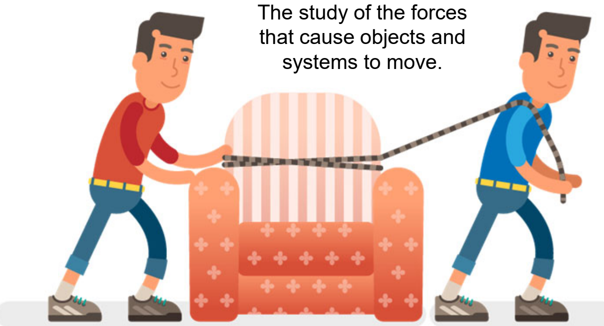
# Dynamics

The study of the forces that cause objects and systems to move.

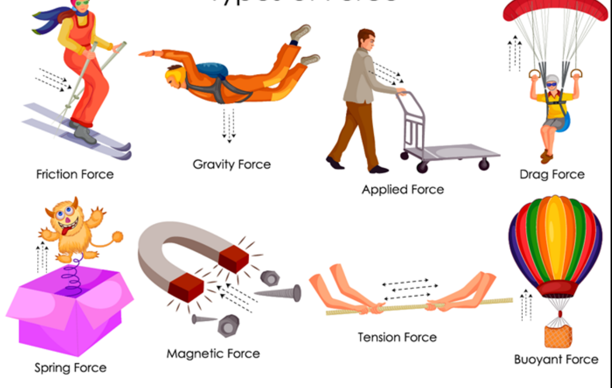


VectorMine (Adobe Stock)

# Forces

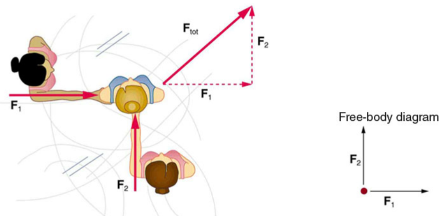
- Intuitively, we experience force as a push or a pull on an object.
- By definition, force is always the result of an interaction of two or more objects.
  - No object possesses force on its own.
- No object can exert force on itself.
- Force is a vector quantity measured in Newtons (N).

# Types of Force



## Free Body Diagrams

- A free body diagram is a technique used to illustrate all the external forces acting on a body.

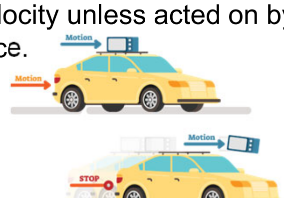



OpenStax, Rice University (CC BY 4.0)

- The body is represented by a single isolated point (or free body), and only those forces acting on the body from the outside (external forces) are shown.
  - These forces are the only ones shown, because only external forces acting on the body affect its motion. We can ignore any internal forces within the body.

## Newton's 1st Law
### (Law of Inertia)

- There exists an inertial frame of reference such that a body at rest remains at rest, or, if in motion, remains in motion at a constant velocity unless acted on by a net external force.

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## Mass

- The property of a body to remain at rest or to remain in motion with constant velocity is called **inertia**.
- Some objects have more inertia than others.
  - It is more difficult to change the motion of a large boulder than that of a basketball.
- The inertia of an object is measured by its mass.

## Newton's 2nd Law

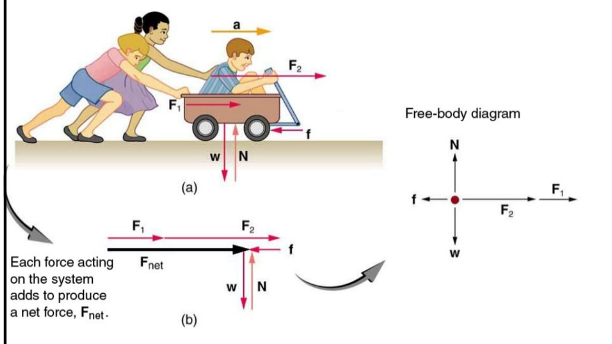
- The acceleration of a system is directly proportional to and in the same direction as the net external force acting on the system, and inversely proportional to its mass.

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

This is often written as $F_{net} = ma$, with the understanding that both force and acceleration are vectors.

## System

- A system is defined by the boundaries of an object or collection of objects being observed; all forces originating from outside of the system are considered external forces.






- When we describe the acceleration of a system, we are modeling the system as a single point which contains all the mass of that system.
- The point we choose for this is the point about which the system's mass is evenly distributed (center of mass).

## Weight

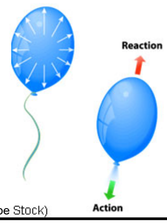
- Weight is defined as the force of gravity acting on an object.

$$w = F_g = mg$$

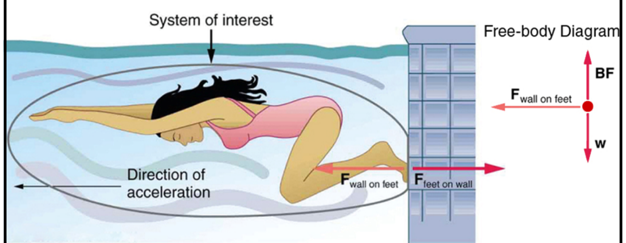
$$\boxed{\vec{g} = \frac{\vec{F}_g}{m}}$$

# Newton's 3rd Law

- Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts.
  - Forces always come in pairs.



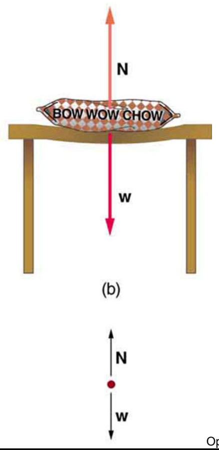




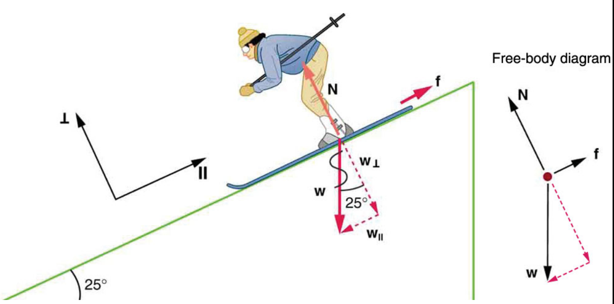

# Normal Force

- When an object is sitting on a surface the surface must support the load by exerting an upwards force equal to the weight.
- If the force supporting a load is perpendicular to the surface of contact between the load and its support, this force is defined to be a normal force.





- In some cases, the normal force is not equal to the weight.



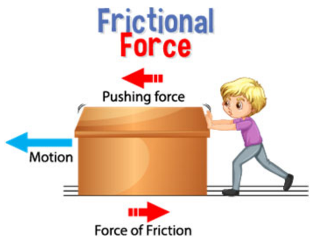


# Fundamental Forces of Nature

- Strong Nuclear Force
  - Holds nucleus of atom together
- Weak Nuclear Force
  - Between subatomic particles
- Gravitational Force
  - Between all objects
- Electromagnetic Force
  - Between charged particles

# Friction

- Friction is a force that opposes relative motion between systems in contact.

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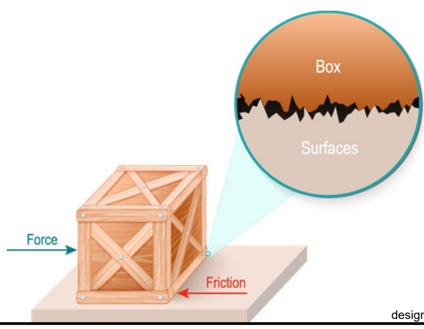
- Friction exists between two solid surfaces because even the smoothest looking surface is quite rough on a microscopic and atomic scale.

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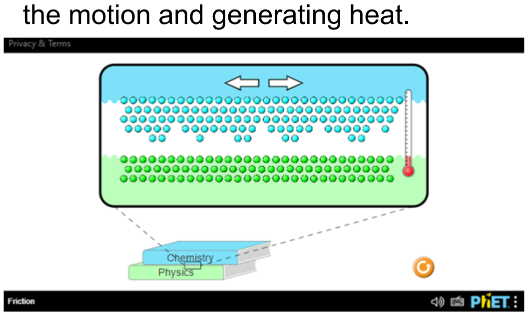
- As we try to slide an object across another surface the atoms of each surface rub against each other impeding the motion and generating heat.




https://phet.colorado.edu/sims/html/friction/latest/friction_en.html

- If two systems are in contact and moving relative to one another, then the friction between them is called **kinetic friction**.
- When objects are stationary, **static friction** can act between them; the static friction is usually greater than the kinetic friction between the objects.
- The magnitude of both types of friction is proportional to the normal force.

- Kinetic Friction

$$F_f = \mu_k F_n$$

- Static Friction

$$F_f \leq \mu_s F_n$$

- $\mu$ is the coefficient of friction.
  - The value of $\mu$ depends on the surfaces in contact with each other.

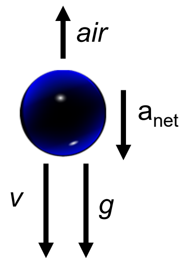
| **System** | $\boldsymbol{\mu_k}$ | $\boldsymbol{\mu_s}$ |
|---|---|---|
| Rubber on dry concrete | 0.7 | 1.0 |
| Rubber on wet concrete | 0.5 | 0.7 |
| Steel on ice | 0.02 | 0.04 |

$$\left|\vec{F}_f\right| \leq \mu\left|\vec{F}_n\right|$$

## Drag Force

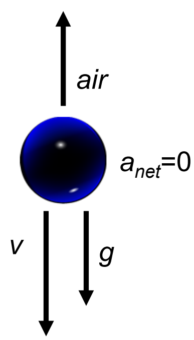
- The drag force always opposes the motion of an object as it moves through a fluid.
- The drag force is proportional to some function of the velocity of the object in that fluid.
  - This functionality is complicated and depends upon the shape of the object, its size, its velocity, and the fluid it is in.

- When objects fall through the air, gravity pulls down and the air pushes up on the falling object.
- This reduces the net acceleration of the object.
- The drag force due to the air will increase the longer the object falls.




Credit: Sabrog (public domain)

- Eventually, the drag force will equal the force of gravity resulting in a net acceleration of zero.
- The object will continue to fall but will no longer accelerate.

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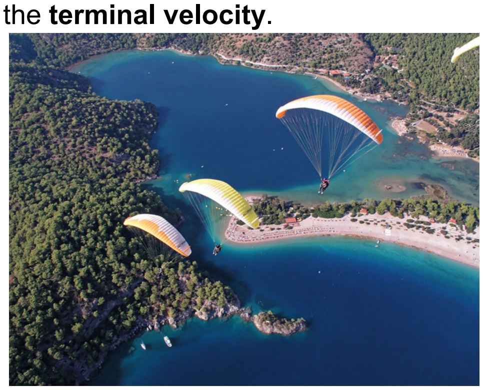
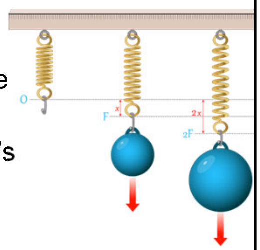
- This maximum velocity is referred to as the **terminal velocity**.



Kevin Phillips (Pixabay)

# Elastic (Spring) Force

- When a force is applied to a spring the spring stretches by an amount that is proportional to the force.
- This is known as Hooke's Law.




$$\left|\vec{F}_s\right| = k|\vec{x}|$$

$k$ is the spring constant

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