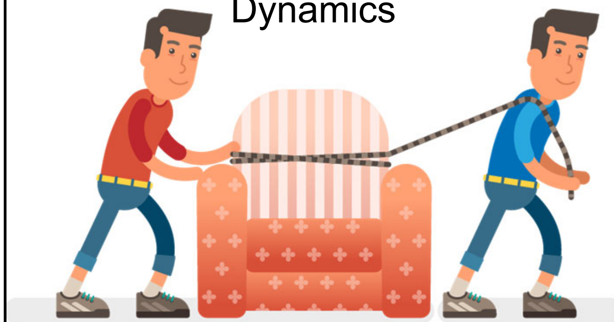
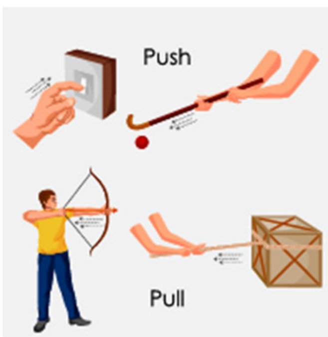
Dynamics



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

VectorMine (Adobe Stock)

- **Force** is the cause of motion.
- A force pushes or pulls an object.



Credit: vectron (Adobe Stock)

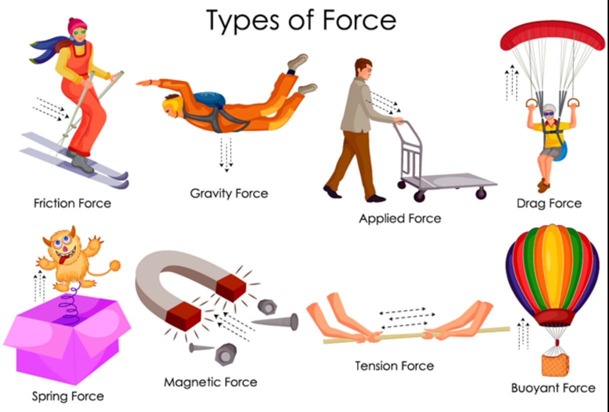
- When multiple forces act on an object, the forces combine.
- Adding together all the forces acting on an object gives the total force, or **net force**.
- An **external force** is a force that acts on an object within the system from outside the system.
- An **internal force** acts between two objects that are both within the system.

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.

- 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

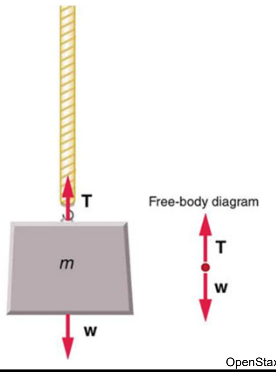


Vecton (Adobe Stock Photo)

Free-body Diagram

- A free-body diagram represents the object being acted upon as a single point.
- Only the forces acting on the body (external forces) are shown and are represented by vectors (drawn as arrows).
  - Only external forces acting on the body affect its motion.
  - Internal forces within the body can be ignored because they cancel each other out.

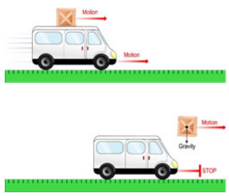
- Free-body diagrams are very useful for analyzing forces acting on an object.



OpenStax, Rice University (CC BY 4.0)

Newton's 1st Law

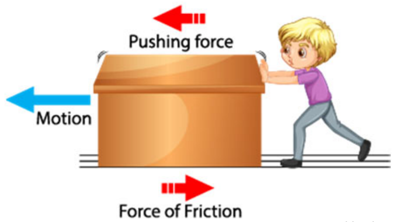
- A body at rest tends to remain at rest.
- A body in motion tends to remain in motion at a constant velocity unless acted on by a net external force.



Credit: designus (Adobe Stock)

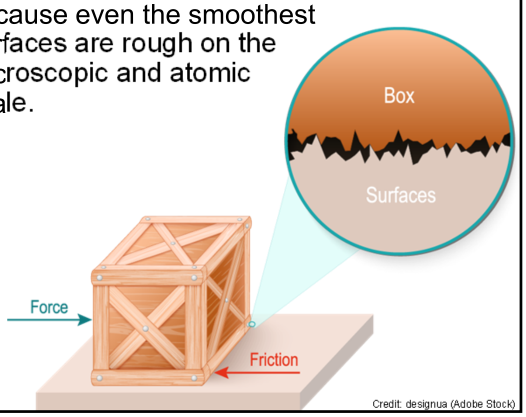
Friction

- Friction is an external force that acts opposite to the direction of relative motion or to prevent slipping.



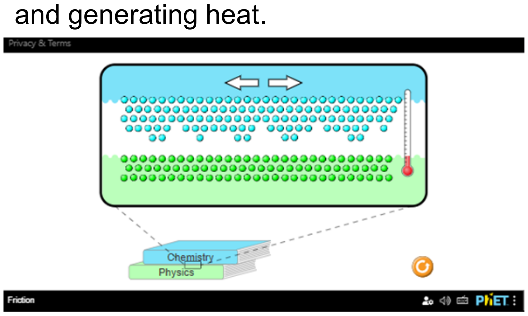
blueringmedia (Adobe Stock)

- Friction exists between two solid surfaces because even the smoothest surfaces are rough on the microscopic and atomic scale.



Credit: designua (Adobe Stock)

- 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.

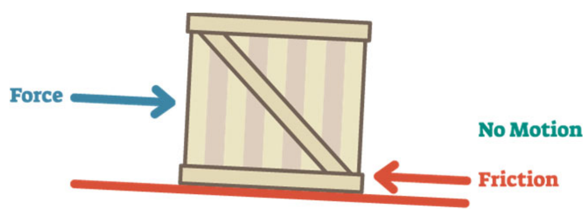


https://phet.colorado.edu/sims/html/friction/latest/friction_en.html

- If two systems are in contact and moving relative to one another, then the friction between them is called **kinetic friction**.

Fridas (Adobe Stock)

- 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.

Credit: VectorMine (Adobe Stock)

- Kinetic Friction

  $F_f = \mu_k F_n$

- Static Friction

  $F_f \leq \mu_s F_n$

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

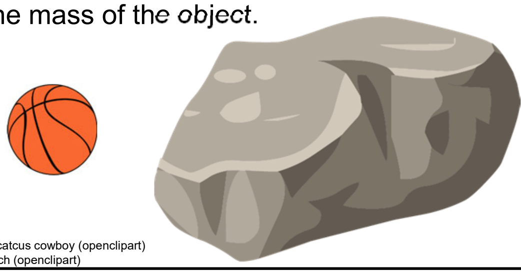
System	$\boldsymbol{\mu_k}$	$\boldsymbol{\mu_s}$
Rubber on dry concrete	0.7	1.0
Rubber on wet concrete	0.5	0.7
Steel on ice	0.02	0.04

$$F_f \leq \mu F_N$$

Mass and Inertia

- **Inertia** is the tendency for an object at rest to remain at rest, or for a moving object to remain in motion in a straight line with constant speed.
- This key property of objects was first described by Galileo. Later, Newton incorporated the concept of inertia into his first law, which is often referred to as the **law of 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 proportional to the mass of the object.



basketball – catcus cowboy (openclipart)
boulder – glitch (openclipart)

- **Mass** is a measure of the amount of matter in an object.
  - The amount of matter is determined by the number and types of atoms the object contains.
  - Unlike weight (which changes if the gravitational force changes), mass does not depend on gravity.

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 in terms of force with the understanding that both force and acceleration are vectors.

$$\boxed{F = ma}$$

Credit: anatolir (Adobe Stock)

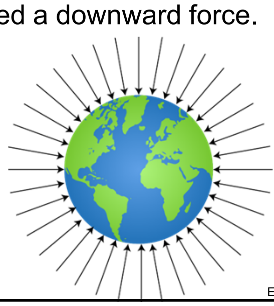
- When we describe the acceleration of a system, we are modeling the system as a single point which contains all the mass of that system.
- The point we choose for this is the point about which the system's mass is evenly distributed (center of mass).

Weight

- One of the most important applications of Newton's second law is to calculate weight (also known as the gravitational force), which is usually represented mathematically as w.

- When an object is dropped, it accelerates toward the center of Earth.
  - All objects accelerate at the same rate.
- Newton's second law states that the net external force acting on an object is responsible for the acceleration of the object.
- If air resistance is negligible, the net external force on a falling object is only the gravitational force (i.e., the weight of the object).

- Weight can be represented by a vector because it has a direction.
- Down is defined as the direction in which gravity pulls, so weight is normally considered a downward force.



Earth – martialred (Adobe Stock)

- Consider an object with mass m falling toward Earth.
- It experiences only the force of gravity (weight), w.
- The acceleration of an object due to gravity is denoted as g.

$$F = ma$$

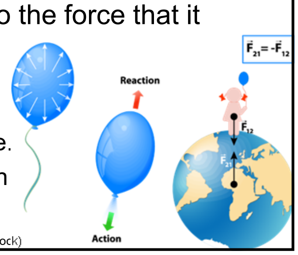
Substituting for force and acceleration gives

$$\boxed{w = mg}$$

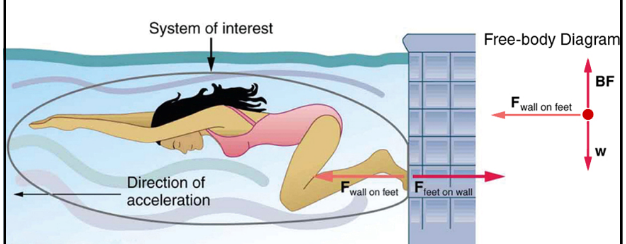
For Earth, $g = 9.8\ \mathrm{m/s}^2$.

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.
  - For every action force there is an equal and opposite reaction force.
  - Forces always come in pairs.



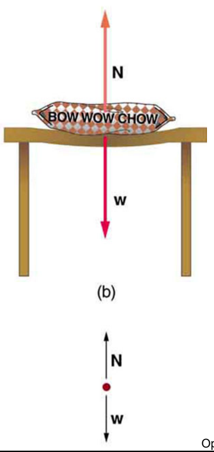
designua (Adobe Stock)



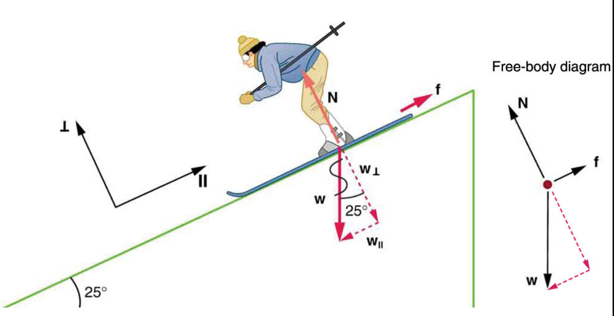
OpenStax, Rice University (CC BY 4.0)

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

Concept Problem 1

- A car is driving on an icy road. It tries to turn around a curve, but it continues straight and ends up in the ditch. Explain why.

Answer

- Objects in motion continue moving with a constant velocity unless acted on by an external force. This is explained by Newton's first law of motion. There is very little friction on an icy road, therefore, there is not enough frictional force for the car to change direction and so it continues moving straight.

Concept Problem 2

- You are riding a bus that is moving 5 m/s south. You toss a coin straight up into the air. You do not move your hand. Where will the coin land? Why?

Answer

- The coin will land back in your hand. Newton's first law says that objects in motion will continue to move with a constant velocity unless acted on by an external force. The coin's horizontal velocity is equal to the that of the bus and you, which is constant. There are no horizontal forces acting on the coin, therefore, the coin will move horizontally at the same velocity.

Concept Problem 3

- A person dressed for winter is standing outside in the middle of a pond with frictionless ice. What should the person do (no one is around to help) to reach the shore?

Answer

- The person should throw their jacket (and more if necessary). Newton's third law states that forces come in pairs. Throwing the coat (action force) produces an equal and opposite force (reaction force) on the person. Newton's second law states that a net force acting on an object causes it to accelerate. Assuming no friction from the ice, the force will cause the person to accelerate towards the edge.

Numerical Example 1

- A boy pulls a 2 kg wagon with a horizontal net force of 10 N. Calculate the horizontal acceleration of the wagon.

$$F = ma$$

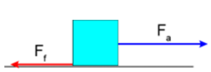
$$a = \frac{F}{m}$$

$$a = \frac{10}{2}$$

$$a = 5 \text{ N}$$

Numerical Example 2

- An applied horizontal force of 75.0 N accelerates a 100 kg box along a rough surface at a rate of 0.5 m/s^2. Calculate the force of friction between the box and the surface.



$$F = ma$$

$$F_a - F_f = ma$$

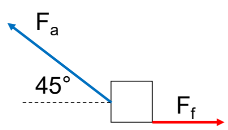
$$F_f = F_a - ma$$

$$F_f = 75 - (100)0.5$$

$$F_f = 25 \text{ N}$$

Numerical Example 3

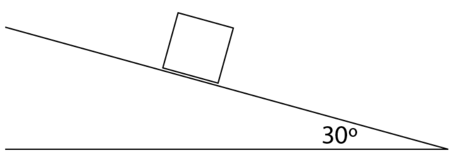
- A boy is pulling a sled across the snow at constant velocity with a force of 250 N at an angle of 45° with the surface. Calculate the frictional force acting on sled.

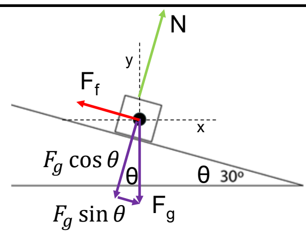


$$F = ma$$
$$F_{ax} - F_f = ma$$
$$F_{ax} - F_f = 0$$
$$F_a \cos\theta - F_f = 0$$
$$F_f = F_a \cos\theta$$
$$F_f = (250)\cos 45$$
$$F_f = 177 = 180\text{ N}$$

Numerical Example 4

- A 25 kg box slides down an incline plane as shown below. The box moves with a constant velocity. Calculate the coefficient of friction between the box and the surface.





$$F_f = \mu F_N$$

$$\mu = \frac{F_f}{F_N}$$

$$\mu = \frac{F_g \sin\theta}{F_g \cos\theta}$$

$$\mu = \frac{\sin 30}{\cos 30} = 0.58$$

<u>x</u>

$$F = ma$$

$$-F_f + F_g \sin\theta = 0$$

$$F_f = F_g \sin\theta$$

<u>y</u>

$$F = ma$$

$$N - F_g \cos\theta = 0$$

$$N = F_g \cos\theta$$