10.3: Connecting Newton's First and Second Laws

Astronauts weigh less on the moon than on Earth because the force of gravity is weaker on the moon

Figure 3.3.1

This image is of Buzz Aldrin, one of the first men to walk on the moon. Apollo 11 was the spaceflight that landed the first humans, Neil Armstrong and Buzz Aldrin, on the moon on July 20, 1969. Armstrong became the first to step onto the lunar surface 6 hours later on July 21. As you probably already know, men weigh less on the moon than on Earth; this is because the force of gravity is less on the moon than on Earth.

What is a force?

Newton’s First and Second Laws of Motion

A **force** is a push or a pull on an object. When you place a book on a table, the book pushes downward on the table and the table pushes upward on the book. The two forces are equal and there is no resulting motion of the book. If, on the other hand, you hold the book in the air and let go, the force of gravity will pull the book to the ground.

If you slide a book across the floor or a table, the book will experience a frictional force, which acts in the opposite direction of the motion. This force will slow down the motion of the book and eventually bring it to rest. A smoother surface has a smaller force of friction, which will allow the book to slide further before coming to rest. If a perfectly smooth floor could be created, there would be no friction and the book would slide forever at constant speed.

Newton’s First Law of Motion states that an object at rest will stay at rest and an object in motion will remain in motion. It describes a phenomenon called **inertia**. Inertia is the tendency of an object to resist change in its state of motion. In the absence of any force, an object will continue to move at the same constant speed and in the same straight line. If the object is at rest, in the absence of any force, it will remain at rest. Newton’s First Law states that an object with no force acting on it moves with constant velocity. (The constant velocity could, of course, be 0 m/s.)

According to Newton’s First Law, is a force needed to keep a sled sliding on ice at a constant velocity? Use the simulation below to discover more:

Newton’s First Law is equivalent to saying that “if there is no net force on an object, there will be no acceleration.” In the absence of acceleration, an object will remain at rest or will move with constant velocity in a straight line. The acceleration of an object is the result of an unbalanced force. If an object undergoes two forces, the motion of the object is determined by the net force. The magnitude of the acceleration is directly proportional to the magnitude of the unbalanced force. The direction of the acceleration is the same direction as the direction of the unbalanced force. The magnitude of the acceleration is inversely proportional to the mass of the object; the more massive the object, the smaller the acceleration produced by the same force.

These relationships are stated in **Newton’s Second Law of Motion**: "the acceleration of an object is directly proportional to the net force on the object and inversely proportional to the mass of the object."

Newton’s Second Law can be summarized in an equation:

a=F/m or more commonly, F=ma

According to Newton’s Second Law, a new force on an object causes it to accelerate. However, the larger the mass, the smaller the acceleration. We say that a more massive object has a greater inertia.

The units for force are defined by the equation for Newton’s Second Law. Suppose we wish to express the force that will give a 1.00 kg object an acceleration of 1.00 m/s^2.

$$\mathbf{F=ma=(1.00\ kg)(1.00\ m/s^2)=1.00\ kg{\cdot}m/s^2}$$

This unit is defined as 1.00 newton or 1.00 N.

$$\mathbf{kg{\cdot}m/s^2=newton}$$

What Forces are Acting on You?

A classic physics example of the applications of Newton’s Second Law is the acceleration we experience while riding in an elevator. How can you accelerate upward if your weight (or the force due to gravity) always remains the same? At what points are you speeding up in the elevator? Slowing down? Moving at a constant rate? What is the net force required for these accelerations to occur? Use the simulation below to explore these questions and gain a deeper understanding of Newton’s Second Law:

Examples

Example 3.3.1

What force is required to accelerate a 2000. kg car at 2.000 m/s^2?

Solution

$F=ma=(2000.\ kg)(2.000\ m/s^2)=4000.\ N$

Example 3.3.2

A net force of 150 N is exerted on a rock. The rock has an acceleration of 20. m/s^2 due to this force. What is the mass of the rock?

Solution

$m=F/a=(150\ N)(20.\ m/s^2)=7.5\ kg$

Example 3.3.3

A net force of 100. N is exerted on a ball. If the ball has a mass of 0.72 kg, what acceleration will it undergo?

Solution

$a=F/m=(100.\ N)(0.72\ kg)=140\ m/s^2$

Apply Newton's Second Law in this simulation to determine the acceleration of an airboat with a given mass and a variety of forces acting on it:

Summary

- A force is a push or pull on an object.
- Newton's First Law states that an object with no net force acting on it remains at rest or moves with constant velocity in a straight line.
- Newton's Second Law states that the acceleration of an object is directly proportional to the net force on the object and inversely proportional to the mass of the object.
- Newton's Second Law is expressed as an equation, F=ma.

Review

1. A car of mass 1200 kg traveling westward at 30. m/s is slowed to a stop in a distance of 50. m by the car's brakes. What was the braking force?
2. Calculate the average force that must be exerted on a 0.145 kg baseball in order to give it an acceleration of 130 m/s^2.
3. After a rocket ship going from the Earth to the moon leaves the gravitational pull of the Earth, it can shut off its engine and the ship will continue on to the moon due to the gravitational pull of the moon.
    1. True
    2. False
4. If a space ship traveling at 1000 miles per hour enters an area free of gravitational forces, its engine must run at some minimum level in order to maintain the ships velocity.
    1. True
    2. False
5. Suppose a space ship traveling at 1000 miles per hour enters an area free of gravitational forces and free of air resistance. If the pilot wishes to slow the ship down, he can accomplish that by shutting off the engine for a while.
    1. True
    2. False

Explore More

Use the resource below to answer the questions that follow.

1. What is a Hero’s Engine?
2. How does Newton’s First Law of Motion have to do with the Hero’s Engine?
3. Why does the yellow ball go further?

Additional Resources

PLIX: Play, Learn, Interact, eXplore: Newton's First and Second Laws, Bowling for Physics, Determining the Net Force, Hot Air Balloons, The Forces of Flying

Video:

Study Guide: Newton's Laws Study Guide