

Newton's Third Law of Motion

3.4

Examine the photograph in **Figure 1** of an Atlas V rocket during liftoff. What forces are acting on the rocket? An obvious one is gravity pulling the rocket down. The rocket is accelerating upward in the picture. This means that the net force must be up according to Newton's second law. What is this upward force? You might suggest that the ground is pushing up on the rocket with the normal force. This cannot be the answer because the normal force is a contact force and the rocket is no longer in contact with the ground. In this section, you will learn about this upward force as you learn about Newton's third law of motion.

Action and Reaction Forces

If you reach out and push this book away from you, you can actually feel the book pushing back on you. This is an example of a set of action and reaction forces. The action force is you pushing on the book, and the reaction force is the book pushing back on you. An easy way to experience action and reaction forces is by pushing on the boards when you are skating in an ice rink. When you push on the boards (the action force), the boards push back on you (reaction force). It is the reaction force that causes you to accelerate away from the boards.

These action and reaction forces are all around us and go unnoticed most of the time. When you push a door open, the door pushes back on you. When you walk forward across the floor, you push backwards on the ground and the ground pushes forward on you. In fact, whenever one object exerts a force on another, the second object exerts another force back.

Another simple way to demonstrate action and reaction forces is to have a person standing at rest on a skateboard suddenly step forward (**Figure 2**). When this happens, the person and the skateboard will accelerate in opposite directions. According to Newton's second law, both the person and the skateboard have net forces acting on them because they are accelerating. What causes these forces?

The net force on the skateboard is caused by the person's feet pushing backwards on the skateboard. The person's feet exert the action force on the skateboard. The net force on the person is caused by the skateboard pushing forward on the person. The skateboard exerts the reaction force on the person.

Keep in mind that these action and reaction forces are simultaneous. It is incorrect to imply that the action force happens first and then the reaction force happens. These are contact forces, and both the action and reaction forces start whenever contact is made.

Newton's **third law of motion** deals with these action and reaction forces. For this reason, it is sometimes called the action–reaction law.

Third Law of Motion

For every action force, there is a simultaneous reaction force that is equal in magnitude, but opposite in direction.

We can now explain how a rocket can accelerate up off the launch pad. During liftoff, the rocket engines burn rocket fuel, creating tremendous pressure, which causes the expanding hot gases to accelerate from the bottom of the rocket (action force). At the same time, the expanding hot gases push up on the rocket (reaction force), causing the rocket to accelerate up. According to Newton's third law, the action force caused by the expanding hot gases is equal in magnitude to the reaction force of the expanding hot gases on the rocket. If the reaction force up on the rocket from the expanding hot gases is greater than the force of gravity pulling the rocket down, then the rocket will accelerate up. In the following Tutorial, you will apply Newton's third law to problems involving motion.



Figure 1 An Atlas V rocket was launched in June 2009. As the rocket lifted up off the launch pad, what force caused it to accelerate upward?

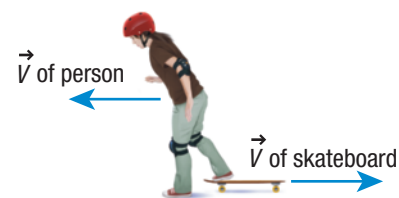


Figure 2 As a person jumps off a skateboard in one direction, the skateboard will accelerate in the other direction.

third law of motion each action force has a reaction force that is equal in magnitude and opposite in direction

Tutorial 1 Explaining Motion Using Newton's Third Law

In the following Sample Problem, we will clarify Newton's third law and demonstrate how it can be used to explain motion when objects exert forces on each other.

Sample Problem 1

Explain each event in terms of Newton's third law.

- A swimmer moves through the water.
- A small balloon releases air and flies around the classroom.
- You start walking across the floor.

Solution

- The swimmer's arms and legs exert an action force backwards on the water, causing the water to accelerate backwards. According to Newton's third law, the water exerts an equal but opposite force forward on the swimmer, propelling the swimmer forward through the water.

- As the rubber in the balloon contracts, it forces air out the back of the balloon (action force). According to Newton's third law, the reaction force is caused by the air pushing back on the balloon, which accelerates the balloon forward.
- The bottom of your shoe exerts a horizontal backward action force on the floor. According to Newton's third law, the reaction force is caused by friction when the floor pushes forward on your feet. Friction causes you to accelerate forward.

Practice

- Explain each event in terms of Newton's third law. K/U
 - A rocket can accelerate in outer space.
 - A motorboat accelerates east in the water.
 - Football player 1 tackles football player 2.

Mini Investigation

Demonstrating the Third Law

Skills: Predicting, Performing, Observing, Analyzing, Communicating

SKILLS
HANDBOOK  A2.1

In this investigation, you will perform and observe several actions that involve Newton's third law. Your task is to predict what will happen at each station, observe carefully what actually happens, and explain why it happens.

Equipment and Materials: office chair with wheels; bathroom scale; desk; ballistics cart; fan cart with removable sail

- Create a table similar to **Table 1** to record your observations. Add six rows to the table.

Table 1

Activity	Prediction	Observation	Action and reaction forces

- Read through the descriptions of activities (a) through (g). For each activity, predict what you think will happen and record your predictions in your table.
- Perform activities (a) to (g) (or observe a classmate performing these activities). Record your observations.
 - Sit on an office chair and push gently against a wall with both hands.
 - Sit on the chair, not touching the wall. Use your hands to pull horizontally on your own shoulders, away from the wall.

- Stand on a bathroom scale placed beside a desk. Put your hands on the desk and push down.
- Stand on a bathroom scale. Push down on your own head with your hands.
- Use a spring-loaded ballistics cart to fire a ball horizontally.
- Obtain a fan cart (**Figure 3(a)**) with no sail. Direct the fan away from the cart. Turn the fan cart on.
- Obtain a fan cart (**Figure 3(b)**) with a sail. Direct the fan toward the sail. Turn the fan cart on.

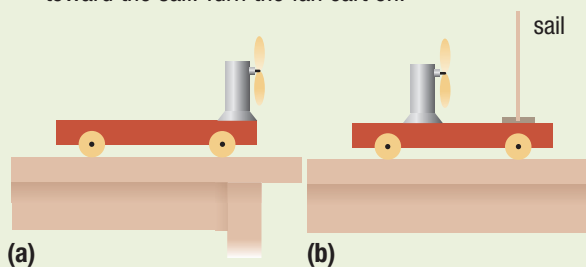


Figure 3

- Use Newton's third law to describe the action and reaction forces you observed in each activity. T/I

You may have noticed that objects will not always accelerate or the reading on a scale will not always change when a force is applied to an object. What is different about these situations? The difference is that in each of these situations there is no external net force acting on the object.

Does this mean that action and reaction forces cancel and we can never accelerate? Definitely not. Action and reaction forces always act on different objects, or different parts of a single object. When two objects are involved, the two forces are not added together and each object can accelerate.

For example, if a ballistics cart pushes backwards on a ball (action force), the ball accelerates backwards because the applied force causes a net force on the ball. According to Newton's third law, the ball will also cause a reaction force on the cart in the opposite direction. This reaction force causes a net force on the cart, making it accelerate the other way. The action and reaction forces do not cancel because they do not act on the same object. When you draw the FBD for each object, the action and reaction forces will appear in separate FBDs (**Figure 4**).

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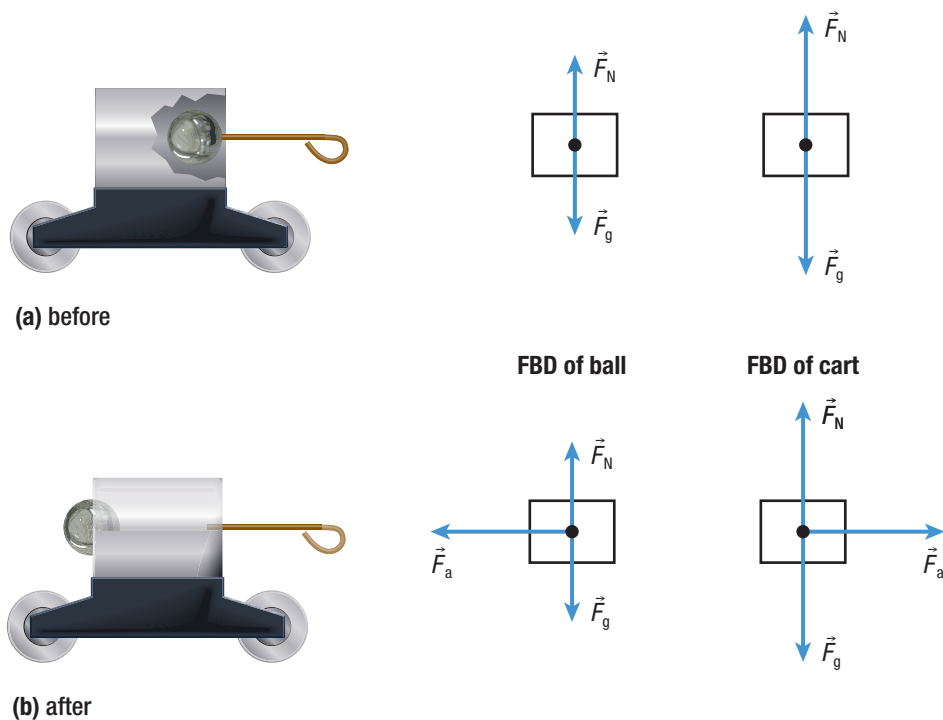


Figure 4 (a) Diagram and FBDs of a ball inside a ballistics cart before firing (b) Diagram and FBDs after firing the ball. The action and reaction forces do not cancel because they act on different objects.

Tutorial 2 Using Newton's Third Law in Calculations

In the following Sample Problem, we will clarify Newton's third law and demonstrate how it can be used to explain motion when objects exert forces on each other.

Sample Problem 1: One Skater Pushing on Another

Two skaters are standing on ice facing each other (**Figure 5**). Skater 1 pushes on skater 2 with a force of 70 N [E]. Assume that no friction acts on either skater. The mass of skater 1 is 50 kg and the mass of skater 2 is 70 kg.

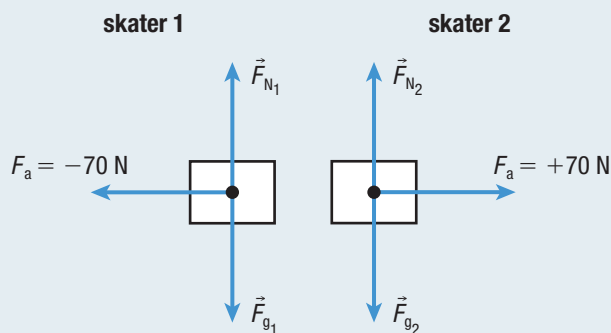
- State the action and reaction forces.
- Draw the FBD of each skater.
- Describe what will happen to each skater.
- Calculate the acceleration of each skater.



Figure 5

Solution

- (a) The action force is skater 1 pushing with 70 N [E] on skater 2. The reaction force is skater 2 pushing with 70 N [W] on skater 1.
- (b) Choose east as positive. So west is negative.



- (c) Skater 1 will accelerate west and skater 2 will accelerate east.

- (d) For each skater, the normal force and the force of gravity cancel. This means that the applied force is equal to the net force. For skater 1,

$$\vec{F}_{\text{net}} = \vec{F}_a$$

$$m_1 a_1 = -70 \text{ N}$$

$$(50 \text{ kg}) a_1 = -70 \text{ N}$$

$$a_1 = -1.4 \text{ m/s}^2$$

The acceleration of skater 1 is 1.4 m/s² [W].

Similarly, for skater 2,

$$\vec{F}_{\text{net}} = \vec{F}_a$$

$$m_2 a_2 = +70 \text{ N}$$

$$(70 \text{ kg}) a_2 = 70 \text{ N}$$

$$a_2 = +1.0 \text{ m/s}^2$$

The acceleration of skater 2 is 1.0 m/s² [E].

Notice that the two skaters accelerate in opposite directions and with different accelerations. The accelerations do not have the same magnitude because the skaters' masses are different.

Practice

- Given the action force, describe the reaction force for each situation. K/U C
 - You push forward on a book with 5.2 N.
 - A boat exerts a force of 450 N [W] on the water.
 - A hockey player hits the boards with a force of 180 N [toward the boards].
- Nobel and Maaham are wearing inline skates. Nobel has a mass of 62 kg and pushes on Maaham, whose mass is 54 kg. Maaham accelerates at 1.2 m/s² [left]. Assume that no friction acts on either person. T/I
 - Determine the force that Nobel exerts on Maaham. [ans: 65 N [left]]
 - Determine Nobel's acceleration. [ans: 1.0 m/s² [right]]
- A horse is tethered to a cart to pull it forward. A student claims, "According to Newton's third law, when the horse pulls forward on the cart, the cart will also pull backwards on the horse. The two objects are attached together, so they cannot accelerate." Discuss the validity of this statement. K/U C
- A student stands on a skateboard and pushes on a wall with a force of 87 N [S]. The total mass of the student and the skateboard is 58 kg. K/U T/I
 - Calculate the acceleration of the student. [ans: 1.5 m/s² [N]]
 - Explain why the wall does not move.

UNIT TASK BOOKMARK

You can apply what you have learned about Newton's third law to the Unit Task on page 204.

3.4 Summary

- Newton's third law always involves situations where two objects exert forces on each other.
- Newton's third law states that for every action force there is a simultaneous reaction force equal in magnitude but opposite in direction.
- When applying Newton's third law, the action and reaction forces will appear on separate FBDs. Since they are on separate FBDs, they are not added together.

3.4 Questions

- Given each action force, state the reaction force. **K/U**
 - A tire pushes on the road with a force of 240 N [backwards].
 - You pull on a desk with a force of 25 N [N].
- Explain each event below in terms of Newton's third law. **K/U**
 - A squid moves through the water by taking in water and expelling it.
 - Walking on a wagon is dangerous.
 - A helicopter can hover above the ground.
- During a space walk, an astronaut notices that her tether is not attached and she is drifting away from the space station. Explain each statement below using Newton's third law. **K/U C**
 - She can pull herself back to the space station if she can reach the space station and pull on it.
 - She cannot push herself back to the station by pulling forward on her space suit.
 - She can get back to the space station even if she cannot reach it if she is holding a tool.
- Figure 6** shows a photograph of an early naval cannon tied to a ship. Explain why the ropes are necessary. **A**



Figure 6

- Figure 7** shows a fan cart. **K/U**
 - Explain why the fan cart cannot accelerate.
 - Explain why the fan cart can accelerate if the rigid sail is removed.

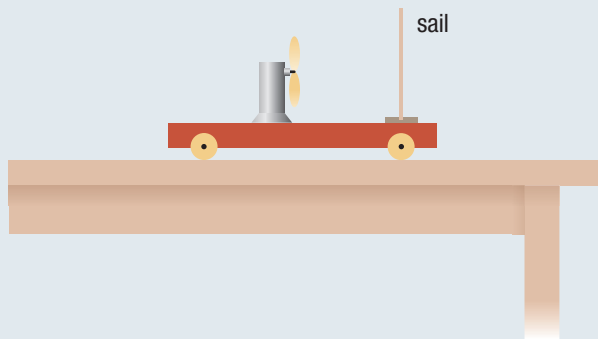


Figure 7

- A toy car (200 g) moves by shooting a plastic ball (50 g) horizontally out the back. The average acceleration of the car is 1.2 m/s^2 [E] and there is negligible friction acting on each part of the toy. **T/A C**
 - Draw an FBD for each object.
 - Identify the action and reaction forces on each part of the toy.
- Two figure skaters are moving east together during a performance. Skater 1 (78 kg) is behind skater 2 (56 kg) when skater 2 pushes on skater 1 with a force of 64 N [W]. Assume that no friction acts on either skater. **T/A**
 - Determine the acceleration of each skater.
 - What will happen to the motion of each skater? Explain your reasoning.
- A milk carton filled with water is hanging from a string (Figure 8). What will happen if you punch two holes in opposite sides of the carton at the opposite corners? Explain your reasoning. **T/A**



Figure 8

- A male astronaut (82 kg) and a female astronaut (64 kg) are floating side by side in space. **T/A**
 - Determine the acceleration of each astronaut if the woman pushes on the man with a force of 16 N [left].
 - How will your answers change if the man pushes with 16 N [right] on the woman instead?
 - How will your answers change if they both reach out and push on each other's shoulders with a force of 16 N?