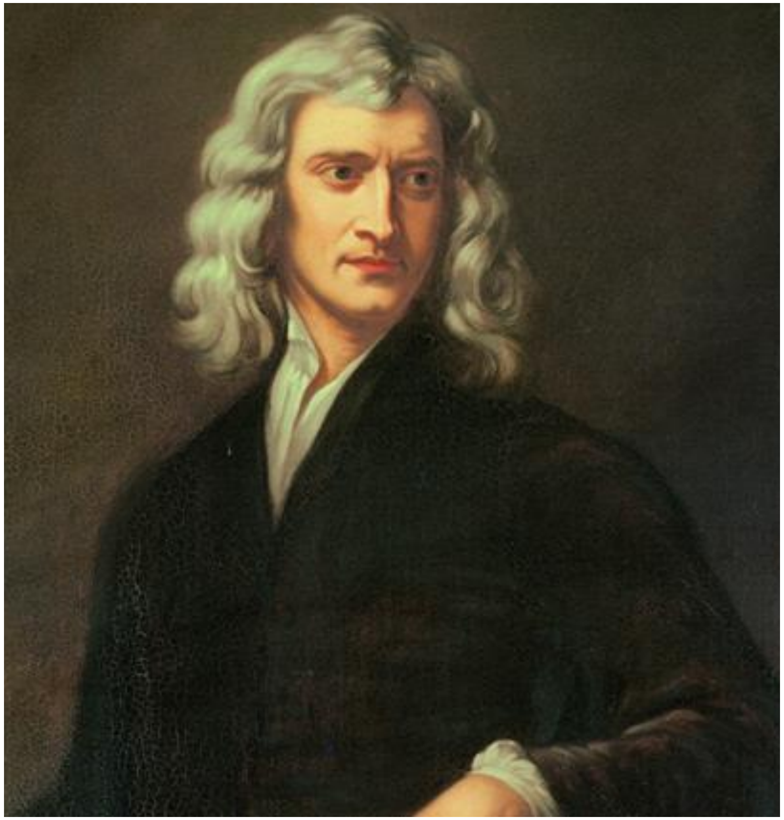
Chapter 4

Newton's Laws

Isaac Newton
1642 - 1727



Some inventions and discoveries:

- 3 laws of motion
- Universal law of gravity
- Calculus
- Ideas on:
  - Sound
  - Light
  - Thermodynamics
- Reflecting telescope

In this chapter, we study his 3 laws of motion which have to do with how forces affect an object's motion.

What is a force?

In everyday language it is a push or a pull.

Some forces we will use in physics 1114:

1) Gravity (Weight)
2) Friction
3) Normal
4) Tension

- A force is *always* the interaction between two objects!
- For every force, you should notice what causes the force and what object the force acts on.
- The SI unit of force is a Newton (N) and the British unit of force is a pound (lb). More on this later…

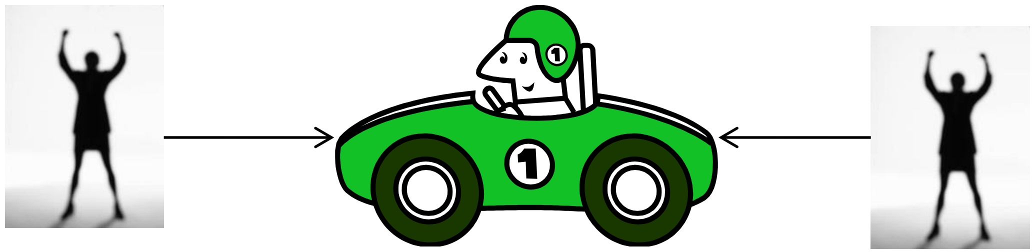
Newton's First Law

An object remains at rest, or at a constant speed in a straight line, unless it is acted upon by a net external force.

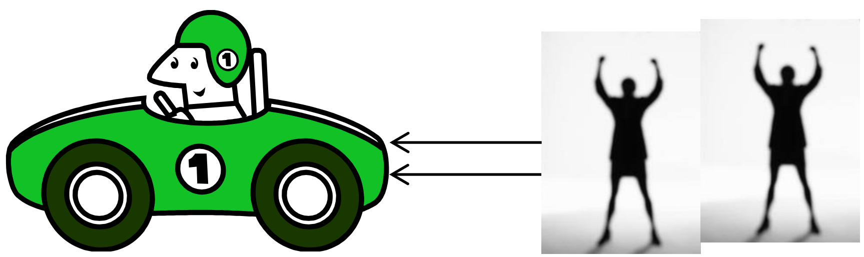
- If an object is either stationary, or moving at a constant speed in a straight line, there is no net force acting on the object.
  - There may be many forces acting on the object, but there is no *net* force acting on the object.
  - Force is a vector, and the net force is the sum of all the forces acting on an object

Pushing a car

You and your friend each push a car at rest with the same force



Car has forces acting on it, but total force is 0 so it does not move



Car now has a net force and will move

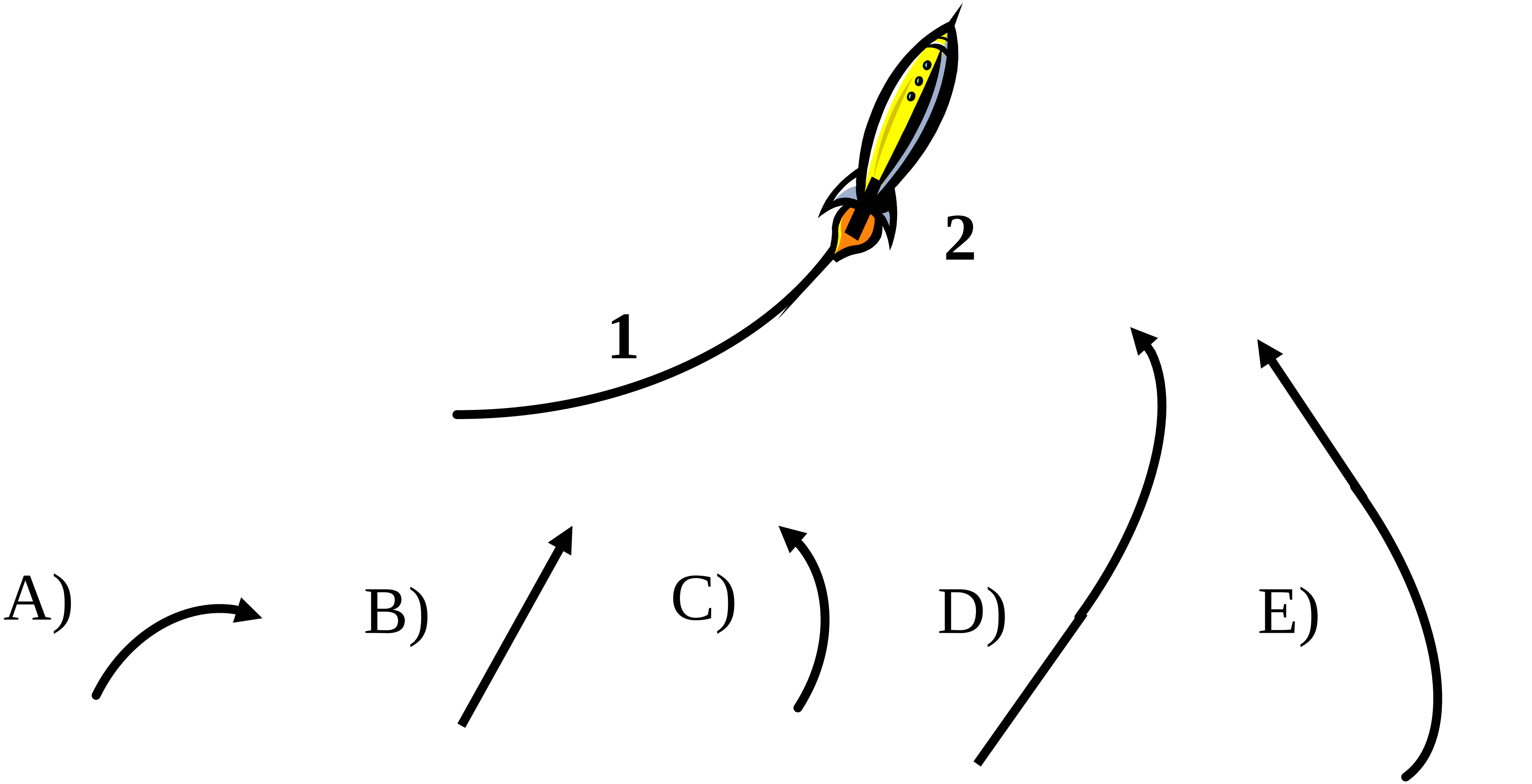
Interactive Question

When the rocket engines of a starship are suddenly turned off, while traveling in empty space far from any stars or planets, the starship will

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

Interactive Question

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



Interactive Question

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

A) The forces acting to make the car go in the forward direction must be greater than the forces acting to make the car go in the backward direction, or the car would not go forward.

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

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

D) There is not enough information to say anything.

Interactive Question

If a single non-zero force is acting on an object, what kind of motion is *not* allowed?

A) The object could be speeding up.
B) The object could be slowing down.
C) The object could be at moving at a constant velocity.
D) The object could be turning.
E) None of the above. They are all allowed

Inertia

- The force required to change an object's state of motion is a measure of the inertia of the body.
- This measure of inertia is called "mass".
- Objects with large inertia, or mass, require a larger force to achieve the same change in the state of motion.
- A change in the state of motion is described as an acceleration.
- SI unit of mass is kilograms (kg)
- British unit of mass is slugs.

Newton's Second Law

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

$$\mathbf{F}_{\text{net}} = m\mathbf{a}$$

This is a vector equation. So it really means:

$$F_{\text{net,(horizontal)}} = ma_{\text{(horizontal)}}$$

$$F_{\text{net,(vertical)}} = ma_{\text{(vertical)}}$$

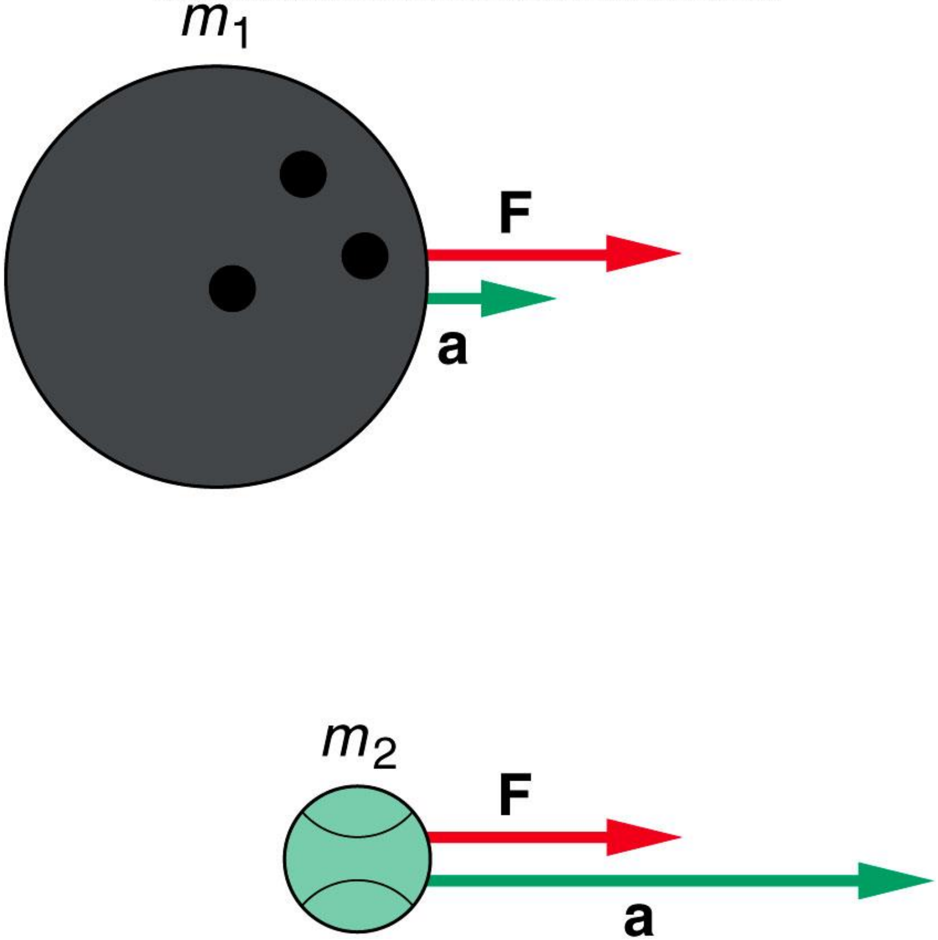
$$\mathbf{F}_{net} = m\mathbf{a}$$

- The left hand side is the *net* force acting *on* the object with the mass *m*.
- The right hand side is the effect of the net force acting on that object.
- The SI unit of force is a Newton (N) = $kg \cdot m/s^2$
- The British unit of force is a pound (lb)
- Newton's 1st law is a special case of the 2nd law when $\mathbf{a}=0$.
- The acceleration in Newton's second law can be related to the acceleration in the equations of motion from Chapters 2 and 3.

Newton's Second Law of Motion

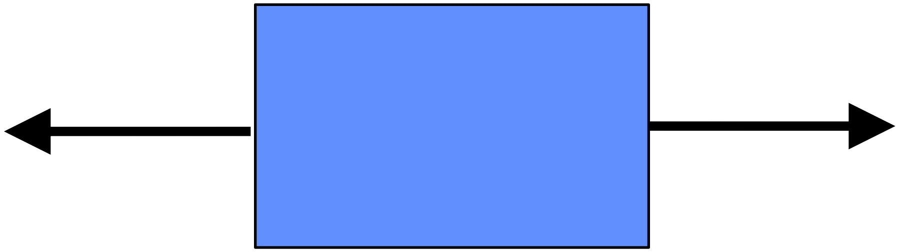
$$\mathbf{F}_{net} = m\mathbf{a}$$

The same net force on an object with more mass will produce less acceleration.



Interactive Question

A box has two forces acting on it as shown by the arrows which have the same length and point in opposite directions. What can you say about the motion of this box?



A) It is definitely not moving

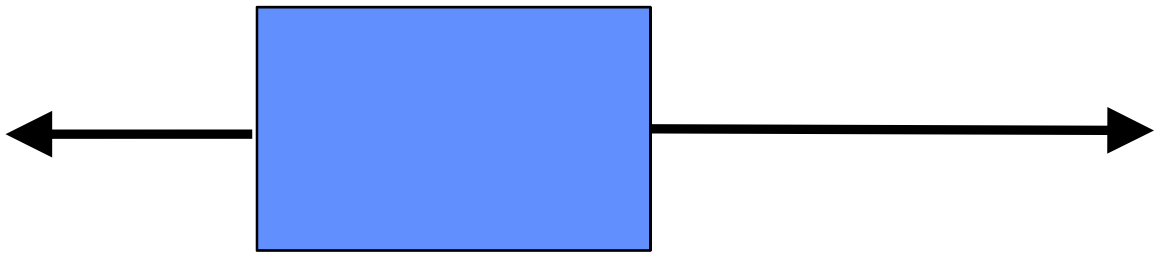
B) It may be moving at a constant velocity or stationary

C) It may be accelerating

D) Not enough information is given

Interactive Question

A box has two forces acting on it as shown by the arrows which have the different lengths and point in opposite directions. What can you say about the motion of this box?



A) It is definitely not moving

B) It is definitely moving to the right

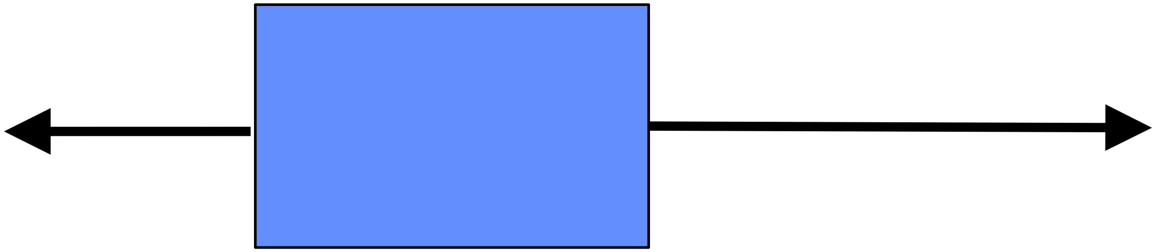
C) It may be moving at a constant velocity or stationary

D) It may be accelerating but not necessarily

E) It is definitely accelerating

Interactive Question

A box has two forces acting on it as shown by the arrows which have the different lengths and point in opposite directions. What can you say about the motion of this box?



A) It is definitely moving to the right

B) It is definitely accelerating to the right

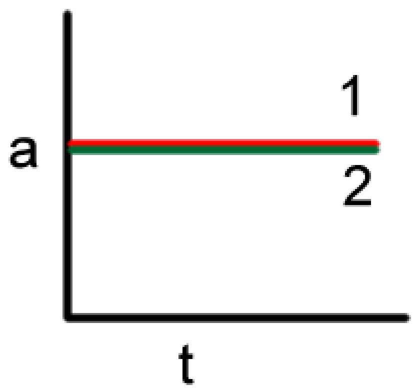
C) Both of the above

D) None of the above

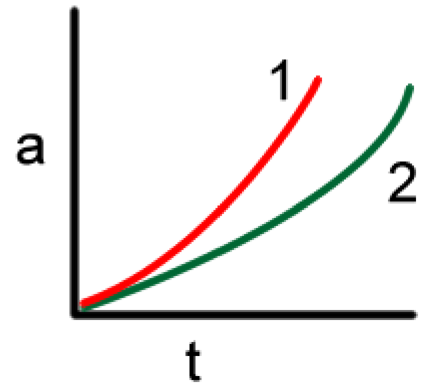
Interactive Question

A constant force *F* acts on block 1 with mass *m* and block 2 with mass 2*m*. Which graph correctly represents the accelerations of the blocks ?

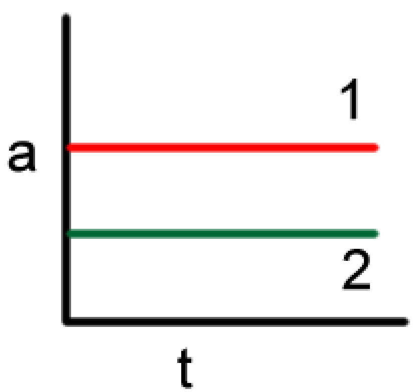
(A)



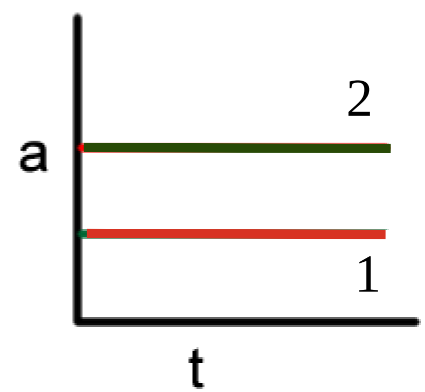
(B)



(C)



(D)



Interactive Question

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

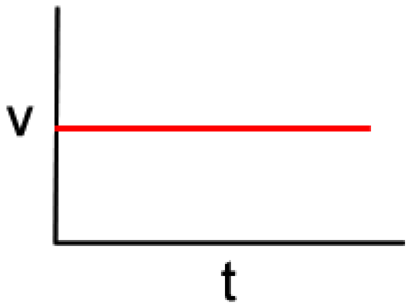
A) a
B) $2a$
C) $3a$
D) $4a$
E) $6a$

Problem: You push horizontally on a box with a 40 N force. A 30 N frictional force opposes the motion. The box accelerates at a rate of 2.2 m/s^2. What is the mass of the box?

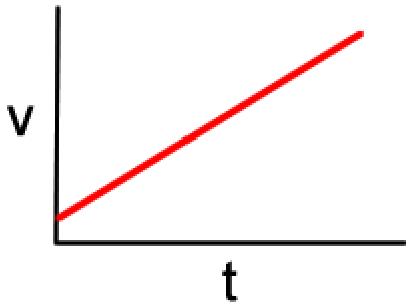
Problem: A 12,500 lb truck (which has a mass of 5680 kg) is traveling at 33 mi/hr when it applies its brakes and comes to a stop in 4.5 seconds. What was the average net force stopping the truck (in Newtons)?

Interactive Question

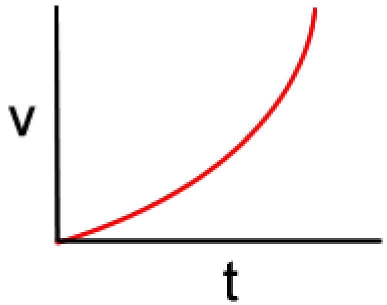
A constant force is acting on an object. Which of these graphs best represents the velocity of the object?



(A)



(B)

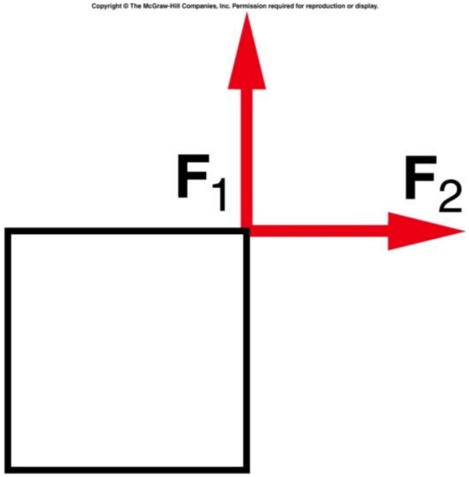


(C)

Interactive Question

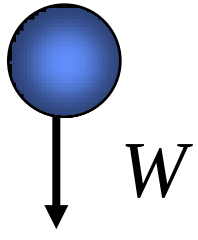
Two equal forces act on an object in the directions shown. If these are the only forces involved, what can you say is definitely true about the motion of the object?

A) It is moving at a constant velocity.
B) It is speeding up
C) It is slowing down
D) It is accelerating
E) Nothing, not enough information



The Force of Gravity: Weight

Consider an object that has only the force of gravity acting on it. We'll call this force *W*. (You'll see why later.)



From Newton's second law

$F_{net} = ma$

$W = ma$

But we also know, that the acceleration of this object will be a constant value we call *g*.

So the strength of the force of gravity, $W = mg$

This force of gravity pulling on an object is called weight.

Mass, Weight, and Inertia

- Mass is a measure of an object's inertia.
  - The SI units of mass are kilograms (kg).
  - Inertia is an object's resistance to a change in its motion so mass is used in Newton's 2nd law, $F_{net} = ma$.
  - A larger force is required to produce the same acceleration for a larger mass.
  - The mass of an object doesn't change as you move the object to a different planet or location.
- Weight is the gravitational force acting on the object.
  - The SI units of weight are newtons (N).
  - The weight of an object depends on the where the location of the object. In the absence of gravity the object has no weight, but still has mass.

We say that 1.0 kg is 2.2 lbs, but this is not an accurate statement because pounds is a unit of weight and kilograms is a unit of mass. Only on earth does a 1.0 kg mass have a weight of 2.2 lbs. In general,

$$F = mg = (1.0\ \text{kg}) \times (10\ \text{m/s}^2) = 10\ \text{N} = 2.2\ \text{lb}$$

because a mass of 1 kg feels a force of 9.8 N on earth.

So 2.2 lb = 10 N, or 1 lb = 4.5 N

Problem: A car has a weight of 3500 lbs. What is the mass of the car in British units?

Interactive Question

Object A is more massive than object B. Which of the following statements is true?

A) Both object A and object B experience the *same* gravitational force.

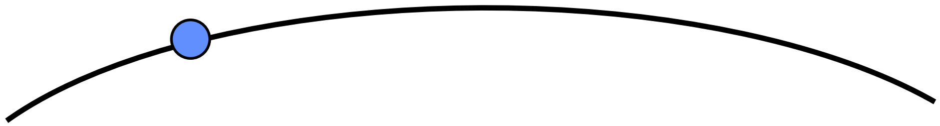
B) Both object A and object B experience the *same* gravitational acceleration.

C) Object A experiences a *greater* gravitational force and *greater* gravitational acceleration than object B.

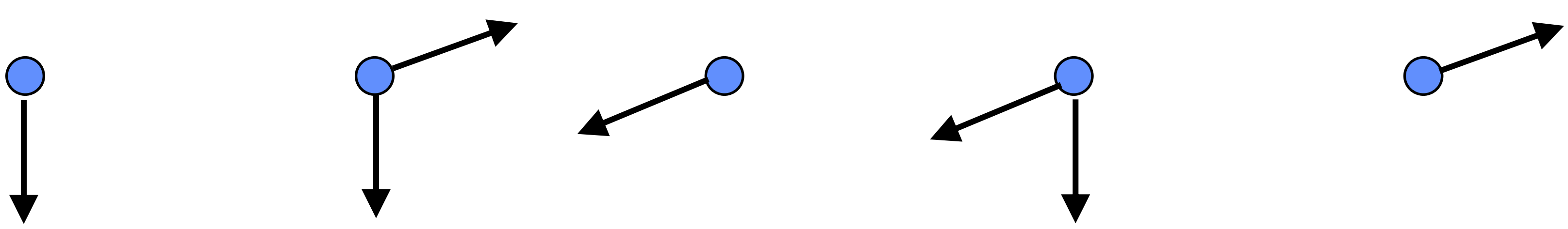
D) More than one of the above is true

Interactive Question

A ball is thrown through the air and follows the path shown. It is traveling from the left to the right.



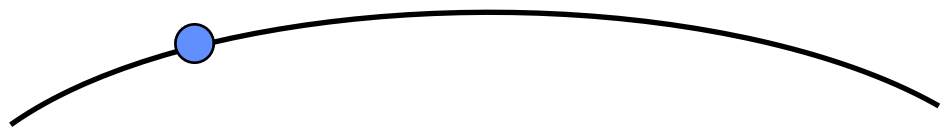
When the ball is at the position shown, which of the following diagrams correctly shows the forces acting on the ball, neglecting air resistance.



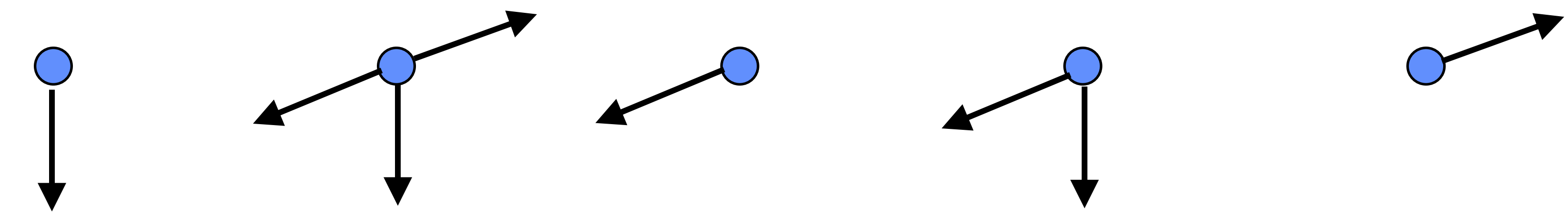
(A) (B) (C) (D) (E)

Interactive Question

A ball is thrown through the air and follows the path shown. It is traveling from the left to the right.

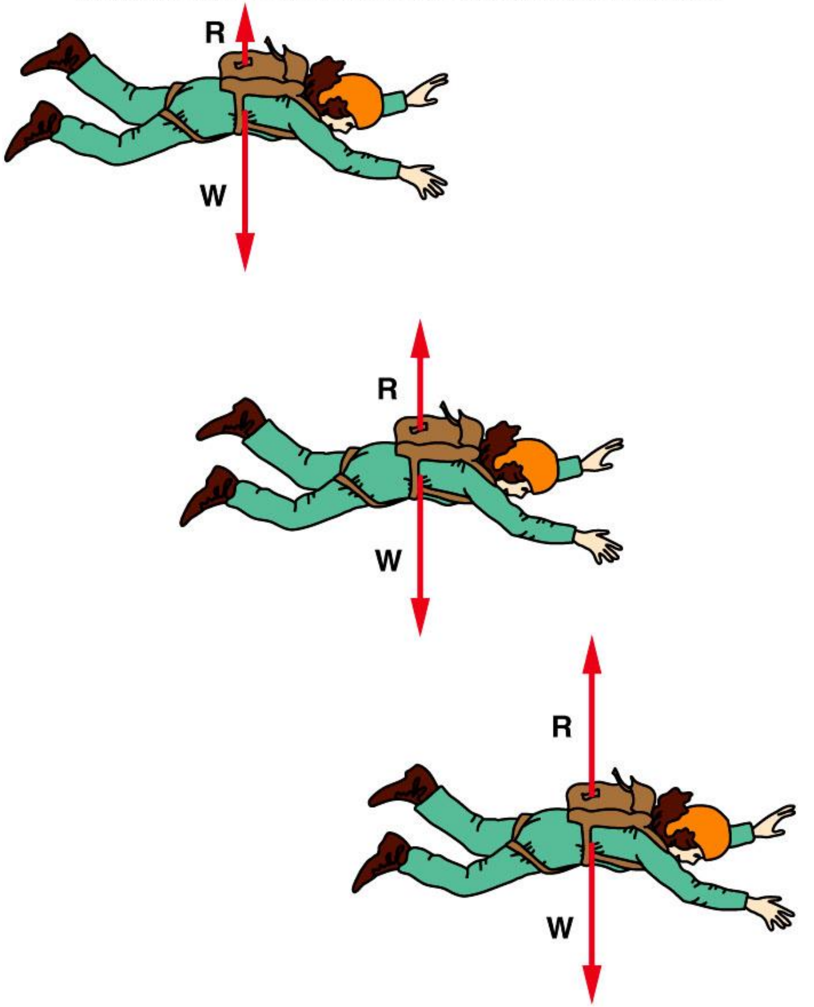


When the ball is at the position shown, which of the following diagrams correctly shows the forces acting on the ball, not neglecting air resistance.

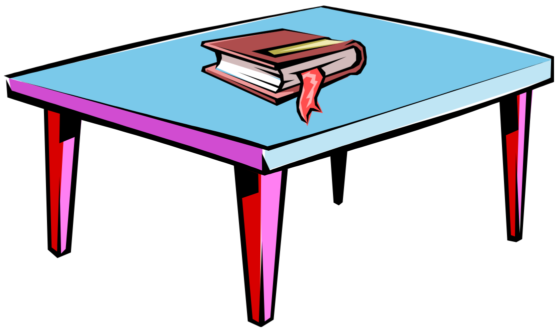


(A) (B) (C) (D) (E)

- When an object moves fast enough through the air we cannot ignore air resistance.
- Air resistance always acts opposite the direction of motion.
- For instance as a sky diver falls, her weight **W** stays the same but the force of air resistance **R** increases as her speed increases.
- When the force of air resistance has increased to equal the magnitude of her weight, the net force is zero so the acceleration is zero ($F_{net} = ma$)
- The velocity is then at its maximum value, the ***terminal velocity***

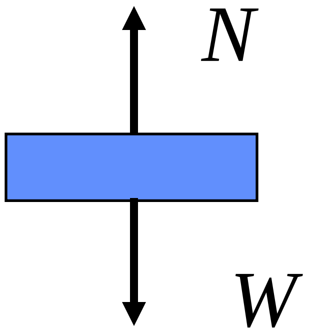


The Normal Force



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

We call the force of the table pushing up on the book the “Normal” force which means perpendicular. Whenever one object pushes on another it produces this normal force.



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

The normal force is not always equal to the weight, as this problem illustrates.

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

Problem: A book with a mass of 0.80 kg is stationary on a table. You have a weight of 640 N and sit on the book. What is the normal force acting on the book?

Interactive Question

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

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

the downward weight W of the person

Interactive Question

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

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

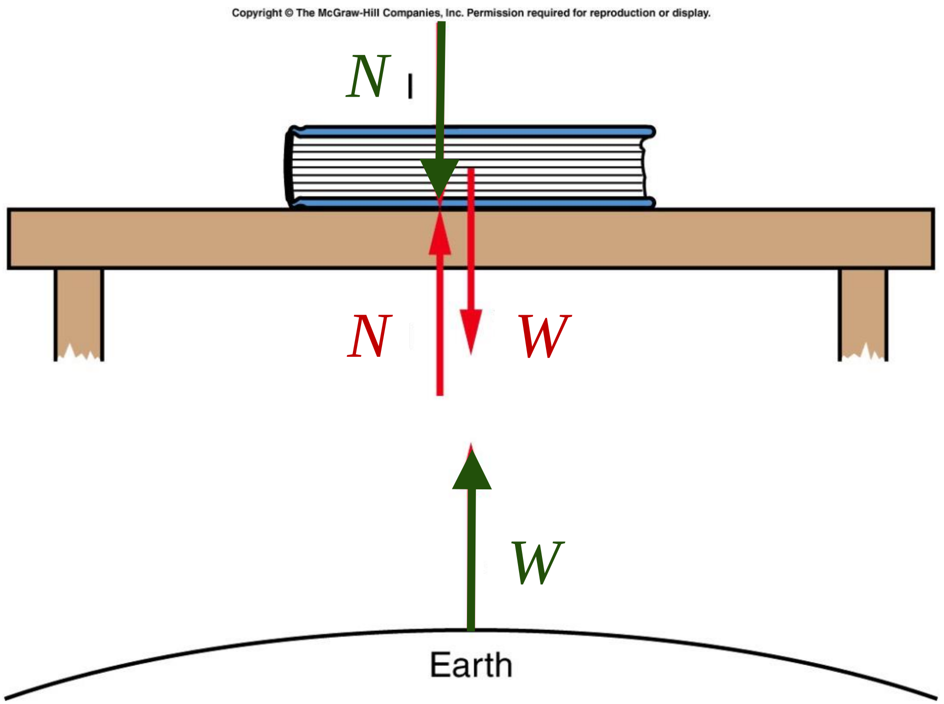
the downward weight W of the person

Newton's Third Law

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

Let's look at a book sitting on a table in light of Newton's 2nd and 3rd laws.

- The two forces acting on the book are the weight of the book, *W*, (the force of the earth pulling down on the book), and the normal force, *N*, (the force of the table pushing up on the book.).
- Because of Newton's 2nd law, $F_{net} = ma = 0$, $W = N$.



- By Newton's 3rd law, we also know that the book pushes down on the table with the same force as the table pushes up on the book, *N*, and that the book pulls up on the earth with the same force that the earth pulls down on the book, *W*.

Interactive Question

A ping-pong ball collides with a bowling ball. Which of experiences a greater force from the other one due to the collision?

A) The ping-pong ball
B) The bowling ball
C) They experience the same force
D) The force on each depends on its velocity
E) The force on each depends on its mass

Interactive Question

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

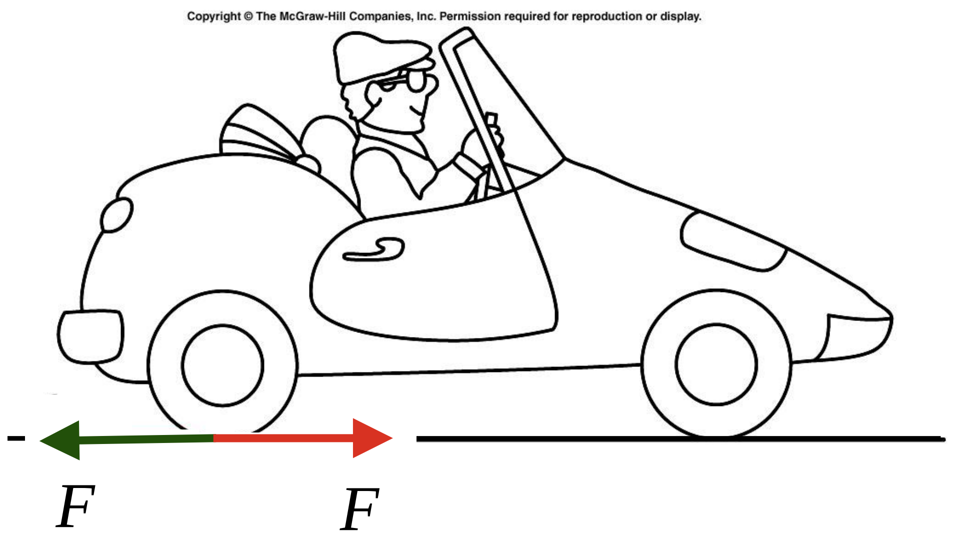
(1) the force of the earth pulling on the book
(2) the force of the table pushing on the book
(3) the force of the book pushing on the table
(4) the force of the book pulling on the earth

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

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

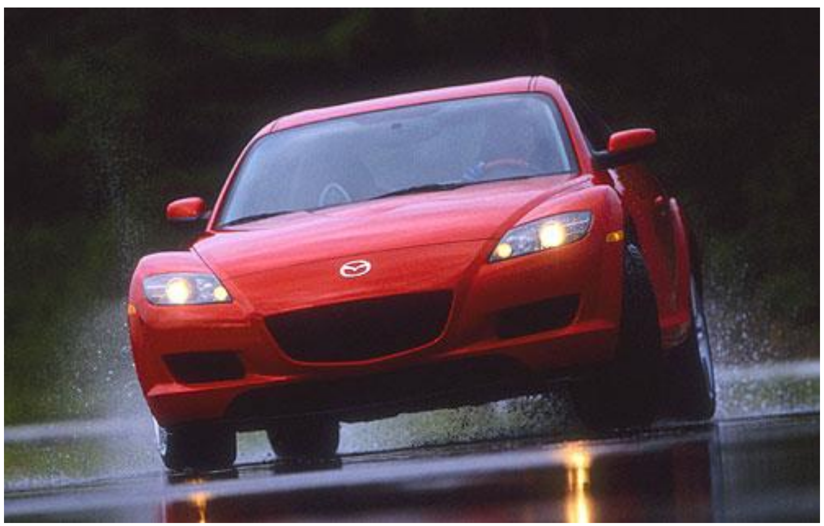
Newton's 3rd law, and Motion

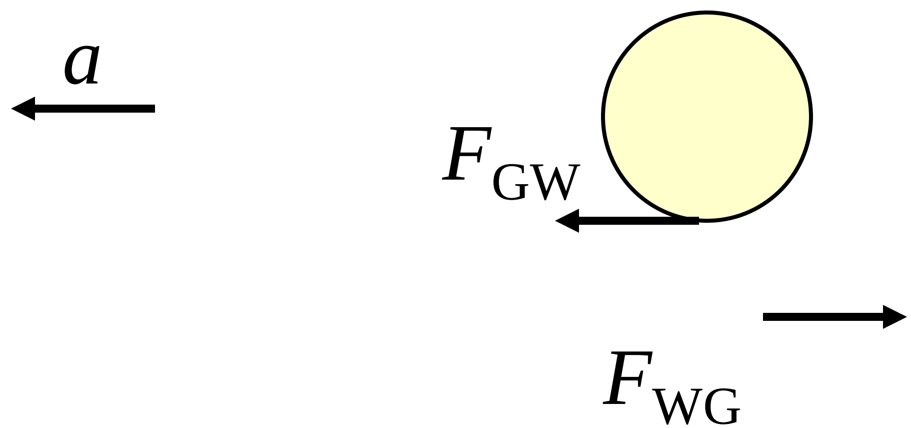
What makes a car accelerate forward?



The car's wheels push against the road (a force on the road), and by Newton's 3rd law, the road pushes back against the car (a force on the car). It is this force on the car which makes the car accelerate forward.

Friction, Newton's 3rd Law, and Motion





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

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

Interactive Question

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

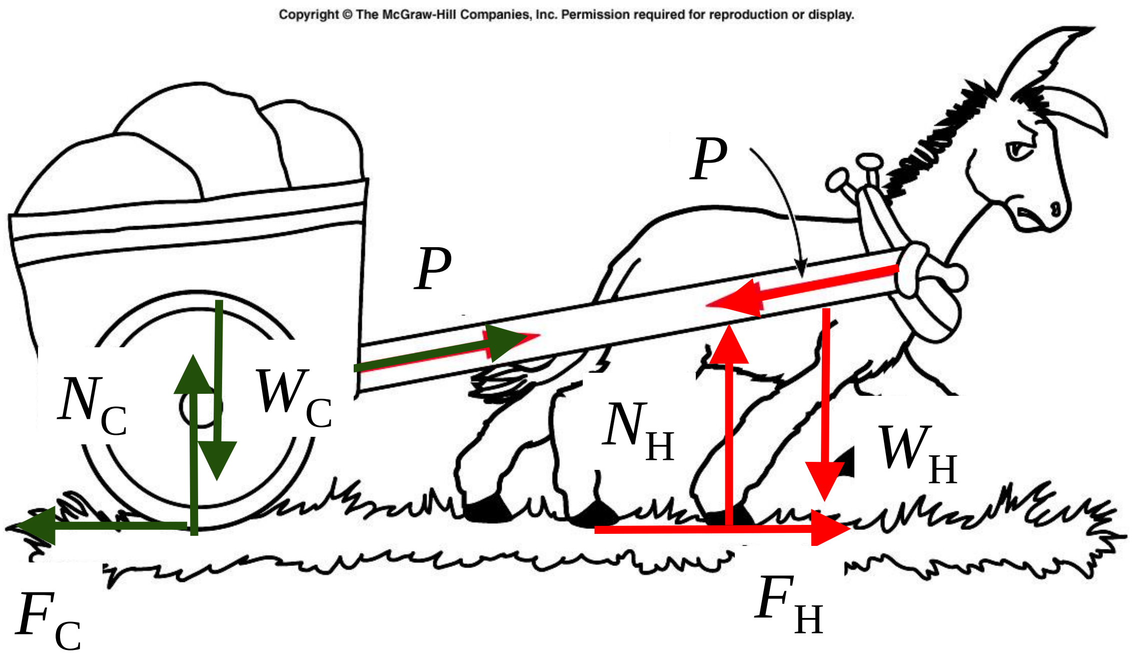
(1) The force of the horse pulling on the cart.
(2) The force of the cart pulling on the horse.
(3) The force of the horse pushing on the road.
(4) The force of the road pushing on the horse.

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

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

Third-Law Action/Reaction Pair

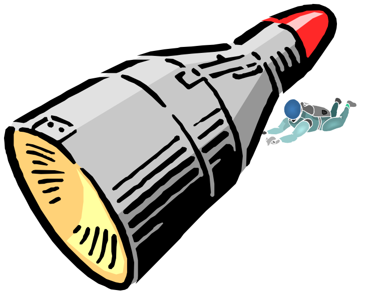
The cart pulls back on the horse with the same magnitude of force as the horse pulls forward on the cart. So how does this system ever move?



To analyze why the horse moves we must look only at the forces acting on the horse and to analyze why the cart moves we must look only at the forces acting on the cart.

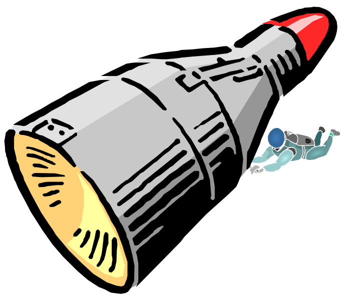
Interactive Question

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



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

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

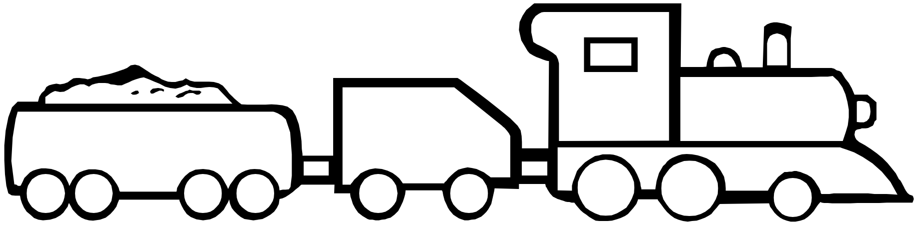


Systems, Internal Forces, and External Forces

- You can always solve problems with more than one object by working with each object separately as a "system."
- Sometimes it is more convenient to chose a number of objects as a system.
- Internal forces are forces that act only between objects in the system.
- External forces act between an object outside of the system and an object inside the system.
- In Newton's second law, only external forces need to be considered.

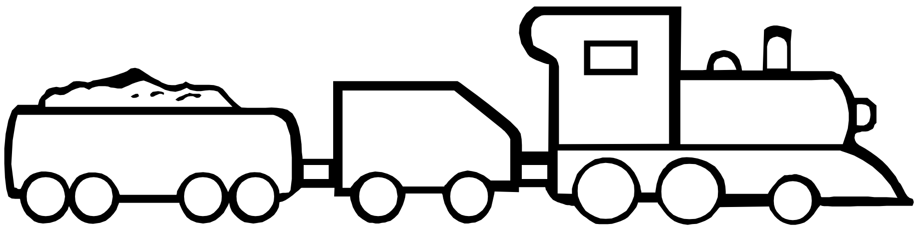
Interactive Question

A train is *accelerating* to the right. There is no friction opposing the motion. How does the tension between the engine and the 2^{nd} car compare with the tension between the 2^{nd} car and the third car?



A) It is less.
B) It is the same.
C) It is greater.
D) More information is needed.

Problem: A train is *accelerating* at a rate of 5.0 m/s^2. There is no friction opposing the motion. What is the tension between each of the cars?



1500 kg 1000 kg 2500 kg

Problem: A 4 kg block and a 2 kg block can move on a horizontal surface. The blocks are pushed by a 24 N force in the positive *x* direction as shown. A frictional force of 8 N acts on the 4 kg block and a frictional force of 4 N acts on the 2 kg block.

A) What is the net force acting on the two blocks?

B) Determine the acceleration of the blocks.

C) What is the force of the 2 kg block pushing on the 4 kg block?