4 Dynamics of Straight Line Motion

What is a Force?

- A force is a *push* or a *pull*; it's a specific action.
- It acts on an object and requires an agent.
- Fundamental forces like gravity are *long-range* forces, but most forces you encounter everyday require *contact*.
- A force is represented by a vector – it has a magnitude measured in Newtons (1 N = 1 kg m/s^2) and a direction.
- Forces can be combined to create a *net force*:

$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \cdots = \sum_i \vec{F}_i.$$

You *must* add the forces together as vectors.

Newton's First Law

An object that is at rest will remain at rest, or an object that is moving at constant velocity will continue to move at constant velocity, if and only if the net force on the object is zero.

An object on which the net force is zero is said to be in *mechanical equilibrium*.

Newton's Second Law

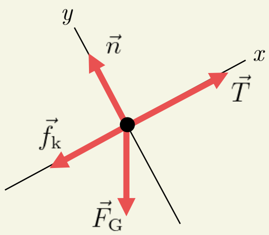
An object of mass m will undergo an acceleration $\vec{a}$ given by

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

where $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \cdots$ is the sum of all forces acting on the object.

Free Body Diagrams

A free body diagram is a useful took for using Newton's second law. It shows all forces acting on the object, and should have: clear labels, coordinate axes, and a dot representing the object.



Model: Constant Force

If the net force on an object is constant, then the object's acceleration is also constant, and we can use the kinematic equations to model the motion of the object.

Forces

Gravity $\vec{F}_G$ **(Long-range force)**
For objects near the surface of the Earth, we can model the force of gravity on an object of mass m as

$$\vec{F}_{\text{G}} = (mg,\ \text{straight down})$$

where $g = 9.80$ m/s^2 is the free-fall acceleration.

Tension $\vec{T}$ **(Contact force)**
A rope or string exerts a constant force called *tension*. The magnitude of the force depends on the situation, and the direction of the tension is always along the rope or string.

Spring Force $\vec{F}_{sp}$ **(Contact force)**
Springs exert a force when they are stretched or compressed. The force can be modeled by Hooke's law,

$$\vec{F}_{\text{sp}} = -k\Delta\vec{r}$$

where k is the spring constant.

Normal Force $\vec{n}$ **(Contact force)**
The normal force is a constant force exerted by a surface on an object that is pressing against that surface. The force is always perpendicular to the surface and its magnitude changes depending on the situation.

Static Friction $\vec{f}_s$ **(Contact force)**
The static friction force keeps an object from slipping on a surface. Its direction is parallel to the surface and prevents motion. The magnitude changes depending on the situation but has a maximum value that can be modeled by

$$f_{\text{s, max}} = \mu_s n$$

where μ_s is the *coefficient of static friction.*

Kinetic Friction $\vec{f}_k$ **(Contact force)**
Kinetic friction acts when an object slides on a surface. Its direction is parallel to the surface and opposite the motion. The force can be modeled as

$$\vec{f}_{\text{k}} = (\mu_k n,\ \text{opposes motion})$$

where μ_k is the *coefficient of kinetic friction.*

Drag $\vec{F}_{drag}$ **(Contact force)**
An object moving through a fluid feels a resistance called *drag*. The drag force can be modeled as

$$F_{\text{drag}} = (\tfrac{1}{2}C\rho A v^2,\ \text{opposes motion})$$

where ρ is the density of the fluid, A is the cross-sectional area of the object, and C is the *drag coefficient.*

Thrust $\vec{F}_{thrust}$ **(Contact force)**
Thrust occurs when a jet or rocket engine expels gas molecules at high speed. Its direction is opposite the exhaust, and the magnitude depends on the situation.