

STAAR Science Tutorial 25 **TEK 8.6C: Newton's Laws**

TEK 8.6C: Investigate and describe applications of Newton's law of inertia, law of force and acceleration, and law of action-reaction such as in vehicle restraints, sports activities, amusement park rides, Earth's tectonic activities, and rocket launches.

- **Issac Newton** is regarded as one of the most important scientists in human history. His book titled "Mathematical Principles of Natural Philosophy", worked out at the height of the black plague in Europe and first published in 1687, laid the foundations for classical physics, including his laws of motion and law of universal gravitation. Almost all of the concepts described below remain unchanged since their discovery over 300 years ago.
- A **force** is a push or a pull. Forces can either be **contact forces**, such as the collision between two balls on a pool table, or **long-range forces** such as gravity or magnetism, which exert a force without contact. The unit for force in the metric system is the **newton (N)**, which is the force needed to accelerate a mass of one kilogram by one meter per second squared (m/s^2). In the American system, one newton is equal to the force needed to lift an object weighing about 0.225 pounds. To convert newtons into pounds, divide the force in newtons by 0.225.
- In studying Newton's Laws of Motion, do not try to memorize the exact words of the law. In fact, most textbooks state the law slightly differently from one another, and none state the law exactly as Newton did (in Latin), though each version means the same thing. Instead, try to understand the laws conceptually, by the way that objects respond to force.
- **Newton's First Law of Motion**, sometimes called the **law of inertia**, states that:

An object at rest will stay at rest, and an object in motion will stay in motion with constant velocity, unless acted on by an unbalanced force.

On Earth, we are used to all moving objects slowing down and eventually stopping. The law's first part stating that "objects at rest stay at rest" fits our experience on Earth, because objects only move when some force moves them. Before Newton, scientists believed that all objects came to rest naturally. The second part of the law stating that "an object in motion will stay in motion with constant velocity" is much harder to see on Earth, where every moving object eventually stops moving. The property of inertia, along with the forces of friction and air resistance, explain why Newton's first law is really true.

- **Inertia** is the measure of an object's tendency to resist a change in motion; it is directly proportional to the object's mass. In other words, the greater the

mass of an object, the greater its inertia, and the more force will be needed to change its motion. We have all experienced inertia. It is easy to move an object with little mass, such as a toy car, but very hard to move an object with large mass such as a real automobile. We wear seat belts in cars because of inertia—if we did not, we would become the “object in motion staying in motion” when the car stopped suddenly, flying through the car’s windshield. A seat belt overcomes inertia by anchoring us to the car. If you are playing football, the bigger your opponent, the harder he is to tackle and move. On a roller coaster, it is inertia (and the related concept of momentum) that carries a moving car up the next hill.

- **Mass** is a measurement of the amount of matter contained in an object. Non-scientists on Earth use the same measurement scales for mass and weight: grams or kilograms in the metric system, or ounces and pounds in the U.S. system. Scientists use newtons for force, which includes measurement of the force of gravity (weight), and use grams or kilograms for mass.
- A **net force** is the sum of all forces acting on an object. An **unbalanced force** is a net force that is not cancelled out (balanced) by other forces. In other words, an unbalanced force has a net force greater than zero, while a balanced force has a net force equal to zero. Unbalanced forces cause motion; balanced forces do not cause motion. A chair sitting on the floor does not move because all of the forces acting on it, gravity, friction, the upward push of the floor, and air movement, are balanced and cancel out one another. The concepts of balanced and unbalanced forces are discussed in more detail in Tutorial 20.
- On Earth, objects come to rest because of two unbalanced “forces” that resist motion: friction and air resistance. **Friction** occurs when one object slides or rolls over a surface, converting some of the kinetic mechanical energy of an object’s motion into heat (thermal) energy. To feel the friction energy conversion, rub your hands together. **Air resistance** resists motion because as an object moves, it has to push air molecules out of the way, thus transferring some of the object’s kinetic mechanical energy to the air molecules. To feel air resistance, hold your hand out of a car window as the car moves.
- In space, where objects are floating weightless in a vacuum, there is no surface to create friction, and no air to cause air resistance. In space, a moving object really can continue to move at a constant velocity.
- **Newton’s Second Law of Motion**, sometimes called the **law of force and motion**, states that:

An object acted on by an unbalanced force will accelerate in the direction of that force, in direct proportion to the strength of the force, and in inverse proportion to the mass of the object.

Newton’s second law is best described with a mathematical equation that relates three variables, force, acceleration and mass, to one another. The equation can be stated in three forms:

$$\text{force} = \text{mass} \bullet \text{acceleration}$$

$$f = m \bullet a$$

$$\text{mass} = \frac{\text{force}}{\text{acceleration}}$$

$$m = f/a$$

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$

$$a = f/m$$

- These equations require matching units: mass is measured in kilograms (kg), acceleration is measured in meters per second per second (m/s^2), and force is measured in newtons (N). Remember that a newton is defined as the force needed to accelerate a mass of 1 kg by 1 m/s^2 . If a problem gives the mass in grams, it must first be converted to kilograms (by dividing by 1000).
- To understand Newton's second law of motion, it is helpful to apply numbers to the equations in "thought experiments" to see how changes in each of the three variables affect the others. In the first set of examples that follow, the mass of the object will always be 1.0 kilogram (the controlled variable), and the force will be changed (the independent or manipulated variable) to see how acceleration (the dependent or responding variable) is affected:

$$A = f/m \quad 1 \text{ N} / 1 \text{ kg} = 1 \text{ m/s}^2 \quad 2 \text{ N} / 1 \text{ kg} = 2 \text{ m/s}^2 \quad 3 \text{ N} / 1 \text{ kg} = 3 \text{ m/s}^2$$

As you can see, as the force is increased, the resulting acceleration increases in proportion. In mathematical terms, force is directly proportional to acceleration.

In the next set of experiments, we will fix the force at 1 N (the controlled variable), and change the mass (the independent or manipulated variable) to see how acceleration (the dependent or responding variable) is affected:

$$A = f/m \quad 1 \text{ N} / 1 \text{ kg} = 1 \text{ m/s}^2 \quad 1 \text{ N} / 2 \text{ kg} = 0.5 \text{ m/s}^2 \quad 1 \text{ N} / 3 \text{ kg} = 0.33 \text{ m/s}^2$$

In these examples, as the mass increases, the acceleration decreases. In mathematical terms, mass is inversely proportional to acceleration.

- **Newton's Third Law of Motion**, sometimes called the **law of action-reaction**, is usually stated in one of two different ways:

For every action, there is an equal but opposite reaction.

Forces act in equal but opposite pairs.

The best example of Newton's third law is seen in the launch of a rocket. The rocket's engine sends hot gases down out of the rocket, and the rocket responds by moving upward. The upward movement of the rocket is the reaction to the downward action of hot gases. Another example of this law can be seen when one skater pushes off of another skater. Both skaters move backwards in proportion to their mass. The skater doing the pushing moves backward because of the reaction force. The pushed skater moves backwards because of the action force. The same amount of force acts on both skaters, but their different masses affects how much acceleration each will experience.

- Every object in motion can be analyzed using Newton's Laws of Motion to describe how the force acting on the object, and the mass of that object, result in acceleration. Consider the game of pool or billiards. The cue ball is set on the table, and does not move until hit with the cue stick. Newton's first law says that an object at rest will remain at rest, unless acted upon by an unbalanced force. When the cue ball is hit with the tip of the cue stick, the unbalanced force causes the cue ball to move in the direction of the force, again in accord with Newton's first law. The harder the cue stick hits the cue ball, the faster the cue ball will accelerate. This is in accord with Newton's second law. When the now moving cue ball hits another ball, the action force of the collision caused the second ball to move in the same direction that the cue ball was moving. The backwards reaction force on the cue ball is cancelled out by the forward inertia of the cue ball, causing the cue ball to stop. These movements are all in accord to Newton's third law.

Practice Questions

1. A _____ is a push or a pull.
2. The collision between two objects is an example of a _____ force.
3. Gravity and magnetism are examples of _____ forces.
4. The metric unit of measurement for force is the _____.
5. Newton's First Law of Motion is also called the law of _____.
6. State Newton's First Law of Motion: _____

_____.
7. Define "inertia." _____
_____.
8. Give two examples of inertia: _____

_____.
9. What is "net force." _____
_____.
10. What is an "unbalanced force." _____
_____.
11. What is caused by unbalanced forces? _____
12. What is friction? _____
_____.
13. Newton's Second Law of Motion is also called the law of _____
_____.

14. State Newton's Second Law of Motion: _____

15. State the three forms of the formula for Newton's Second Law of Motion:

16. Newton's Third Law of Motion is also called the _____
law.

17. State Newton's Third Law of Motion: _____

18. Give two examples of Newton's Third Law in action: _____
