

# Newton's Laws & Classical Mechanics

or

## How things move at speeds considerably less than the speed of light

**N**ewton's laws of motion consist of three physical laws that form the basis for classical mechanics. Classical mechanics is a fancy name for the standard way to think of and predict how things move and why. Classical mechanics was "invented" by Newton...who is better known for his best invention...the fig newton. Classical mechanics describes the relationship between the forces acting on a body and the body's motion due to those forces. They can be summarized as follows:

**First law:** Every body (a fig for example) remains in a state of rest or uniform motion (constant velocity) unless it is acted upon by an external force. This means that in the absence of forces, a body either remains at rest, or moves at a constant speed in a straight line.

**Second law:** A body of mass  $m$  subject to a force  $\mathbf{F}$  (forces are typically given in newtons) undergoes an acceleration  $\mathbf{a}$  that has the same direction as the force and a magnitude that is directly proportional to the force and inversely proportional to the mass, i.e.,  $\mathbf{F} = m\mathbf{a}$ . This is possibly the most important formula in all of physics and even all of science and engineering technology, and economics, or even the entire universe or even another universe, or my house, a hospital, or a vinyl-sided two car garage with a cupola.

**Third law:** The mutual forces of action and reaction between two bodies are equal, opposite and collinear. This means that whenever a first body exerts a force  $\mathbf{F}$  on a second body, the second body exerts a force  $-\mathbf{F}$  on the first body.  $\mathbf{F}$  and  $-\mathbf{F}$  are equal in magnitude and opposite in direction. This law is sometimes referred to as the *action-reaction law*, with  $\mathbf{F}$  called the "action" and  $-\mathbf{F}$  the "reaction". The action and the reaction are simultaneous.

Newton carefully studied the works of Johannes Kepler and Galileo Galilee and discovered the underlying reasons for what each of them had found. Kepler had figured out that the planets orbit the Sun in ellipses and described some specifics in Kepler's three laws of planetary motion. Before Kepler, Galileo formed the idea of inertia in his experiments chucking things off of tall buildings in the town of Pisa. Galileo found that all solid bodies, regardless of weight, if they were made of the same substance (like rock) and were roughly spherical, fell at the same speed and accelerated at the same rates.

The three laws of motion were first carefully described by Sir Isaac Newton in his work *Philosophiæ Naturalis Principia Mathematica*, (generally called The Principia; pronounced PRINK-ip-EE-ah) first published on July 5, 1687. Newton began this work at the ripe old age of about 19. Newton used these laws to explain and investigate the motion of physical objects and systems. For example, in The Principia, Newton showed that these laws of motion, combined with his law of universal gravitation, explained Kepler's laws of planetary motion.

**Force**...A force is a push or pull on something. If there is a net force on an object and it is not “balanced”... opposed or counteracted by another force... the object will move.

Before discussing forces we need to get some scientific units straight in our heads.

**The most important unit is the newton (abbreviated as: N)**

1 newton or 1N is equal to the force needed to accelerate a 1 kilogram object at 1 meter per second for every second it travels. This is when friction is ignored.

A common brick used to build houses, chimneys, sidewalks, buildings, bridges, wall, ramparts, columns, ramps, archways, masonry ovens, beehive ovens, retainers, foundations etc. is about 1 kilogram. The force needed to speed up the brick from rest to 1 meter per second in 1 second is 1N.

The newton is handy in the measurements of the force of gravity. If the force of gravity is 9.8 meters per second squared then how many newtons does a 100 kg object weigh?

$$9.8 \times 100 = 980\text{N}$$

Let us now apply this to a question →

Ignoring friction, how many newtons of force must be applied to a block of ice with a mass of 100 kilograms in order to accelerate the block across a frozen lake at 2 meters per second squared?  $F = ma \rightarrow$  How many newtons are needed?  $= 100 \text{ kg} \times 10 \text{ m/sec}^2$

How about another example question:

Engineers at the NASA must determine the net force needed for a rocket to accelerate at  $70 \text{ m/s}^2$ . If the mass of the rocket is 45,000 kg, how much net force must the rocket develop?

Using Newton's second law,  $F=ma$

$$F=(45,000 \text{ kg})(70 \text{ m/s}^2) = 3,150,000 \text{ kg m/s}^2 \quad F=3,150,000 \text{ N}$$

*Note that the units “kg m/s<sup>2</sup>” and “newtons” are equivalent; that is, 1 kg m/s<sup>2</sup>*

### **PRACTICE PROBLEMS**

1. What net force is required to accelerate a car at a rate of  $2 \text{ m/s}^2$  if the car has a mass of 3,000 kg?

$$F = \underline{\hspace{2cm}}$$

$$m = \underline{\hspace{2cm}} \quad a = \underline{\hspace{2cm}}$$

2. A 10 kg bowling ball would require what force to accelerate down an alleyway at a rate of  $3 \text{ m/s}^2$ ?

$$F = \underline{\hspace{2cm}} \quad m = \underline{\hspace{2cm}}$$

$$a = \underline{\hspace{2cm}}$$

3. Sally has a car that accelerates at  $5 \text{ m/s}^2$ . If the car has a mass of 1000 kg, how much force does the car produce?

$$F = \underline{\hspace{2cm}} \quad m = \underline{\hspace{2cm}}$$

$$a = \underline{\hspace{2cm}}$$

4. What is the mass of a falling rock if it produces a force of 147 N?

$$F = \underline{\hspace{2cm}} \quad m = \underline{\hspace{2cm}}$$

$$a = \underline{\hspace{2cm}}$$

### **VECTORS and VECTOR ADDITION**

Forces are often described without numbers. The way this is done is with arrows. The arrow that represents a force is called a vector.

Vectors show two things: direction of the force and the size (or magnitude) of the force

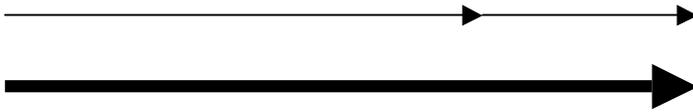
The direction in which the arrow points indicates the direction of the force. The length of the

arrow is directly related to how much force there is in the vector...smaller arrows have less force.



The first vector is twice as long as the second; therefore the second vector has twice the force.

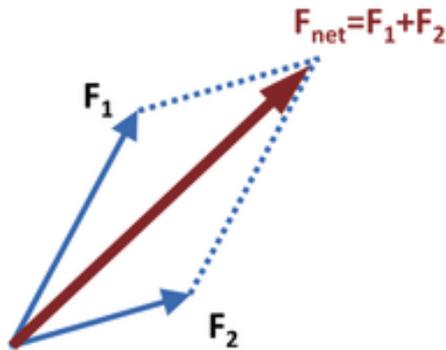
We can add the two vectors by placing them end-to-end. Below I have added the two vectors by placing them end to end and I show the resultant vector in bold.



We can subtract vectors by placing them in opposite directions end to end



What is the resultant vector here?



If  $F_1$  is 10N and  $F_2$  is 8N what is the magnitude of the resultant vector (the large arrow) in newtons. I suggest you do it on graph paper.