. We know this is wrong, because an arrow shot in a vacuum chamber does not instantly drop to the floor as it leaves the bow. Galileo and Newton realized that a force would only be needed to change the arrow's motion, not to make its motion continue.



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Newton discovered the relationship between force and motion, and revolutionized our view of the universe by showing that the same physical laws applied to all matter, whether living or nonliving, on or off of our planet's surface. His book on force and motion, the **Mathematical Principles of Natural Philosophy**, was uncontradicted by experiment for 200 years, but his other main work, **Optics**, was on the wrong track, asserting that light was composed of particles rather than waves. Newton was also an avid alchemist, a fact that modern scientists would like to forget.

Newton's first law

If the total force acting on an object is zero, its center of mass continues in the same state of motion.

Newton's second law

$$a = F_{total}/m,$$

where

m is an object's mass, a measure of its resistance to changes in its motion

F_{total} is the sum of the forces acting on it, and

a is the acceleration of the object's center of mass.

An elevator *example 1*

▷ An elevator has a weight of 5000 N. Compare the forces that the cable must exert to raise it at constant velocity, lower it at constant velocity, and just keep it hanging.

An elevator *example 1*

▷ An elevator has a weight of 5000 N. Compare the forces that the cable must exert to raise it at constant velocity, lower it at constant velocity, and just keep it hanging.

▷ In all three cases the cable must pull up with a force of exactly 5000 N. Most people think you'd need at least a little more than 5000 N to make it go up, and a little less than 5000 N to let it down, but that's incorrect. Extra force from the cable is only necessary for speeding the car up when it starts going up or slowing it down when it finishes going down. Decreased force is needed to speed the car up when it gets going down and to slow it down when it finishes going up. But when the elevator is cruising at constant velocity, Newton's first law says that you just need to cancel the force of the earth's gravity.

Terminal velocity for falling objects *example 2*

▷ An object like a feather that is not dense or streamlined does not fall with constant acceleration, because air resistance is nonnegligible. In fact, its acceleration tapers off to nearly zero within a fraction of a second, and the feather finishes dropping at constant speed (known as its terminal velocity). Why does this happen?

Terminal velocity for falling objects *example 2*

▷ An object like a feather that is not dense or streamlined does not fall with constant acceleration, because air resistance is nonnegligible. In fact, its acceleration tapers off to nearly zero within a fraction of a second, and the feather finishes dropping at constant speed (known as its terminal velocity). Why does this happen?

▷ Newton's first law tells us that the total force on the feather must have been reduced to nearly zero after a short time. There are two forces acting on the feather: a downward gravitational force from the planet earth, and an upward frictional force from the air. As the feather speeds up, the air friction becomes stronger and stronger, and eventually it cancels out the earth's gravitational force, so the feather just continues with constant velocity without speeding up any more.

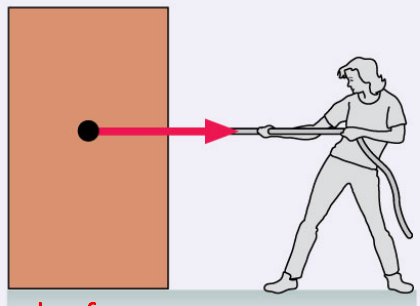
The situation for a skydiver is exactly analogous. It's just that the skydiver experiences perhaps a million times more gravitational force than the feather, and it is not until she is falling very fast that the force of air friction becomes as strong as the gravitational force. It takes her several seconds to reach terminal velocity, which is on the order of a hundred miles per hour.

What is a force?

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

Attraction or repulsion

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



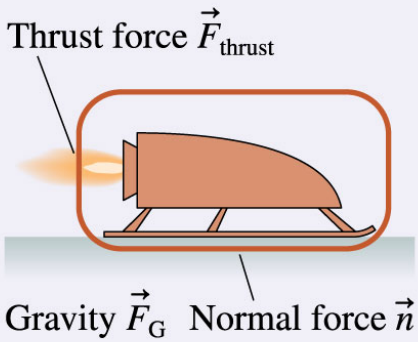
Something that exerts the force

Has magnitude and direction

How do we identify forces?

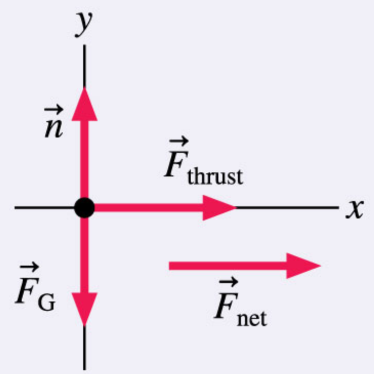
A force can be a contact force or a long-range force.

- 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.



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.



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,

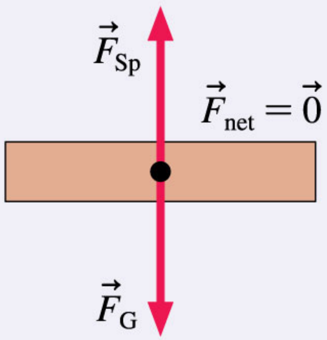
$$\vec{a} = \frac{1}{m}\vec{F}_{\text{net}}$$

« LOOKING BACK Sections 1.4, 2.4, and 3.2
Acceleration and vector addition

Before we looked at acceleration but not its cause.
Whenever there is acceleration there are forces involved.

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.

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.

What is a “net force?”

A. The weight excluding the container.

B. The vector sum of all forces in a problem. Why not?

✔ **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. Why not?

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.

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

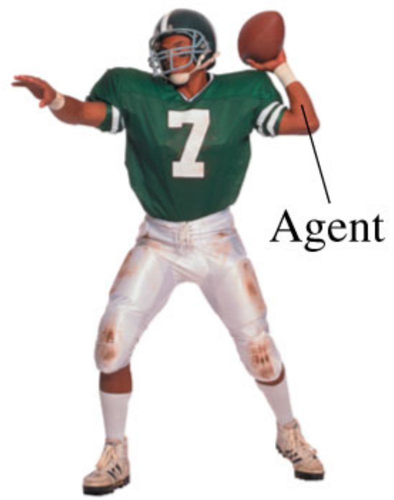
Difference between system and environment?

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.

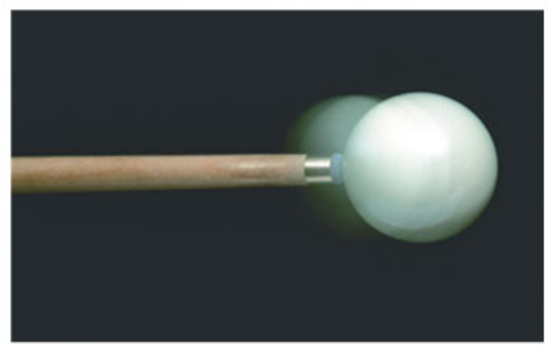
- A force is a *push* or a *pull*.

- 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.

- 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.

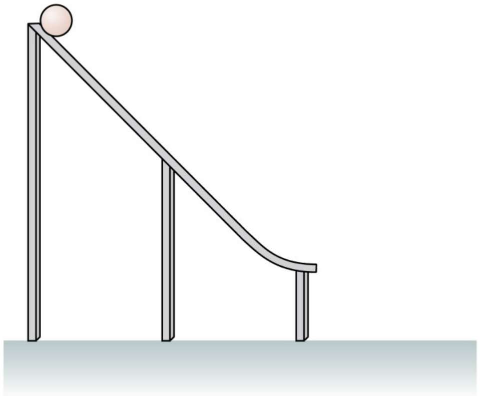


Although objects really never touch…

- **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. [Force?]

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.

Let's discuss the options

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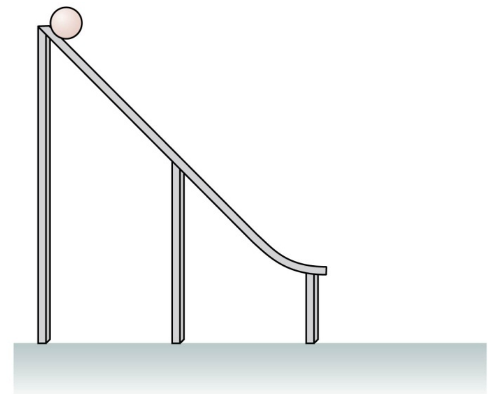

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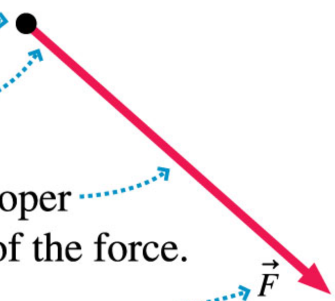
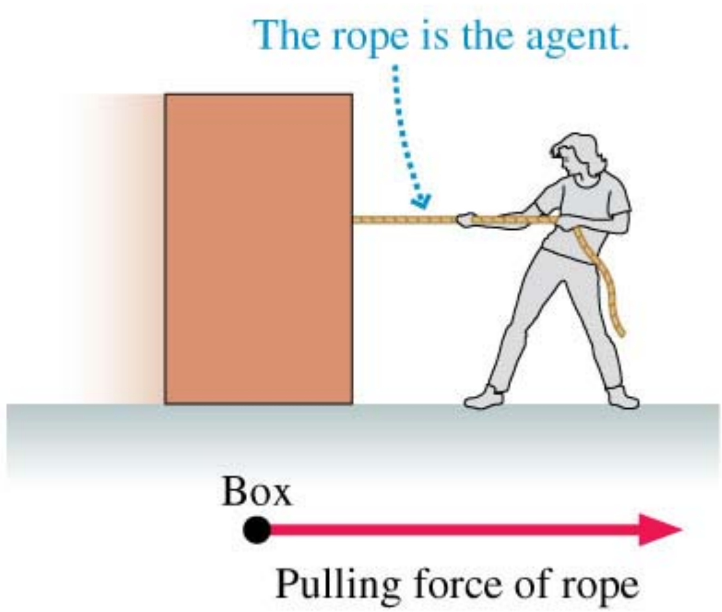
TACTICS BOX 5.1

Drawing force vectors

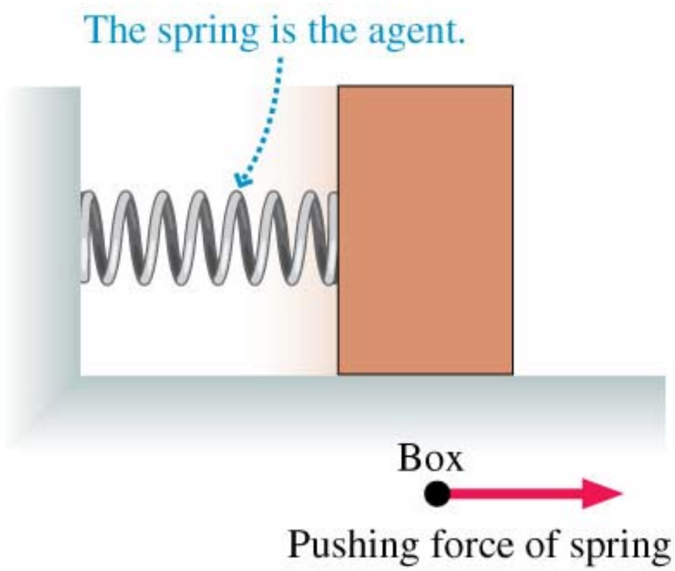
1. Model the object as a particle.
2. Place the *tail* of the force vector on the particle.
3. Draw the force vector as an arrow pointing in the proper direction and with a length proportional to the size of the force.
4. Give the vector an appropriate label.



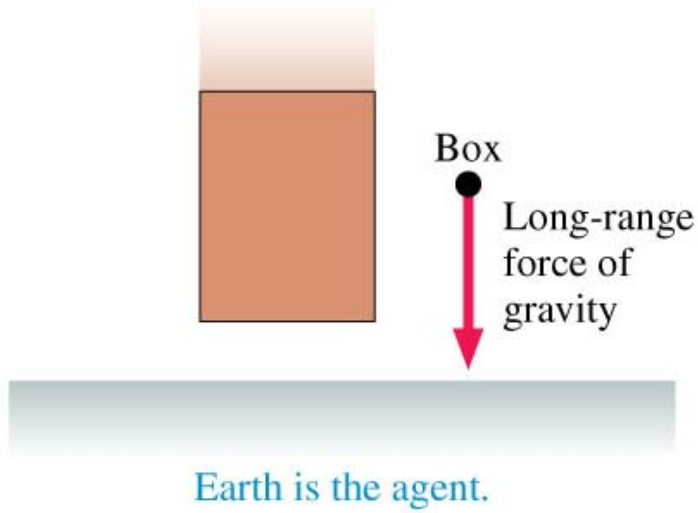
A box is pulled to the right by a rope.



A box is pushed to the right by a spring.



A box is pulled down by gravity.

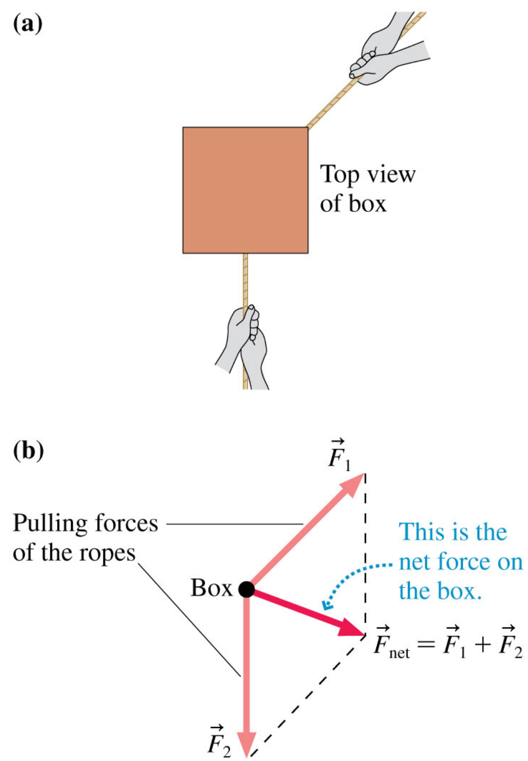


Inertial vs gravitational mass…

- 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:

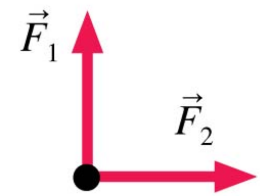
$$\vec{F}_{\text{net}} \equiv \sum_{i=1}^{N} \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \cdots + \vec{F}_N$$

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

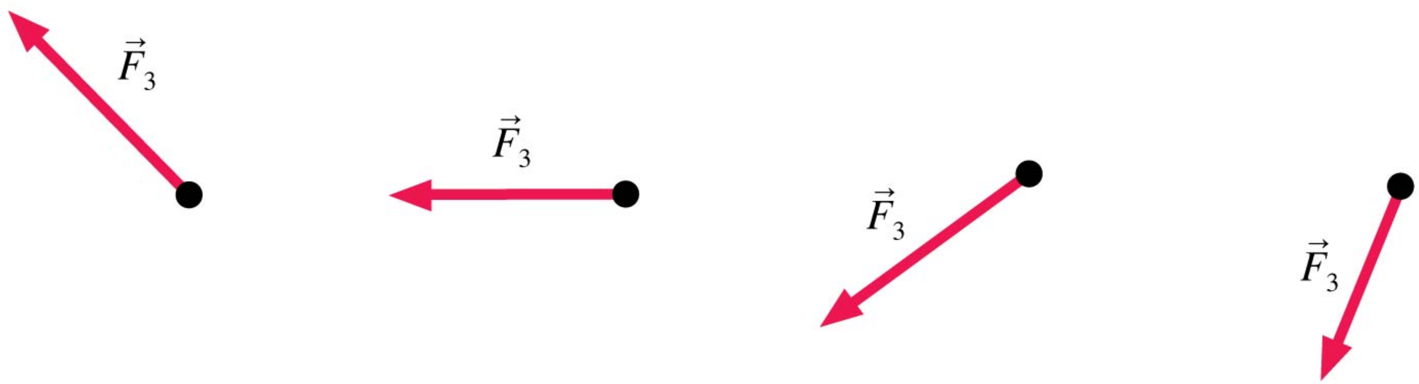


Methods that we used for velocity, etc. are the same

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.

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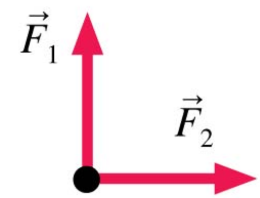

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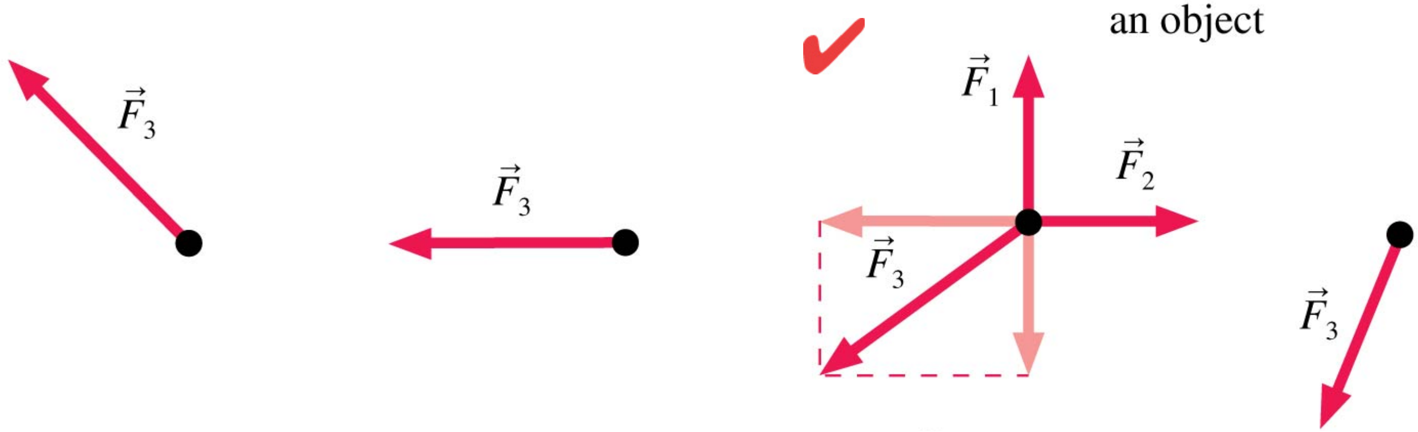
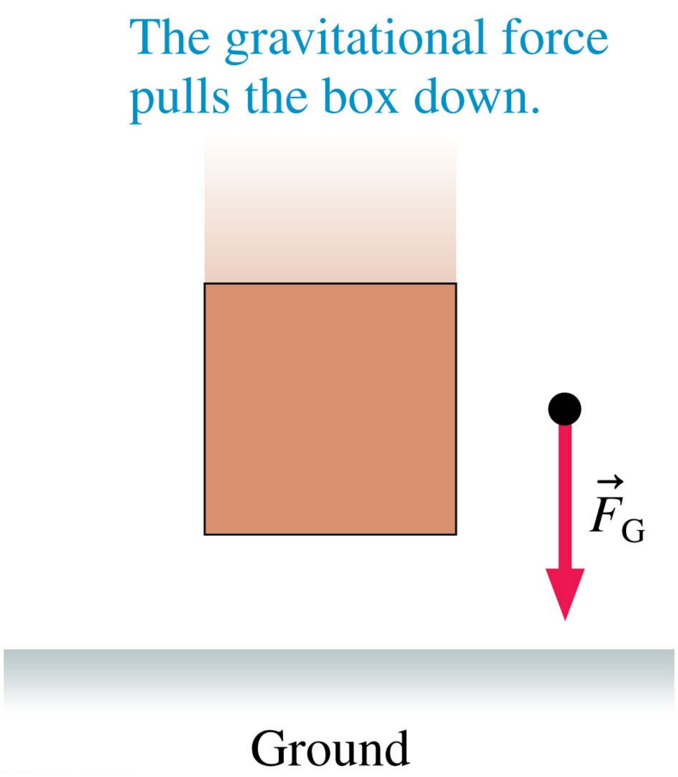


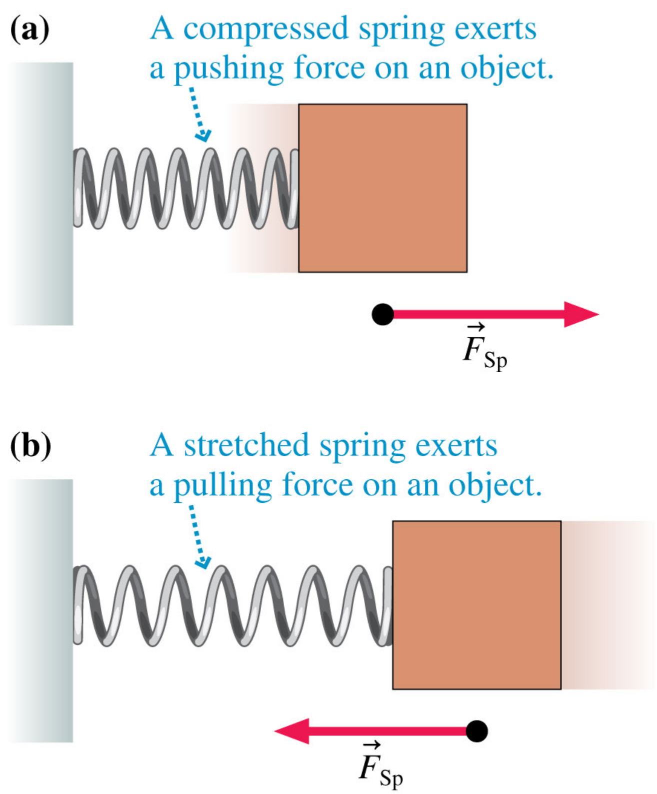
A. B. **C.** D.

Vertical components cancel

- 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.



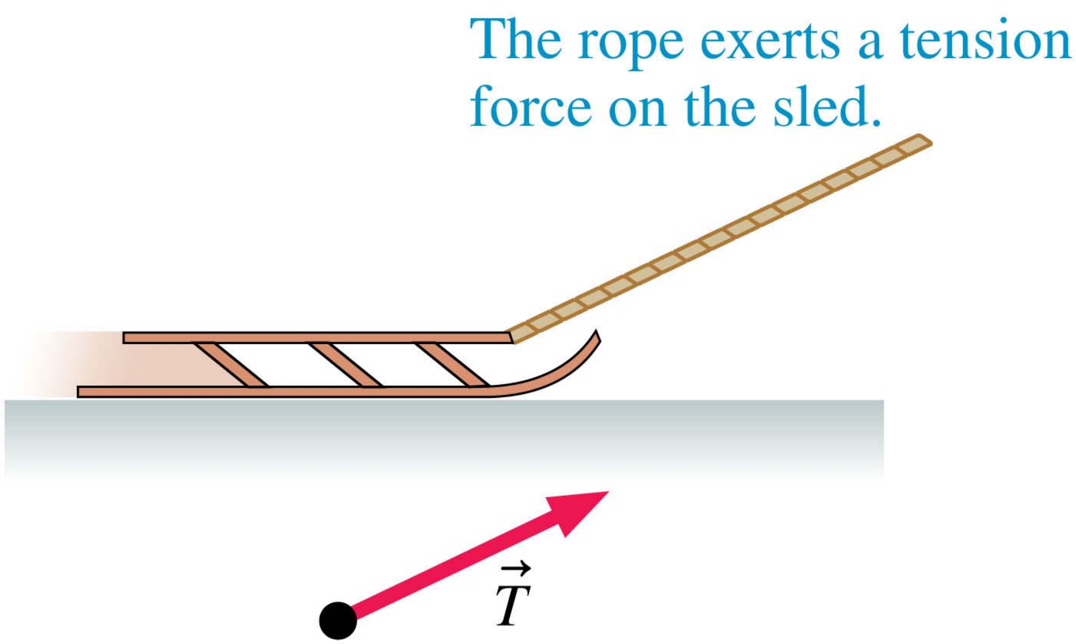
- A spring can either push (when compressed) or pull (when stretched).
- Not all springs are metal coils.
- Whenever an elastic object is flexed or deformed in some way, and then “springs” back to its original shape when you let it go, this is a **spring force**.



What are examples of this?

h / Example 10.

- 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.



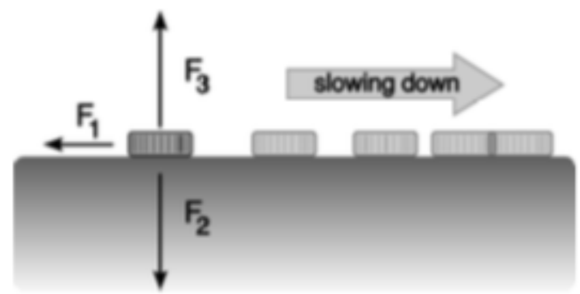
parallel to the line.

A coin sliding across a table *example 9*

Suppose a coin is sliding to the right across a table, f, and let's choose a positive x axis that points to the right. The coin's velocity is positive, and we expect based on experience that it will slow down, i.e., its acceleration should be negative.

Although the coin's motion is purely horizontal, it feels both vertical and horizontal forces. The Earth exerts a downward gravitational force F_2 on it, and the table makes an upward force F_3 that prevents the coin from sinking into the wood. In fact, without these vertical forces the horizontal frictional force wouldn't exist: surfaces don't exert friction against one another unless they are being pressed together.

Although F_2 and F_3 contribute to the physics, they do so only indirectly. The only thing that directly relates to the acceleration along the horizontal direction is the horizontal force: $a = F_1/m$.



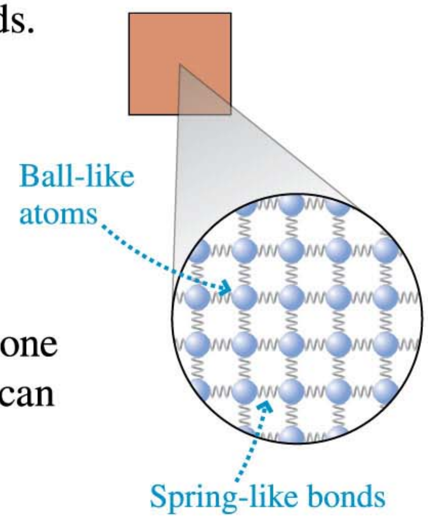
f / A coin slides across a table. Even for motion in one dimension, some of the forces may not lie along the line of the motion.

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.



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.

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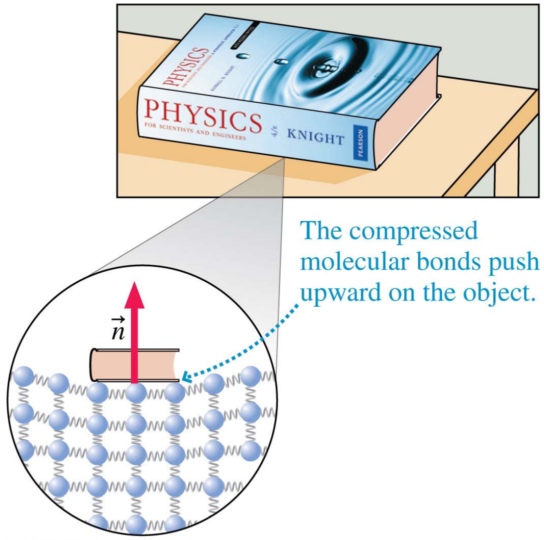
A book rests on a horizontal table. Gravity pulls down on the book. You may have learned something in a previous physics class about an upward force called the “normal force.” Deep in your heart, do you really believe the table is exerting an upward force on the book?

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.


Bed of Nails

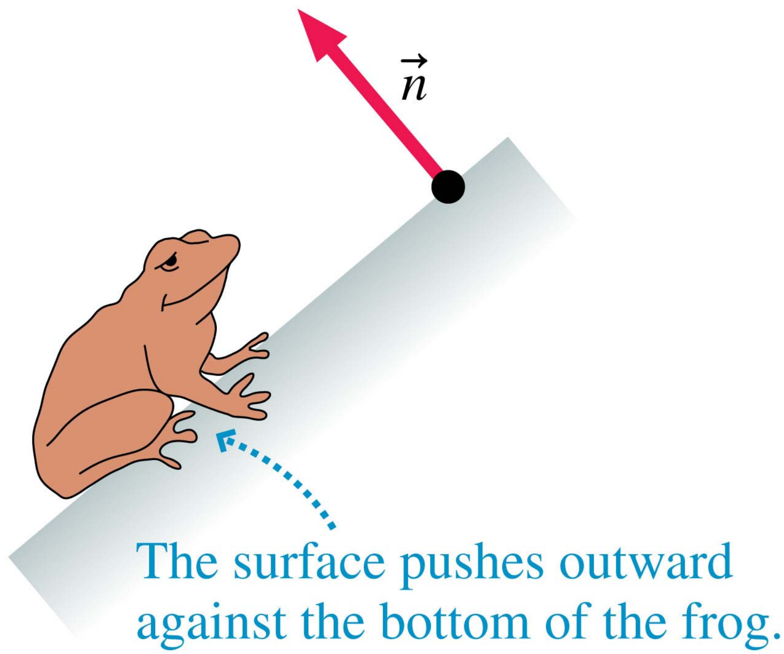
- When an object sits on a table, the table surface exerts an upward contact force on the object.
- This pushing force is directed *perpendicular* to the surface, and thus is called the **normal force**.



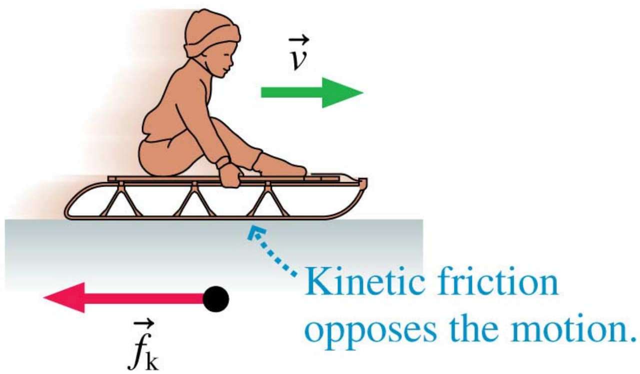
- A table is made of *atoms* joined together by *molecular bonds* which can be modeled as springs.
- Normal force is a result of many molecular springs being compressed ever so slightly.

- 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.

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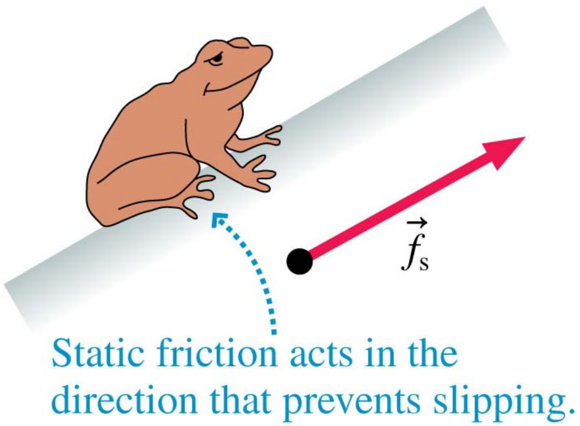
C. Gravity and the force of the push.

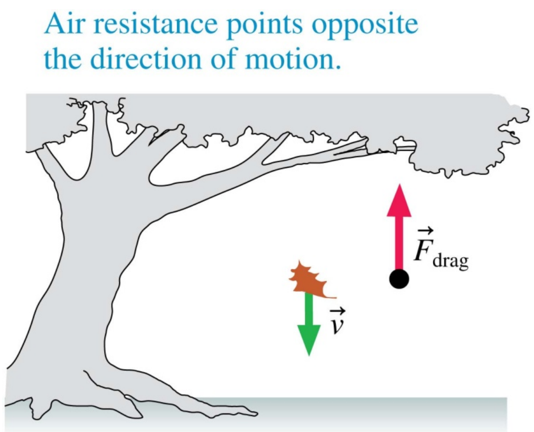
✔ **D. Gravity, a normal force, and kinetic friction.**

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.

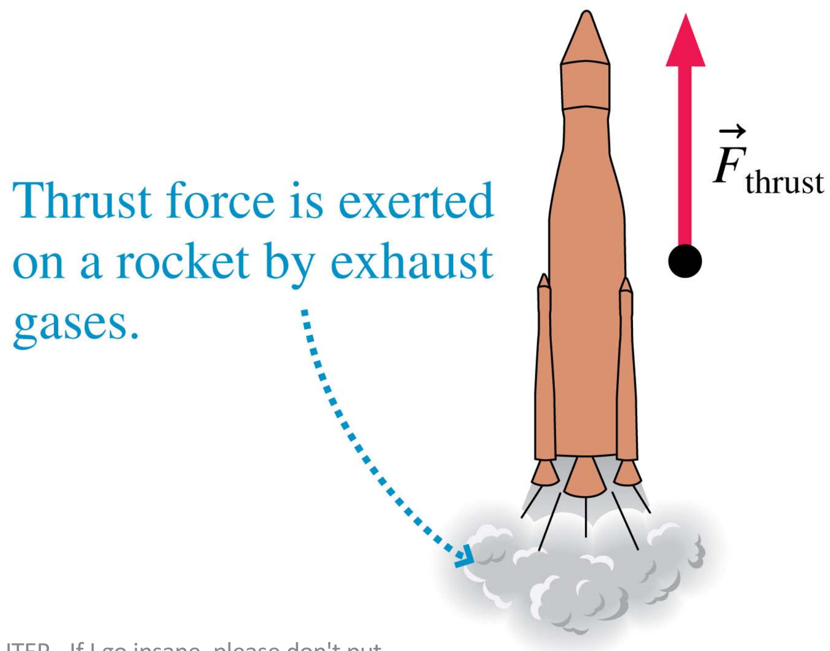


- Kinetic friction is a *resistive force*, which opposes or resists motion.
- Resistive forces are also experienced by objects moving through fluids.



- 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

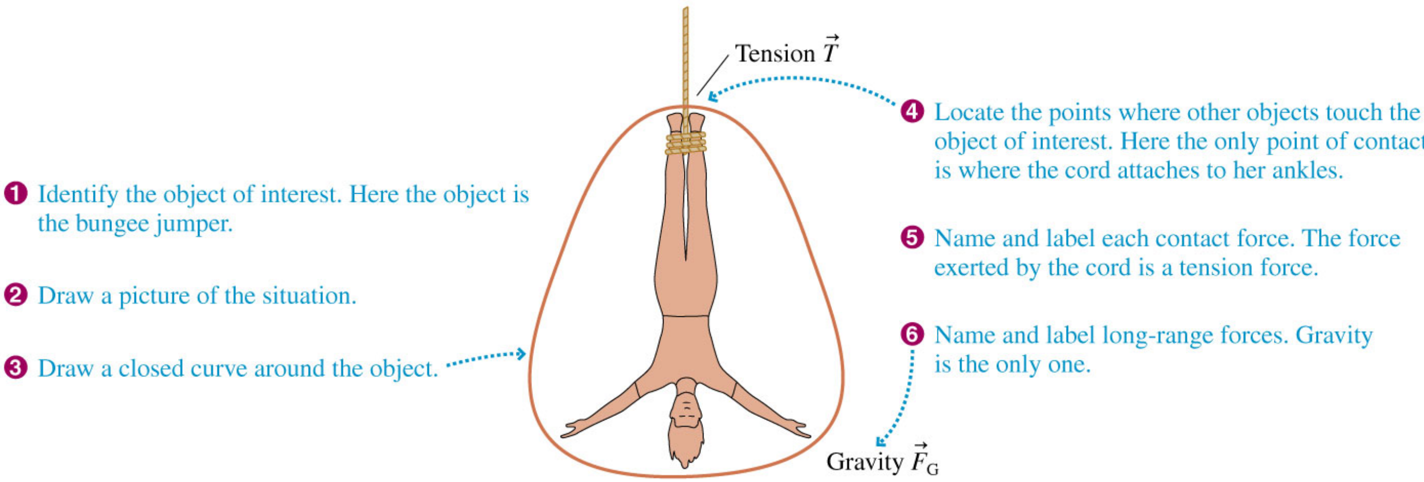
1. **Identify the object of interest.** This is the object you wish to study.
2. **Draw a picture of the situation.** Show the object of interest and all other objects—such as ropes, springs, or surfaces—that touch it.
3. **Draw a closed curve around the object.** Only the object of interest is inside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

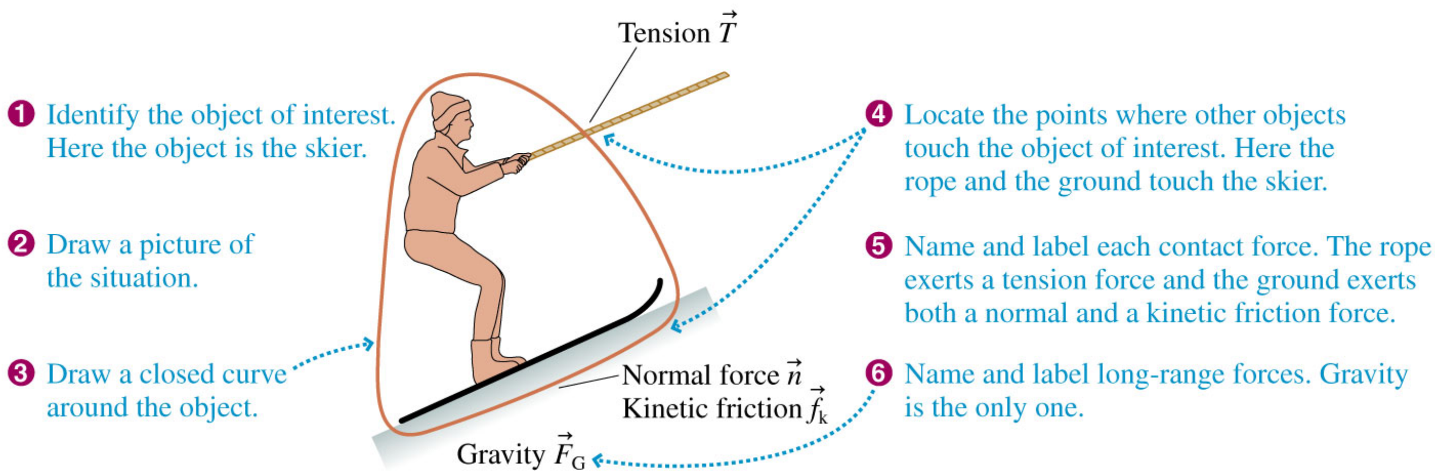
VISUALIZE



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?

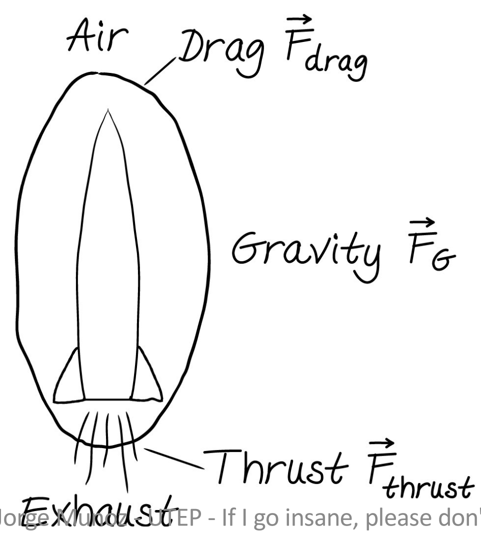
VISUALIZE



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?

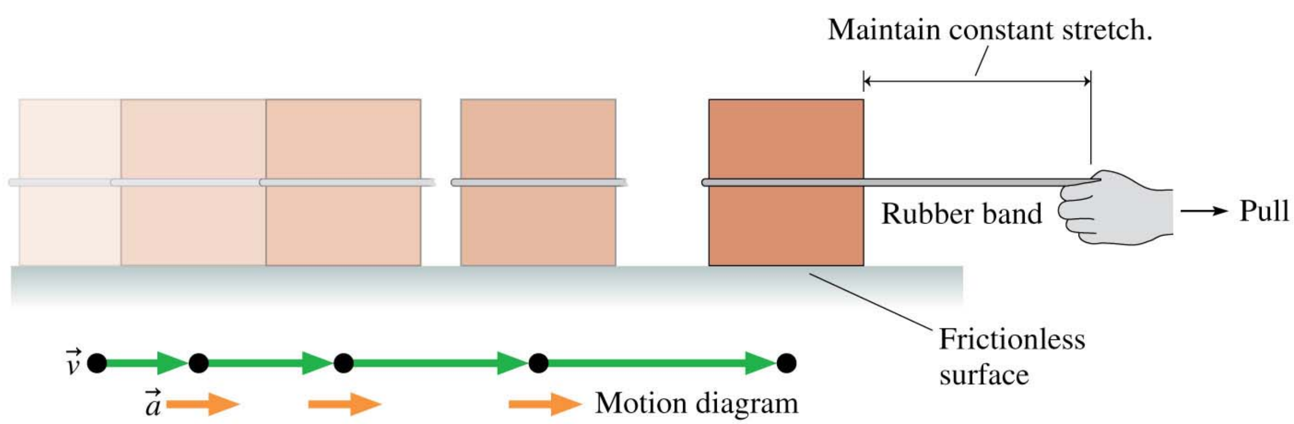
VISUALIZE This drawing is much more like the sketch you would make when identifying forces as part of solving a problem.



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

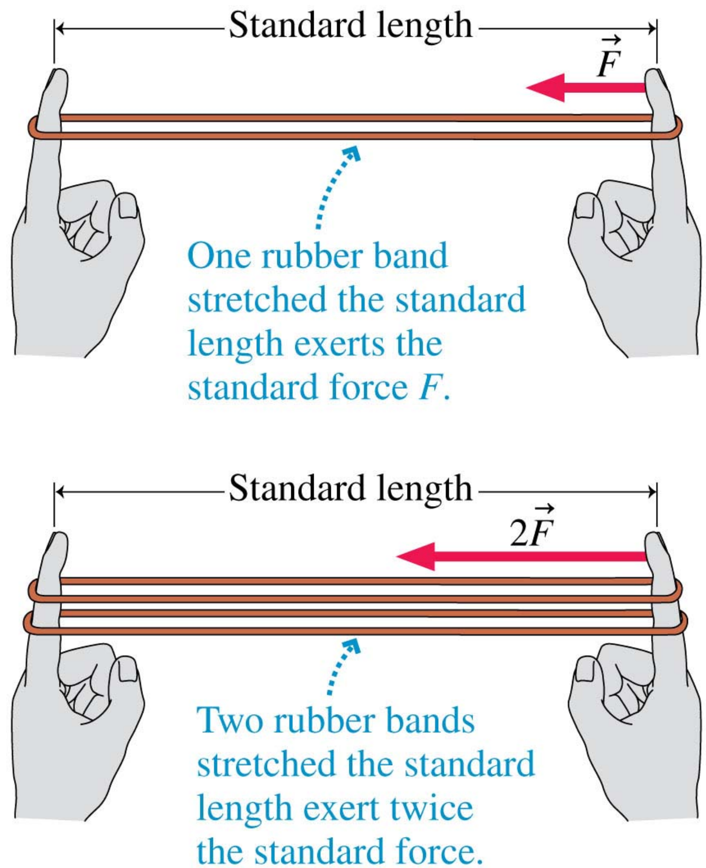
What if not fixed?

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

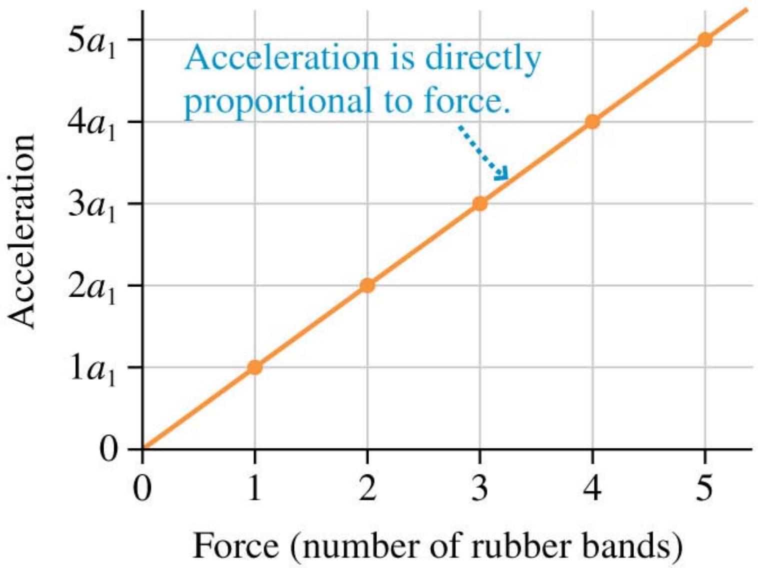


Our friend the motion diagram!

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



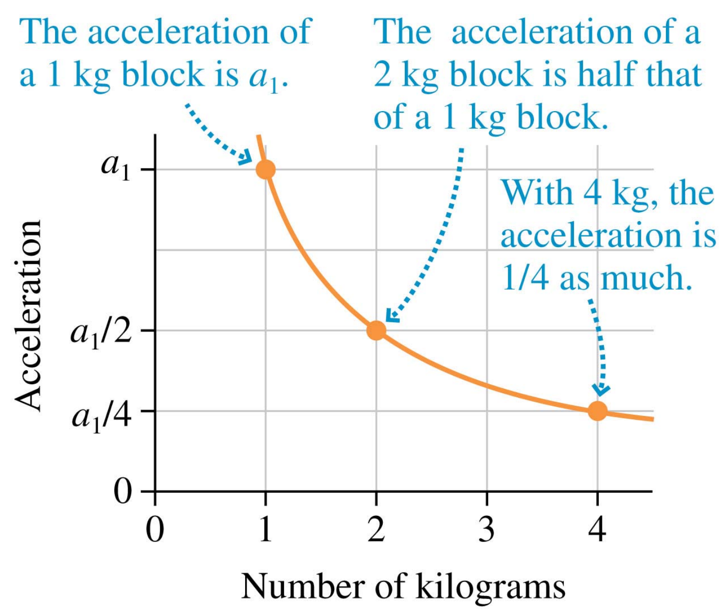
- When a 1 kg block is pulled on a frictionless surface by a single elastic band stretched to the standard length, it accelerates with *constant acceleration* a_1.
- Repeat the experiment with 2, 3, 4, and 5 rubber bands attached side-by-side.



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

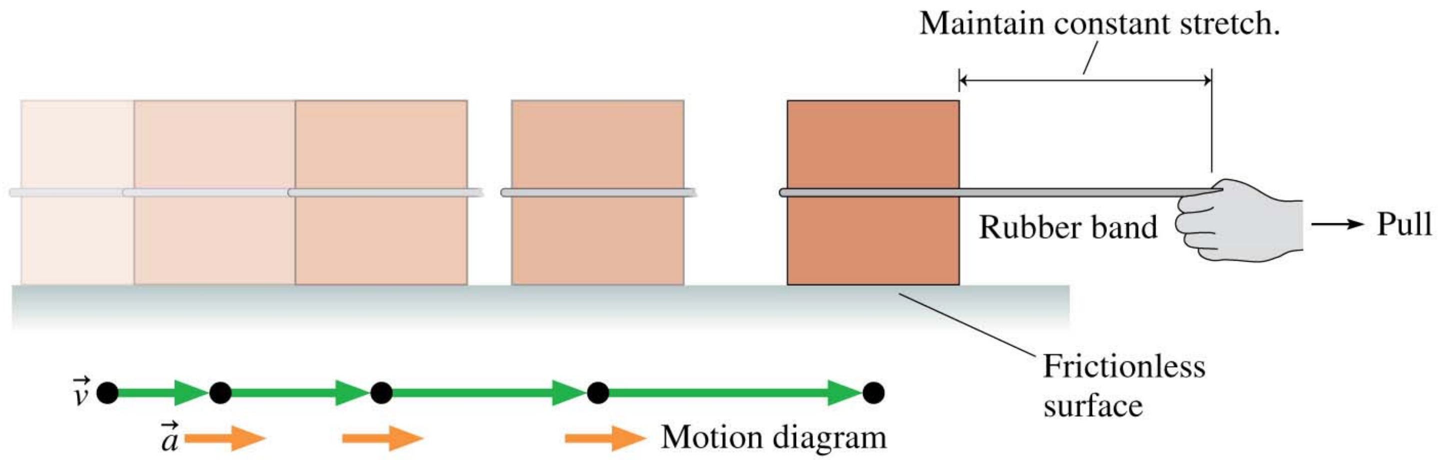
What is the proportionality constant?

- 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.

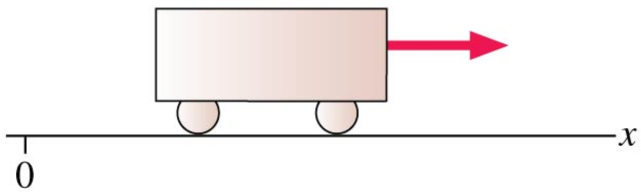


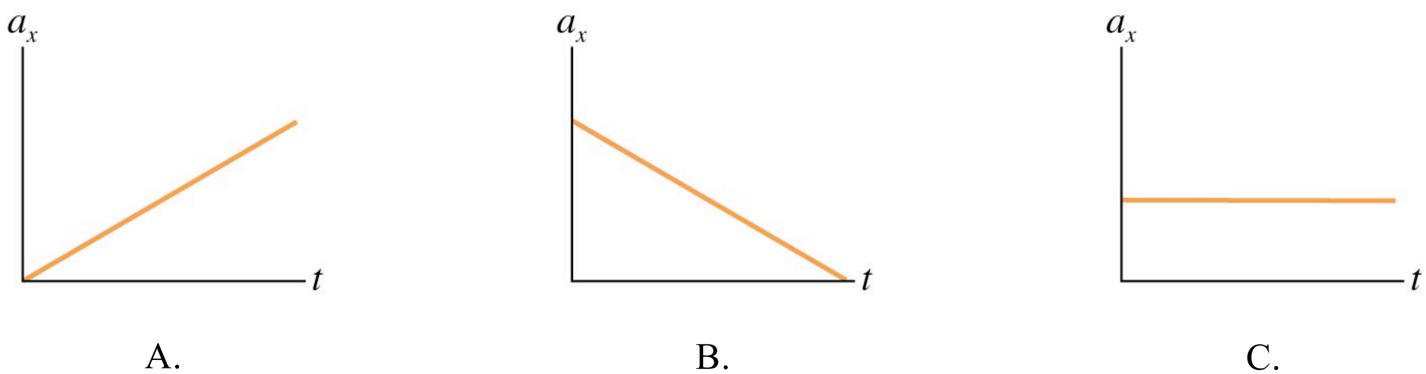
- **The acceleration is inversely proportional to the mass.**

- 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).
- $1\ \text{N} = 1\ \text{kg m/s}^2$

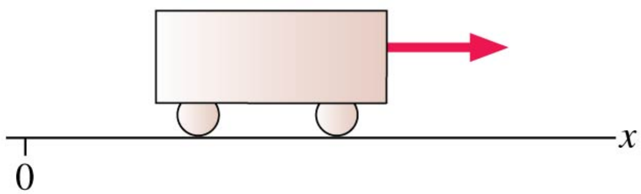


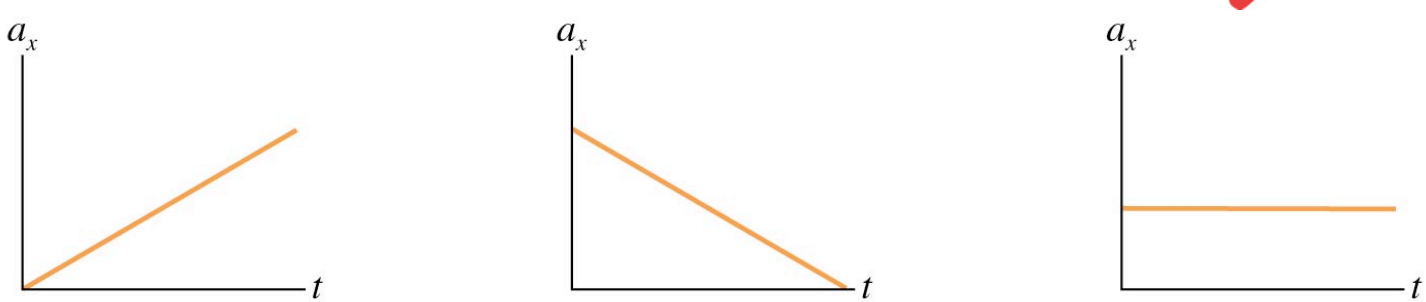
A cart is pulled to the right with a constant, steady force. How will its acceleration graph look?





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 <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