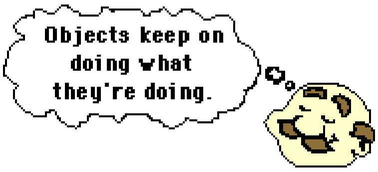
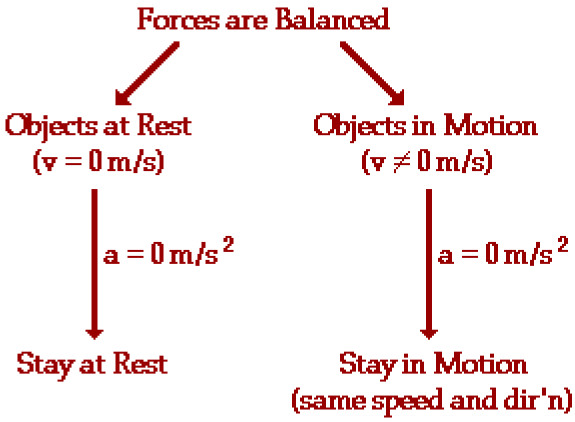


Newton's First Law of Motion

Isaac Newton (a 17th century scientist) put forth three laws which explain why objects move (or don't move) as they do and these three laws have become known as Newton's three laws of motion.

Newton's first law of motion is often stated as:

An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction <u>unless acted upon by an external force</u>.



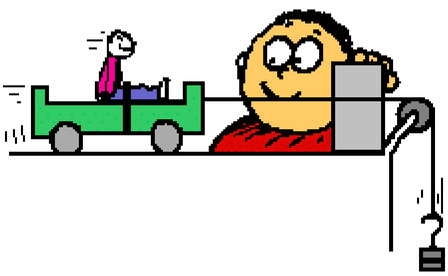
The behavior of all objects can be described by saying **that objects tend to "keep on doing what they're doing"** (<u>unless acted upon by an external force</u>). If at rest, they will continue in this same state of rest. If in motion with an eastward velocity of 5 m/s, they will continue in this same state of motion (5 m/s, East). If in motion with a leftward velocity of 2 m/s, they will continue in this same state of motion (2 m/s, left). **The state of motion of an object is maintained as long as the object is not acted upon by an external force.** All objects resist changes in their state of motion – they tend to "keep on doing what they're doing."

There is a Pass the Water exercise that demonstrates this principle. If students participate in a relay race carrying a plastic container of water around a race track, the water will have a tendency to spill from the container at specific locations on the track. In general the water will spill when:

the container is at rest and you attempt to move it

the container is in motion and you attempt to stop it

the container is moving in one direction and you attempt to change its direction.



The behavior of the water during the relay race can be explained by Newton's first law of motion. The water spills whenever the **<u>state of motion</u>** of the container changes. The water resists this change in its own state of motion and tends to "keep on doing what it is doing." If the container is moved from rest to a high speed at the starting line; the water remains at rest and spills onto the table. When the container stops near the finish line; the water keeps moving and spills over the container's leading edge. If the container is forced to move in a different direction to make it around a curve; the water keeps moving in the original direction and spills over its edge.

There are many applications of Newton's first law of motion. Consider some of your experiences in an automobile. Have you ever observed the behavior of coffee in a coffee cup filled to the rim while starting a car from rest or while bringing a car to rest from a state of motion? Coffee tends to "keep on doing what it is doing." When you accelerate a car from rest, the road provides an external force on the spinning wheels to push the car forward; yet the coffee (which is at rest) wants to stay at rest. While the car accelerates forward, the coffee remains in the same position; subsequently, the car accelerates out from under the coffee and the coffee spills in your lap. On the other hand, when braking from a state of motion the coffee continues to move forward with the same speed and in the same direction, ultimately hitting the windshield or the dashboard. Coffee in motion tends to stay in motion.

Have you ever experienced **inertia** (resisting changes in your state of motion) in an automobile while it is braking to a stop? The force of the road on the locked wheels provides the external force to change the car's state of motion, yet there is no external force to change your own state of motion. Thus, you continue in motion, sliding forward along the seat. A person in motion tends to stay in motion with the same speed and in the same direction ... unless <u>acted upon by the external force</u> of a seat belt. Yes, seat belts are used to provide safety for passengers whose motion is governed by Newton's laws. The seat belt provides the external force which brings you from a state of motion to a state of rest. Perhaps you could speculate what would occur when no seat belt is used.

The Car and The Wall

According to Newton's first law, an object in motion continues in motion with the same speed and in the same direction unless acted upon by an external force. It is the natural tendency of objects to keep on doing what they're doing. All objects resist changes in their state of motion. In the absence of an external force, an object in motion will maintain this state of motion. This is often called the **law of inertia.**

The law of inertia is most commonly experienced when riding in cars and trucks. In fact, the tendency of moving objects to continue in motion is a common cause of a variety of transportation accidents - of both small and large magnitudes. Consider for instance the unfortunate collision of a car with a wall. Upon contact with the wall, an external force acts upon the car to abruptly decelerate it to rest. Any passengers in the car will also be deccelerated to rest if they are strapped to the car by seat belts. Being strapped tightly to the car, the passengers share the same state of motion as the car. As the car accelerates, the passengers accelerate with it; as the car decelerates, the passengers decelerate with it; and as the car maintains a constant speed, the passengers maintain a constant speed as well.

But what would happen if the passengers were not wearing the seat belt? What motion would the passengers undergo if they failed to use their seat belts and the car were brought to a sudden and abrupt halt by a collision with a wall? Were this scenario to occur, the passengers would no longer share the same state of motion as the car. The presence of the strap assures that the forces necessary for accelerated and decelerated motion exist. Yet, once the strap is no longer present to do its *job*, the passengers are more likely to maintain its state of motion.

If the car were to abruptly stop and the seat belts were not being worn, then the passengers in motion would continue in motion. Assuming a negligible amount of friction between the passengers and the seats, the passengers would likely be propelled from the car and be hurled into the air. Once they leave the car, the passengers becomes projectiles and continue in projectile-like motion.

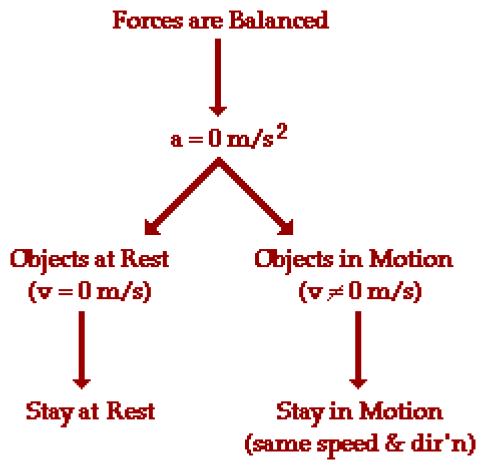
Now perhaps you will be convince of the need to wear your seat belt. Remember it's the law - the law of inertia.

There are many more applications of Newton's first law of motion. Several applications are listed below – try to provide explanations for each application.

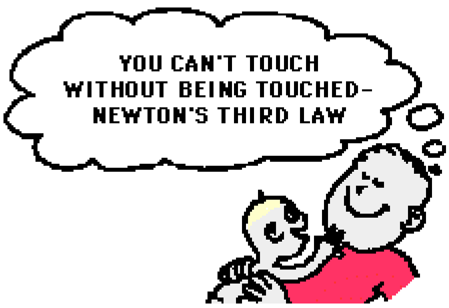
1. blood rushes from your head to your feet when riding on a descending elevator which suddenly stops.
2. the head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.
3. a brick is painlessly broken over the hand of a physics teacher by slamming the brick with a hammer. (CAUTION: Do not attempt this at home!)
4. to dislodge ketchup from the bottom of a ketchup bottle, the bottle is often turned upside down, thrust downward at a high speed and then abruptly halted.
5. headrests are placed in cars to prevent whiplash injuries during rear-end collisions.
6. while riding a skateboard (or wagon or bicycle), you fly forward off the board when hitting a curb, a rock or another object which abruptly halts the motion of the skateboard.

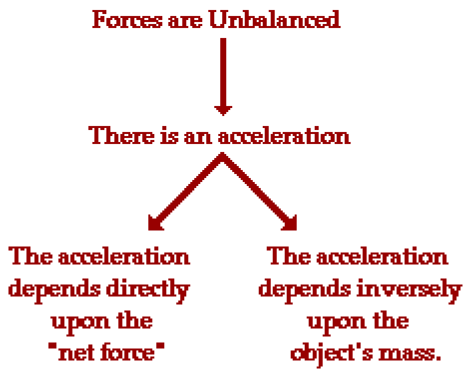
Newton's Second Law of Motion

Newton's first law of motion predicts the behavior of objects for which all existing forces are balanced. The first law – sometimes referred to as the "law of inertia" – states that if the forces acting upon an object are balanced, then the acceleration of that object will be 0 m/s^2. Objects at equilibrium (the condition in which all forces balance) will not accelerate. According to Newton, an object will only accelerate if there is a net or external force acting upon it. The presence of an external force will accelerate an object – changing its speed, its direction, or both its speed and direction.



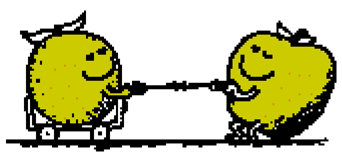
Newton's second law of motion pertains to the behavior of objects for which all existing forces are not balanced. The second law states that the acceleration of an object is dependent upon two variables – the net force acting upon the object and the mass of the object. The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object. As the net force increases, so will the object's acceleration. However, as the mass of the object increases, its acceleration will decrease.





Newton's second law of motion can be formally stated as follows:

The acceleration of an object as produced by a force is directly proportional to the magnitude of the force, in the same direction as the force, and inversely proportional to the mass of the object.



In terms of an equation, the net force is equal to the product of the object's mass and its acceleration.

$$F = m * a$$

The above equation also indicates that a unit of force is equal to a unit of mass multiplied by a unit of acceleration. By substituting standard metric units for force, mass, and acceleration into the above equation, the following unit can be written:

$$1 \text{ Newton} = 1 \text{ kg} * \frac{m}{s^2}$$

Thus, the definition of the standard metric unit of force is given by the above equation.

One Newton is defined as the amount of force required to give a 1-kg mass an acceleration of 1 m/s^2.

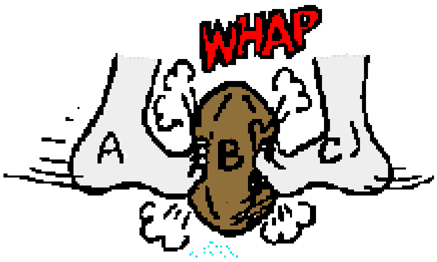
Newton's Third Law of Motion

A force is a push or a pull upon an object which results from its interaction with another object. **Forces result from interactions**! According to Newton, **whenever objects A and B interact with each other, they exert forces upon each other**. When you sit in your chair, your body exerts a downward force on the chair and the chair exerts an upward force on your body. There are two forces resulting from this interaction — a force on the chair and a force on your body. These two forces are called action and reaction forces and are the subject of Newton's third law of motion. Formally stated, Newton's third law is:

"For every action, there is an equal and opposite reaction."

The statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The size of the force on the first object equals the size of the force on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. **Forces always come in pairs – equal and opposite action-reaction force pairs.**

A variety of action-reaction force pairs are evident in nature. Consider the propulsion of a fish through the water. A fish uses its fins to push water backwards. But a push on the water will only serve to accelerate the water. In turn, the water reacts by pushing the fish forwards, propelling the fish through the water. The size of the force on the water equals the size of the force on the fish; the direction of the force on the water (backwards) is opposite to the direction of the force on the fish (forwards). For every action, there is an equal (in size) and opposite (in direction) reaction force. Action-reaction force pairs make it

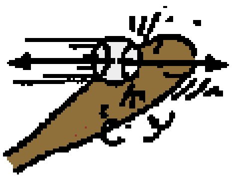


Consider the flying motion of birds. A bird flies by use of its wings. The wings of a bird push air downwards. In turn, the air reacts by pushing the bird upwards. The size of the force on the air equals the size of the force on the bird; the direction of the force on the air (downwards) is opposite to the direction of the force on the bird (upwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for birds to fly.

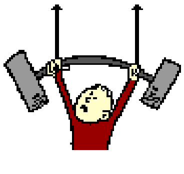
Consider the motion of your automobile on your way to school. An automobile is equipped with wheels that spin backwards. As the wheels spin backwards, they push the road backwards. In turn, the road reacts by pushing the wheels forward. The size of the force on the road equals the size of the force on the wheels (or automobile); the direction of the force on the road (backwards) is opposite to the direction of the force on the wheels (forwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for automobiles to move.

Identifying Action and Reaction Force Pairs

According to Newton's third law, for every action force there is an equal (in size) and opposite (in direction) reaction force. Forces always come in pairs — known as "action-reaction force pairs." Identifying and describing action-reaction force pairs is a simple matter of identifying the two interacting objects and making two statements describing who is pushing on whom and in which direction. For example, consider the interaction between a baseball bat and a baseball.

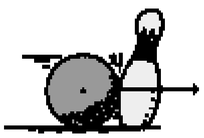


The baseball forces the bat to the right (an action); the bat forces the ball to the left (the reaction). Note that the nouns in the sentence describing the action force switch places when describing the reaction force.



Consider the following three examples. The action force is stated; determine the reaction force

Athlete pushes bar upwards.



Bowling ball pushes pin rightwards.

Compressed air pushes balloon wall outwards.