Chapter Title: Force and Motion-I

Sections: Newton’s First Law, Inertial Reference Frames, Newton's Second Law, Some Particular Forces, Newton’s Third Law

---

Newton’s First Law of Motion

Days before Galileo Galilei:

It was thought that a steady force, such as a push or pull, was always needed to keep an object moving with constant velocity.

Galileo, and later Newton, recognized that the slowing of objects in everyday experience is due to the force of friction. If friction is reduced, the rate of slowing is reduced.

Difference Between Old Idea and Galilean Idea:

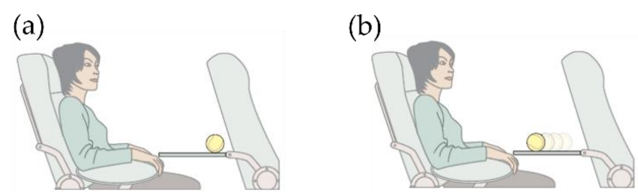
Did not recognize all the forces and the action of forces.

Newton’s First Law of Motion

Galileo described that, if we could remove all external forces including friction from an object, then the velocity of the object would never change—a property of matter he described as inertia.

(a) The plane continues to fly at constant velocity (relative to the ground) and the ball remains at rest on the tray.

(b) The pilot suddenly opens the throttle, and plane rapidly gains speed. The ball does not gain speed as quickly as the plane, so it accelerates (relative to the plane) toward the back of the plane.



An object at rest stays at rest unless acted on by an external force. An object in motion continues to travel with constant velocity unless acted on by an external force.

Or, if no net force ($\vec{F}_{net} = 0$) acts on a body, the body's velocity cannot change; that is, the body cannot accelerate.

It is also called the law of inertia.

It’s important to note that the net force is what matters in Newton’s first law.

In a short, No net force, no acceleration!

$\vec{F}_{net} = 0$, $\vec{a} = 0$ (Constant $\vec{v}$)

Inertia

The tendency of a body to keep moving once it is set in motion results from a property called inertia.

A body is in ***equilibrium***, when the body is either at rest or moving with constant velocity (in a straight line with constant speed).

For a body to be in ***equilibrium***, it must be acted on by no forces, or by several forces such that their vector sum is zero—that is, the net force is zero:

$$\sum \vec{F} = 0$$

Inertial Reference Frames

A frame of reference in which Newton's first law is valid is called an inertial frame of reference, inertial reference frames, or inertial frames.

Mass

Objects intrinsically resist being accelerated. This intrinsic property is called mass of an object. Mass is a quantitative measure of inertia. The greater an object's mass, the more the object resists being accelerated.

The SI unit of mass is kilogram (kg).

The concept of mass is defined as a constant of proportionality in Newton's second law.

Newton's Second Law of Motion

The net force on a body is equal to the product of the body's mass and its acceleration.

Or, the acceleration of an object is directly proportional to the net force acting on it, and the reciprocal of the mass of the object is the constant of proportionality.

$$\vec{F}_{net} = m\vec{a}$$

where $\vec{F}_{net} = \sum \vec{F}$, and $\vec{a} = \frac{\vec{F}_{net}}{m}$

Unit: Force

The unit of force is Newton (N). $F = ma$

A net force on an object causes it to accelerate.

One newton is the amount of net force that gives an acceleration of 1 meter per

second squared to a body with a mass of 1 kilogram.

Some Particular Forces: Gravitational Force

If an object is dropped near the Earth's surface, it accelerates toward the Earth. If air resistance is negligible, all objects fall with the same acceleration, called free-fall acceleration.

The force causing this acceleration is the gravitational force exerted by Earth on the object.

If the gravitational force is the only force acting on an object, the object is said to be ***in freefall***.

Newton's second law to an object of mass m that is in freefall with acceleration $\vec{g}$,

$\vec{F}_g = m\vec{g}$, or simply, $F = mg$ ($\vec{F}_g = -F_g\hat{j} = -mg\hat{j} = m\vec{g}$)

Some Particular Forces: Weight

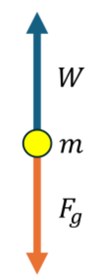
The weight (W) of the object is the magnitude of the gravitational force on it.

In a word, it is the magnitude of the net force required to prevent the body from falling freely.

Newton's second law,

$$F = ma$$

Since $a = 0$ when the weight is acting on a ***freely falling*** object (m),



$$W - F_g = m(0)$$

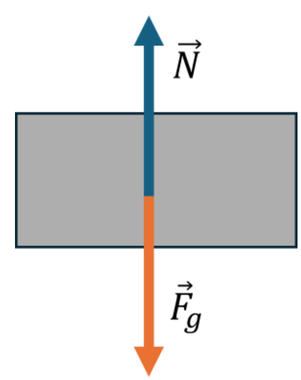
$$W - F_g = 0$$

$$W = F_g$$

$$W = mg$$

Some Particular Forces: Normal Force

Newton's second law,



$$F = ma$$

$$F_N - F_g = ma$$

$$F_N - mg = ma$$

$$F_N = mg + ma$$

$$F_N = m(g + a)$$

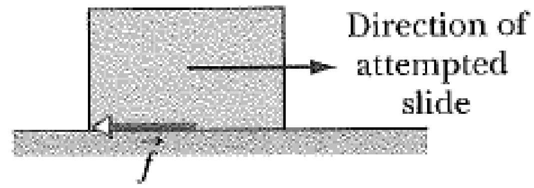
If the block is not accelerating, $a = 0$,

$$F_N = mg$$

Some Particular Forces: Friction Force

If an object either slides or attempts to slide over a surface, the motion of that object is resisted due to a bonding between the object's body and the surface.

This resistance force is called a frictional force or friction. It is denoted by $\vec{f}$.

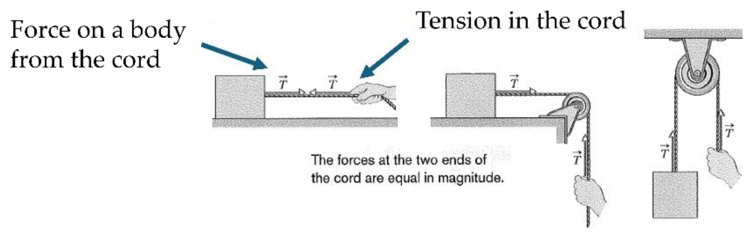


Direction: The force is directed along the surface and opposite the direction of the intended motion.

For simplicity, sometimes an assumption is made such that friction is negligible or the surface is frictionless.

Some Particular Forces: Tension Force

When a body is pulled with a force to move, the force is called a tension force or simply tension. A cord, rope, cable, and such objects are used to pull a body.



It is denoted by T.

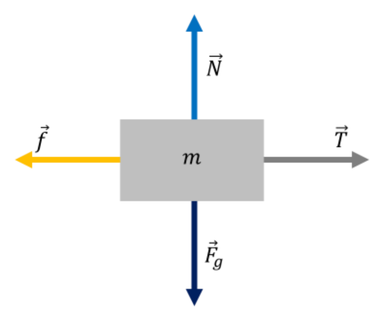
Two forces with the same magnitude: Force on a body from the cord (T), and tension in the cord (T).

Newton's Third Law of Motion

When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

$$\vec{F}_{A\ on\ B} = -\vec{F}_{B\ on\ A}$$

Free-Body Diagram



Newton's second law,

$$\vec{F}_{net} = m\vec{a}$$

$$\vec{N} + \vec{T} - \vec{F}_g - \vec{f} = m\vec{a}$$