Newton's Third Law of Motion

Reflect

The world you see is full of **motion** caused by **forces** that push or pull. What forces are acting in the image of the biker? To start, look where objects are in contact. Examples of these pairs of contact forces are the interactions between the road and the tires (the force of the road acts on the tires, and the force of the tires acts on the road), the biker and the air, the seat and the biker, etc. Any pair could be analyzed as a system of interacting forces. Other force pairs can act at a distance, such as the force of gravity between Earth and the rider.

motion – the change in an object's position with respect to time and in comparison to the position of other objects used as reference points

force – a push or pull that can change the motion of an object

Laws of Motion

Sir Isaac Newton, a 17th-century Englishman, was the first to correctly explain the relationship between force and motion. He developed three laws of motion. The first two laws explain the motion of a single object where forces are absent or present.

Newton's first law of motion states that a body at rest remains at rest and a body in motion continues to move at a constant velocity unless acted upon by an external force (law of inertia).

Newton's second law of motion states that acceleration is directly proportional to force and inversely proportional to mass ($F = ma$ or $a = F/m$).

Newton's third law of motion involves pairs of forces that act on two interacting objects, such as those in the biker image. The law states that for every *action* force, there is an equal and opposite *reaction* force. Where objects contact, they interact with pairs of forces (action-reaction) equal in strength but in the opposite direction. When one object exerts a force on a second object, the second object also exerts a force on the first object at the same time.

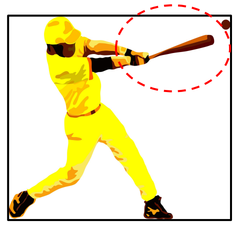
Look Out!

Mass matters! The biggest misunderstanding about Newton's third law is the incorrect assumption that equal and opposite forces result in equal motion. Objects do exert the same amount of force in action-reaction pairs, but the final effect of the forces depends on the mass of the objects. For example, your foot exerts an action force on a kicked soccer ball, while at the same time, the ball exerts an equal and opposite reaction on your foot. You stay put, but the ball flies off. Why? You have much more mass than the ball, so the ball accelerates. The same force that sent the ball into the air is not enough to accelerate your massive body (Newton's second law, in which $F = ma$).

Try Now

Complete the missing labels for the action-reaction force pairs for the systems within the dotted lines. Use the format "Force of _________ on _________."

Shoes and track



Ball and bat

Action:
Reaction: Force of track on shoes (forward)

Action: Force of ball on bat (backward)
Reaction:

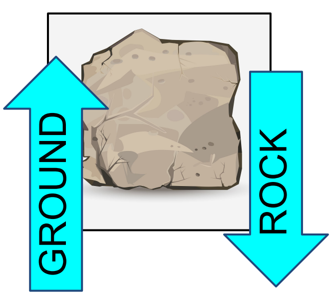
In the first picture, do you see the runner's back foot pushing backward on the track (action)? The track interacts by pushing on the runner's foot, propelling him forward (reaction). In the second picture, the ball forces the bat in one direction (action) and the bat forces the ball in the opposite direction (reaction). The force of the ball can sometimes break a bat!

Look Out!

Action-reaction force pairs are NOT cause-and-effect interactions.

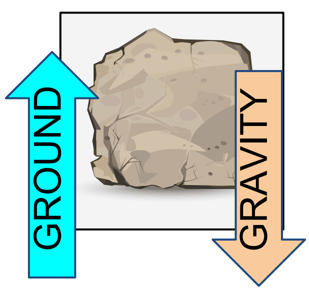
Naming which force is the action or reaction is arbitrary, because the interaction happens at the same time. One force does not come first, nor does the other force follow. The action-reaction name is really a misnomer, because both forces are part of a single interaction. A single event takes place in which force pairs happen at the same time, have equal size, and are in the opposite direction. Either force can be labeled as the action force or the reaction force.

What Do You Think?



Force of ground on rock CONTACT FORCE

Force of rock on ground CONTACT FORCE



Force of ground on rock CONTACT FORCE

Force of gravity AT-A-DISTANCE FORCE

Many forces can act on objects. So how do you know which two forces are the action-reaction force pair? First, be sure you are looking for pairs of the same type of force, i.e., two contact forces or two at-a-distance forces; do NOT pair a contact force with an at-a-distance force. Contact forces occur where objects in the system are touching or colliding. Forces that act at a distance are gravitational, magnetic, or electrical charges. Which diagram do you think has the correct action-reaction force pair?

Reflect

Balanced vs. Unbalanced Forces

If the force pairs act on objects so that the net forces acting on one object are not being balanced by any other force, then the force on that object is considered *unbalanced*. Unbalanced forces cause a change in motion (acceleration). Consider an avalanche. Before the avalanche, the force of gravity on the snow was equal to the force of friction between snowflakes (and any other force acting in opposition to gravity). The forces were balanced, so the snow was motionless. If some event, such as melting, reduces the frictional force so that it is less than the gravitational force, the net force will become unbalanced and the snow will accelerate down the slope. The same unbalanced forces result when a coffee cup falls to the floor. Before, the coffee cup pushed down on the table, which pushed back up on the coffee cup. The cup got knocked off the table. With no contact force supporting the cup, gravity accelerated the cup downward. If an object is accelerating (speeding up, slowing down, or changing directions), then we know the forces acting on that object must be unbalanced.

However, not all pairs of forces result in an acceleration. If all the forces acting on a particular object are *balanced* so that the net force is zero, the object will not accelerate (Newton’s first law). The object will continue its current state of motion. If the object was at rest, it will stay at rest. Such is the case with the rock sitting on the ground. The net force is balanced, so the rock will remain at rest. If the object was in motion and all forces on it are balanced, the object will continue to move at the same speed in the same direction, such as with a plane moving north at 250 m/s. If all the forces acting on the plane are balanced, it will continue north at 250 m/s; the plane cannot slow down, speed up, or change directions without an unbalanced force to make it accelerate.

Look Out!

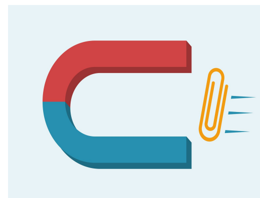
How can rockets accelerate? Rockets move forward by expelling gas backward at high velocity. This means the rocket exerts a large backward force on the gas in the rocket combustion chamber, and the gas, therefore, exerts a large reaction force forward on the rocket. This reaction force is called thrust.

It is a common misconception that rockets propel themselves by pushing on the ground or on the air behind them. They actually work better in a vacuum, where they can more readily expel the exhaust gases.

What Do You Think?

Contact Forces vs. Forces at a Distance

Action-reaction paired forces can occur between objects in direct contact (contact forces) and between objects that are not touching (action-at-a-distance forces). Examples of contact forces are colliding football players, car wrecks, and playing tug-of-war.



Fields around objects, such as gravitational fields, electric fields, and magnetic fields, can cause interactions between objects even without the objects touching. When objects interact due to gravitational, magnetic, or electrical forces, the forces are called action-at-a-distance forces, and they can cause objects to interact even from a distance. The resulting action-reaction forces between the interacting objects are equal in magnitude and opposite in direction.

Distinguish the force from the effect of the force when considering forces acting at a distance. Forces such as gravitational, electrical, and magnetic forces act at a distance, but their effect depends on mass and distance.

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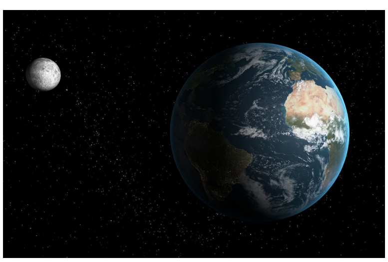

Gravitational Force

The action-reaction of gravitational force pairs at a distance are equal and opposite. The motion effect of the pair is dependent on the mass and strength of the gravitational field. A roller coaster car moving down a hill is not in direct contact with Earth, yet action-reaction forces exist between them. The car exerts a gravitational pull on Earth, and Earth exerts an equal and opposite pull on the car. However, the effect of those forces depends on mass. The mass of the car is so small compared to the mass of Earth that the net effect will be the car accelerating down the hill.

The Moon's orbit around Earth is an example of action-reaction at-a-distance gravitational force. The Moon pulls on Earth while Earth pulls on the Moon; however, the effect on the two objects (motion of orbit) is different due to the large mass of Earth and the smaller mass of the Moon.

Electrical and Magnetic Forces

Objects with magnetic fields can also exert action from paired forces at a distance. Magnets can attract or repel. Electrically charged objects with electric fields also exert paired action-at-a-distance attraction or repulsion forces between objects. The resulting motion depends on the strengths and charges of the magnetic or electrical fields and the mass of the particles.

Try Now

For each scenario below, identify the opposite reaction force.

A baseball bat hits a ball.

A bowling ball pushes up against pins.

Air particles push outward against a balloon.