# Newton's First Law of Motion

3.2

Every year in Canada, there are about 160 000 car accidents. These accidents cause many injuries, and about 3000 are fatal. Many of these injuries and deaths involve motorists who are not wearing seat belts or are driving too fast. An understanding of Newton's first law will help you appreciate the importance of safety features in cars such as seat belts and airbags. **Figure 1** shows a crash test designed to help engineers test and improve the safety features of new cars. What will happen to a crash test dummy during a collision if it is not wearing a seat belt and no airbag is present? Newton's first law will help us answer this question.

**Figure 1** Crash tests are designed to test and improve automotive safety.

## Inertia

If you have ever played air hockey, you may know that a small plastic puck moves with close to uniform velocity after you hit it. In other words, there is very little friction acting on the puck to slow it down. In fact, the net force on the puck is zero because the upward force on the puck exerted by the air and the downward force of gravity cancel each other and there is almost no friction. If you do not hit the puck at all, it will just sit there at rest if the air table is level.

Unfortunately, early scientists and philosophers did not have access to air hockey tables. They noticed that moving objects would spontaneously slow down for no apparent reason. They did not know about friction and incorrectly attributed the decrease in velocity to "lazy" objects. They concluded that a constant net force was needed to keep an object moving. They thought that larger net forces made things move at a higher constant velocity and smaller net forces made them move at a lower constant velocity. If no net force was acting on the object, they thought that the object would stop.

It was not until the 1600s that Galileo was able to perform experiments to help clear up these misconceptions. To help explain the results of his experiments, Galileo used the following thought experiment (**Figure 2**). **Figure 2(a)** shows a ball rolling down an incline, onto a horizontal surface, and up another incline. Galileo reasoned that if there was no friction acting on the ball, it would continue to roll up the second incline until it reached the same height as its starting position. If friction were present, it would not go quite as high on the second slope.

**Figure 2(b)** shows a situation similar to the first, but the steepness of the second incline is decreased. Galileo reasoned that the ball would have to roll farther to reach the same initial height on the second incline. In **Figure 2(c)**, the second incline has been eliminated. In this experiment, the ball will never reach the same height. Galileo concluded that if there is no friction, the ball will continue to roll forever. It will never reach the same initial height since it cannot go up another incline. We can verify Galileo's thought experiment today using equipment such as air tables, where little friction is present.

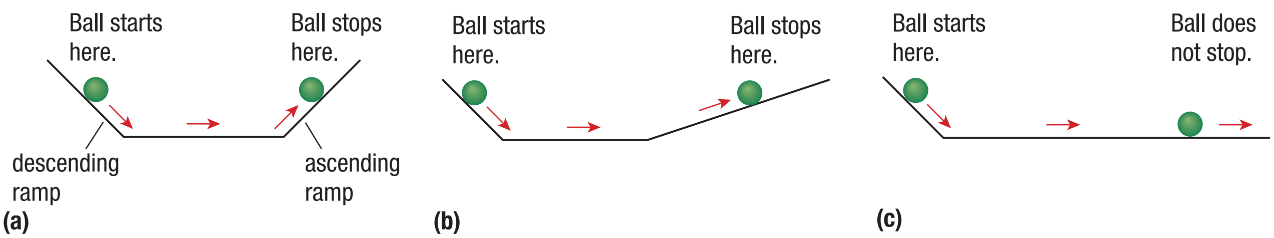



**Figure 2** (a) The ball rolls up the steep second ramp until it rises to the same initial height. (b) The ball rolls up the less steep second ramp, but it still rises to the same height. (c) There is no second ramp and the ball never stops because it cannot get to the same initial height.

**inertia** the property of matter that causes it to resist changes in motion; inertia is directly proportional to the mass of the object

Galileo concluded that once an object starts moving, it will continue moving at a constant velocity if there is no friction present. Galileo used the concept of inertia to help explain his conclusion. **Inertia** is the property of matter that causes it to resist changes in motion. The inertia of an object depends on the mass of the object. An object with more mass has more inertia, whereas an object with less mass has less inertia. In other words, inertia is directly proportional to the mass of the object.

Imagine placing a stuffed animal on the dashboard of a stationary car. If the car speeds up rapidly, the stuffed animal will resist this change in motion due to its inertia and end up in your lap. This does not mean the stuffed animal is moving backwards. The car is moving forward and the stuffed animal is stationary. In other words, the dashboard is being pulled out from under the stuffed animal. If the car is moving with uniform velocity and the stuffed animal is placed on the dashboard, the stuffed animal will stay on the dashboard because there is no change in the velocity of the car. In this case, inertia does not upset the stuffed animal because inertia only resists *changes* in motion. If the stuffed animal is placed on the dashboard and the car suddenly slows down, the stuffed animal will continue to move forward with uniform velocity due to its inertia. Again, we are not implying that the stuffed animal jumps forward. It is the car that is slowing down, not the stuffed animal speeding up. The dashboard slides under the stuffed animal, causing the windshield to move toward the stuffed animal.

Newton was born in 1642, the year that Galileo died. Newton published *Principia Mathematica*, a set of three books which included much of his own work about physics, as well as a description of Galileo's law of inertia. The law of inertia is now called Newton's **first law of motion** because it was included with Newton's other laws of motion.

**first law of motion** an object will remain at rest or continue to move at constant velocity when the net force on the object is zero

**First Law of Motion**

If the net external force on an object is zero, the object will remain at rest or continue to move at a constant velocity.

Below are some of the important implications of Newton's first law:

- A non-zero net force will change the velocity of an object. The velocity can change in magnitude, direction, or both.
- A net force is not required to maintain the velocity of an object.
- External forces are required to change the motion of an object. Internal forces have no effect on the motion of an object.

## Tutorial 1 FBDs and the First Law of Motion

The following Sample Problems will help to clarify the meaning of Newton's first law by using FBDs.

### Sample Problem 1

Use Newton's first law to explain each situation below.

(a) Why does a computer sitting on a desk remain at rest?

(b) Why does a hockey puck moving across smooth ice move at a constant velocity?

(c) Why does a wagon pulled across a rough surface by a child move at a constant velocity?

### Solution

(a) Examine the system diagram and FBD of the computer shown in **Figure 3**. Notice that the desk exerts a normal force up on the computer and the force of gravity pulls down on the computer. These two forces cancel to give a net force of zero. According to Newton's first law, the computer will remain at rest.


**Figure 3** (a) System diagram of a computer on a desk (b) FBD of the computer

(b) Examine the system diagram and FBD of the hockey puck shown in **Figure 4**. Notice that the ice exerts a normal force up on the hockey puck and the force of gravity pulls down on the hockey puck. These two forces cancel to give a net force of zero in the vertical direction. Since no external force acts in the horizontal direction, according to Newton's first law, the hockey puck will continue to move at a constant velocity.

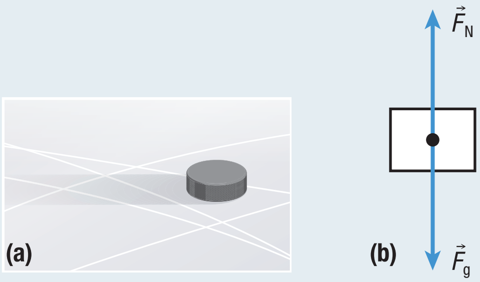



**Figure 4** (a) System diagram of a hockey puck moving on ice (b) FBD of the hockey puck

(c) Examine the system diagram and FBD of the wagon shown in **Figure 5**. The child applies tension forward on the wagon. The ground exerts a normal force up, and the force of friction acts backwards on the wagon. The force of gravity acts down on the wagon. The two vertical forces cancel each other and the two horizontal forces cancel each other to produce a net force of zero. According to Newton's first law, the wagon will move at a constant velocity.

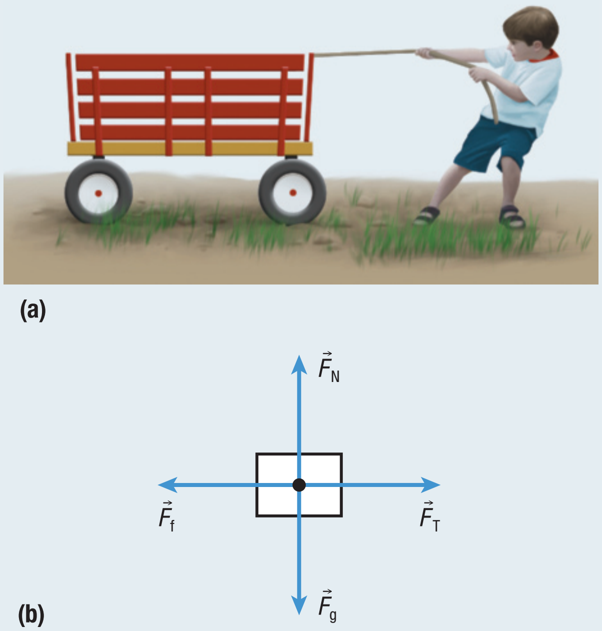



**Figure 5** (a) System diagram of a child and a wagon (b) FBD of the child and the wagon

## Sample Problem 2: Newton's First Law Applied to Headrests

Older cars did not have headrests, but all new cars do. How do headrests help prevent injuries during a rear-end collision? Use Newton's first law to explain your answer.

### Solution

Consider the forces acting on a person's body during a collision. During a rear-end collision, the car will suddenly accelerate forward and so will your body because the seat exerts a force directed forward on your torso. In a vintage car with no headrest (**Figure 6(a)**), there is no force applied to the head. According to Newton's first law, your head will continue to remain at rest. Your head will initially appear to snap backwards relative to your body as your body accelerates forward, possibly resulting in a neck injury known as whiplash. The headrest in a modern car helps push the head forward with the rest of the body (**Figure 6(b)**). This helps to prevent whiplash since your neck does not bend backwards as far during a rear-end collision.

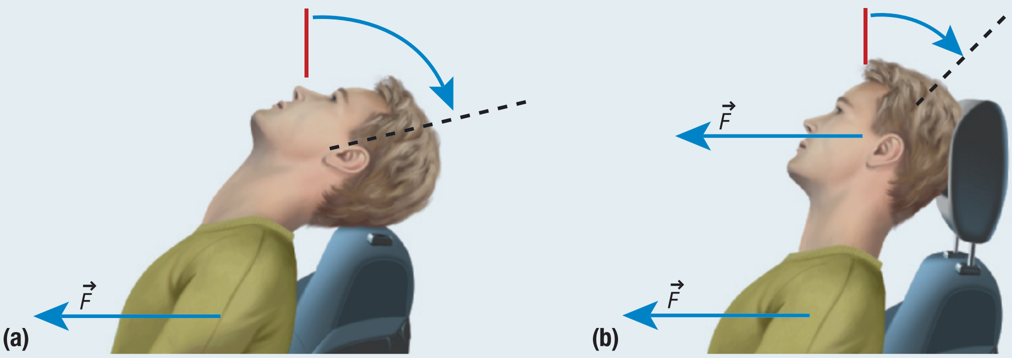
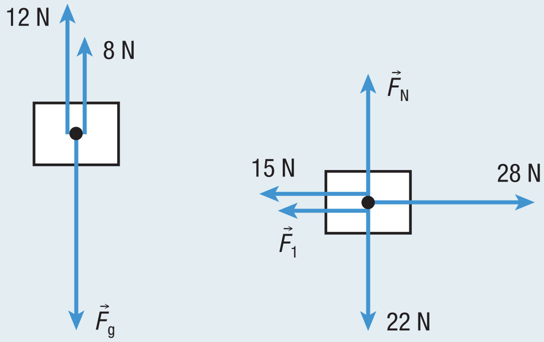



**Figure 6** (a) No headrest (b) Headrest present

## **Sample Problem 3:** Determining the Missing Force

What is the missing force on each FBD shown in **Figure 7**?




**(a)** **(b)**

**Figure 7** (a) FBD for an object at rest (b) FBD for an object moving left at a constant velocity

### Solution

(a) According to Newton's first law, since the object is at rest, the net force must be zero. Choose up as positive. So down is negative.

**Given:** two upward forces of $+12$ N and $+8$ N

**Required:** $\vec{F}_g$

**Analysis:** $\vec{F}_{net} = 0$

**Solution:** $F_{net} = +12\text{ N} + (+8\text{ N}) + F_g$

$0 = 20\text{ N} + F_g$

$F_g = -20\text{ N}$

$\vec{F}_g = 20\text{ N [down]}$

**Statement:** The force of gravity on the object is 20 N [down].

(b) According to Newton's first law, the object must have a net force of zero since it is moving at a constant velocity. Choose up and right as positive. So down and left is negative. We can look at $(F_{net})y$ and $(F_{net})x$ separately. Start with the forces along the *y*-axis.

**Given:** $-22$ N

**Required:** $\vec{F}_N$

**Analysis:** $(F_{net})_y = 0$

**Solution:** $(F_{net})_y = F_N + (-22\text{ N})$

$0 = F_N - 22\text{ N}$

$F_N = +22\text{ N}$

$\vec{F}_N = 22\text{ N [up]}$

Now examine the forces along the *x*-axis.

**Given:** $+28$ N; $-15$ N

**Required:** $\vec{F}_1$

**Analysis:** $(F_{net})_x = 0$

**Solution:** $(F_{net})_x = +28\text{ N} + (-15\text{ N}) + F_1$

$0 = 13\text{ N} + F_1$

$F_1 = -13\text{ N}$

$\vec{F}_1 = 13\text{ N [left]}$

**Statement:** The normal force on the object is 22 N [up]. $\vec{F}_1$ is 13 N [left].

### Practice

1. Explain why it is unsafe to stand when riding a bus or subway without holding onto something. K/U C
2. In a demonstration, a teacher places some plates on top of a smooth tablecloth. The teacher then pulls quickly on the tablecloth. If the tablecloth is a frictionless surface, predict what will happen to the plates. Explain your reasoning. K/U
3. A driver in a car passes over some black ice, which exerts almost no friction on the wheels. Explain why the car cannot slow down when the driver pushes on the brakes. K/U
4. You have some snow stuck on your shovel. Explain how you could apply Newton's first law to get the snow off. K/U
5. The FBD in **Figure 8** is for a car at rest on the ground. T/I
   (a) Determine $\vec{F}_1$ and $\vec{F}_g$. [ans: $\vec{F}_1 = 2650$ N [R]; $\vec{F}_g = 13\ 000$ N [down]]
   (b) How would your answers change if the car was moving at a constant velocity? Assume none of the given forces change.

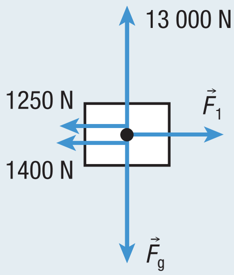



**Figure 8**

## Mini Investigation

### Testing Newton's First Law

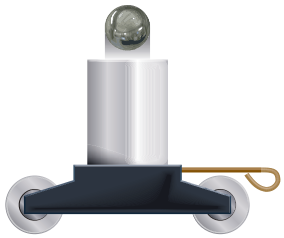
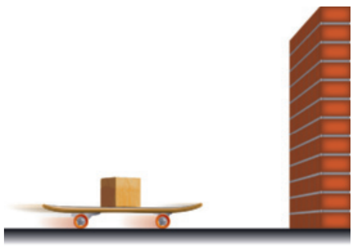
**Skills:** Observing, Analyzing, Communicating

Your teacher will present several situations and ask you to predict what will happen and explain your reasoning. You will then observe the demonstration and record what happens. Finally, you will explain what happens and why in terms of Newton's first law.

**Equipment and Materials:** coin; playing card; ballistics cart and ball; skateboard; thread; two standard masses

1. Create a table in your notebook similar to **Table 1**. The second column in Table 1 shows a sketch of each demonstration. Summarize your results in the appropriate column of your table. T/I C

**Table 1**

| Situation | Sketch of situation | Prediction/ explanation | Observations | Explanation |
|---|---|---|---|---|
| A. A coin is on top of a playing card on the left fist. Hit the card. |  | | | |
| B. A moving ballistics cart fires a ball by exerting a force straight up. |  | | | |
| C. A moving skateboard with an object on top hits a wall. |  | | | |
| D. A thread supports an object. Another thread is underneath. Pull slowly on the bottom thread. |  | | | |
| E. A thread supports an object. Another thread is underneath. Pull quickly on the bottom thread. | | | | |

## Applications of Newton's First Law

A wide range of technologies take advantage of Newton's first law including automobiles, planes, rockets, and construction. The key idea is that the net force must be zero for any object to remain at rest or to keep moving with uniform motion.

Consider the physics of a typical seat belt. What will happen if you are not wearing a seat belt and the car suddenly stops? According to Newton's first law, you will continue to move forward at a constant velocity until an object exerts a net force on you. This could be the dashboard or the windshield. If you are wearing a seat belt, the seat belt will exert a net force on you to slow you down.

WEB LINK

To learn more about how seat belts work,

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One design feature of a seat belt uses the sudden decrease in velocity of the car to activate a gear mechanism. In this design, the seat belt strap is attached to a spool, which in turn is attached to a gear (**Figure 9**). Beneath this gear is a pendulum that is free to swing back and forth. When the car comes to a sudden stop, the pendulum swings forward due to inertia. This causes the pendulum to move a metal stop into the teeth of the gear, locking the seat belt in place.

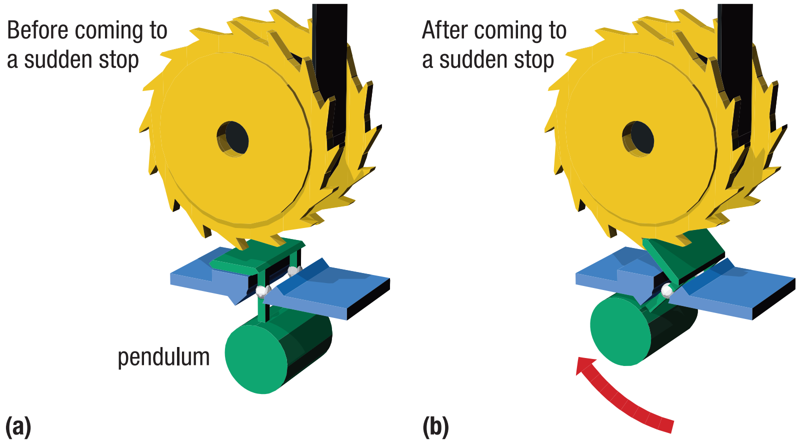


**Figure 9** (a) When the vehicle is moving at constant velocity the seat belt pendulum (shown in green) hangs straight down. (b) After a sudden stop, the pendulum swings, causing the metal stop to lock into the seat belt gear.

Space and flight technology also takes advantage of Newton's first law. During high accelerations in a jet or a rocket, a pilot or astronaut might experience pooling of blood in certain parts of the body such as the legs. The inertia of the blood often causes it to move out of the head and into the legs. A G-suit helps to prevent this condition by exerting pressure on the legs and lower torso. In effect, it is squeezing the blood out of the legs back up toward the brain.

UNIT TASK **BOOKMARK**

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

### 3.2 Summary

- Inertia is the property of matter that causes it to resist changes in motion. Inertia is directly proportional to the mass of the object.
- Newton's first law can also be called the law of inertia. Newton's first law states that if the net force acting on an object is zero, the object will either remain at rest or continue to move at a constant velocity.
- There are many implications of Newton's first law: objects at rest tend to remain at rest; objects in motion tend to remain in motion; if the velocity of an object is constant, then the net force is zero; if a net force acts on an object, the velocity will change in magnitude, direction, or both.
- Newton's first law of motion can be applied in many situations to help increase our understanding of motion.
- Newton's first law of motion has many technological applications.

## 3.2 Questions

1. Explain how modern technology can help demonstrate Galileo's thought experiments. K/U
2. Which has the most inertia, a truck, a desk, or a feather? Which has the least inertia? How do you know? K/U
3. Skater 1 has a mass of 45 kg and is at rest. Skater 2 has a mass of 50 kg and is moving slowly at a constant velocity of 3.2 m/s [E]. Skater 3 has a mass of 75 kg and is moving quickly at a constant velocity of 9.6 m/s [E]. Which skater experiences the greater net force? Explain your reasoning. K/U
4. Explain each statement using inertia or Newton's first law. K/U
   (a) You should not sit in the back (bed) of a pickup truck when it is moving.
   (b) It is hard to get a car moving on very slippery ice.
   (c) You should not put objects on the ledge of a car between the rear windshield and the rear seat.
   (d) During liftoff, astronauts are placed horizontally in the capsule rather than vertically.
5. Headrests and seat belts are two important pieces of safety equipment used in automobiles. K/U
   (a) Will both technologies significantly improve safety if the car suddenly slows down but keeps moving in a straight line? Explain your reasoning.
   (b) Will both technologies significantly improve safety if the car suddenly speeds up but keeps moving in a straight line? Explain your reasoning.
6. Many people buy a coffee or other hot beverage on their way to work. For safety, the cup usually has a lid and is placed in a cup holder. Using Newton's first law, explain why both of these precautions are necessary. C A
7. **Figure 10** shows a string tied to a spike at one end and a puck at the other. The puck is moving around in a circle on the ice. Describe what the puck will do if the string is suddenly cut at the red line. Explain your reasoning using a diagram. K/U C

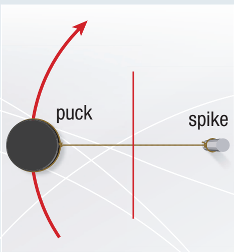


**Figure 10**

8. Use Newton's first law to explain why the normal force must be equal in magnitude to the force of gravity for an object to remain at rest on a horizontal surface when no other forces are acting on the object. K/U C
9. You are inside a car moving fast along a sharp turn in the road. Use Newton's first law to describe what happens to you as you safely make it around the curve. T/I C
10. Use Newton's first law to explain why you should slow down when going around a curve on an icy highway. K/U C
11. **Figure 11** shows some simple equipment used to test Newton's first law. In the experiment, the ring is suddenly pulled horizontally. T/I C
    (a) Predict what will happen to the piece of chalk. Explain your reasoning.
    (b) Why does it help to put some water in the container?

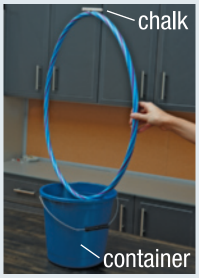


**Figure 11**

12. While on the bus, you throw an apple straight up into the air. What will happen if the bus
    (a) moves at a constant velocity?
    (b) slows down?
    Explain your reasoning using diagrams. T/I C
13. Determine the indicated forces on each FBD shown in **Figure 12.** T/I
    (a) statue at rest on a shelf
    (b) sled pulled right at a constant velocity

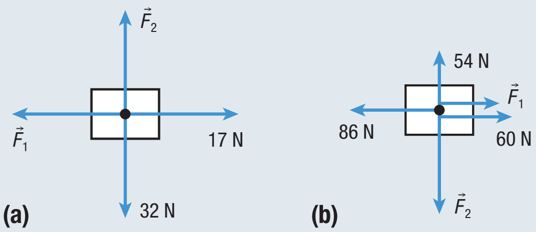


**Figure 12**

14. Your physics teacher challenges the class to the following puzzle. Place eight quarters into a single stack on a desk. Your task is to take the stack apart one quarter at a time using only a thin ruler. You cannot make any contact with the quarters but the ruler can. Only quarters at the bottom of the pile may be removed. T/I C
    (a) Describe how you would complete the task. Carry out your plan to test whether it works.
    (b) Explain why it works.
15. Studies reveal that many people do not use their headrest properly. Research what most people do wrong and how it can be fixed. Prepare a small pamphlet that can be used to make people aware of the problem and how to fix it. Include any useful statistics that might encourage people to make the necessary changes. T/I C

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