Newton's Laws of Motion

Forces

Force (*F*)

- **A push or a pull on an object.**
- **An agent that results in the acceleration or deformation of an object.**
- **Forces are a vector quantity because they have magnitude and direction.**

Newton's First Law of Motion

(Sir Isaac Newton 1642-1727)

The Law of Inertia

An object with no net force acting on it remains at rest or moves with constant velocity in a straight line.

Since more than one force can act upon an object, the sum of all forces or *net* force must be considered.

Inertia

Property of matter that opposes any change in its state of motion.

Newton's Second Law of Motion

Law of Acceleration

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

This law is more useful in its mathematical form.

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

$$\sum F_x = ma \quad \sum F_y = ma$$

Newton's Second Law ($F = ma$)

The relationship between force, mass, and acceleration lets us define the SI unit of force:

$$F = ma [=] \text{ kg} \cdot \frac{\text{m}}{\text{s}^2} = \frac{\text{kg} \cdot \text{m}}{\text{s}^2} = \text{ Newton (N)}$$

Newton's Third Law of Motion

The Law of Interaction

When an object exerts a force on another object, the second object exerts a force on the first that is equal in magnitude, but opposite in direction.

These two forces are called action-reaction forces or third-law force pairs.

$$\vec{F}_{ab} = -\vec{F}_{ba}$$

$\vec{F}_{ab}$ **= the force that object *a* exerts on object *b***

$\vec{F}_{ba}$ **= the force that object *b* exerts on object *a***

Mass (kg) versus Weight (N)

Mass (*m*)

A measure of inertia (quantity of matter). The mass of an object is the *same everywhere*.

Weight (F_g)

The force of that mass and depends upon the gravitational acceleration (g) due to the object attracting that mass.

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

Force Diagrams

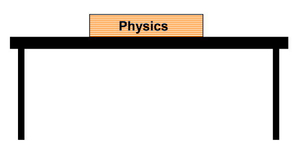
- Referred to as **free-body diagrams**
- Shows only 1 object and all the forces acting on it
- Is used to find the **net external force** acting on a object—using vector analysis
  - **Net external force** is the vector sum of all the forces acting on an object

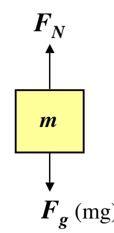
Normal Force

- The normal force is one which prevents objects from 'falling' into whatever it is they are sitting upon.
- It is always perpendicular to the surface with which an object is in contact.
- It is ***ALWAYS*** present when the object is in ***CONTACT*** with a surface.
- It is ***ONLY*** present when the object is in ***CONTACT*** with a surface.

Normal Force

- A physics text book weighing 20 N is sitting on a table.
  - Gravity is pulling down with a force of 20 N.
  - The table is pushing up with a force of 20 N (Newton’s 3rd Law)

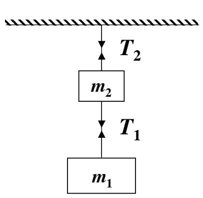




1-D Tension Problems

When a cord or rope is attached to an object and pulled taut, the cord is said to be under *tension*.

Tension (T) is a force whose direction is away from the object and along the cord at the point of attachment.



1-D Tension Problems

Free-Body Diagrams

Net force equations using Newton’s 2nd Law:

$$\sum F_y = ma$$

$$T_1 - F_{g1} = 0$$

$$T_2 - T_1 - F_{g2} = 0$$

Frictional Force

Friction **(F_f)**

The force that opposes motion between two surfaces that are in contact.

- ***Static Friction*** **(F_{fs})**
  The force that opposes the start of motion.
- ***Sliding or Kinetic Friction*** **(F_{fk})**
  The force between two surfaces in relative motion.

In general, the static friction is greater than the kinetic friction for two surfaces in contact.

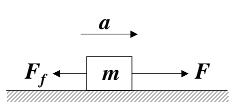
Determining the Frictional Force

The frictional force F_f is directly proportional to the normal force between the object upon which the applied force is exerted and the surface upon which the object is in contact. The proportionality constant is called the *coefficient of friction* (μ). In other words,

$$F_f = \mu F_N$$

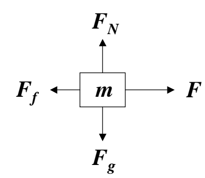
Friction and Newton's 2^nd^ Law

If a force F is applied to a box with mass m, the frictional force F_f opposes the applied force and the acceleration a is in the direction of the applied force.



Friction and Newton's 2^nd^ Law

Free-Body Diagram



Net force equations using Newton's 2nd Law:

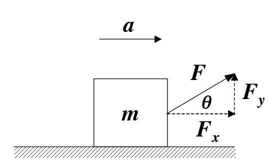
$$\sum F_y = ma \qquad \sum F_x = ma$$

$$F_N - F_g = 0 \qquad F - F_f = ma$$

More About the Normal Force

If an applied force has a component pushing down or pulling up on the object then the normal force is not simply the weight of the object (or component of the weight ⊥ to the contact surface). The normal force also contains the response to the applied force.

Forces Applied at Angles

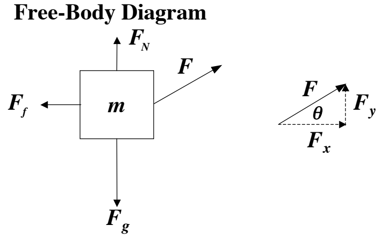


$$F_x = F\cos\theta$$

$$F_y = F\sin\theta$$

Forces Applied at Angles

Free-Body Diagram

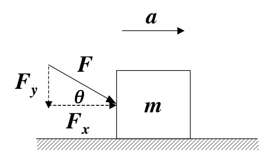


Net force equations using Newton's 2nd Law:

$$\sum F_y = ma \qquad \sum F_x = ma$$

$$F_N - F_g + F_y = 0 \qquad F_x - F_f = ma$$

Forces Applied at Angles

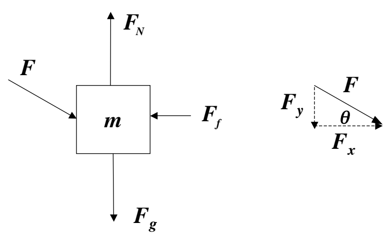


$$F_x = F\cos\theta$$

$$F_y = F\sin\theta$$

Forces Applied at Angles

Free-Body Diagram

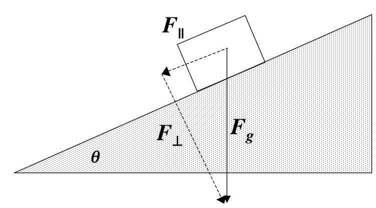


Net force equations using Newton's 2nd Law:

$$\sum F_y = ma \qquad \sum F_x = ma$$

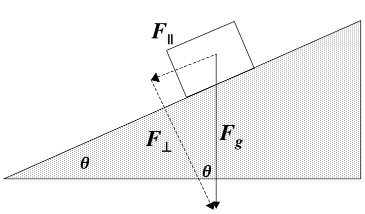
$$F_N - F_g - F_y = 0 \qquad F_x - F_f = ma$$

Inclined Planes



$$\vec{F}_g = \vec{F}_\parallel + \vec{F}_\perp$$

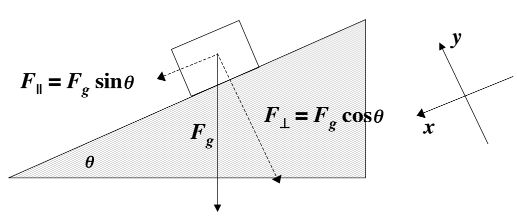
Inclined Planes



$$F_\parallel = F_g \sin\theta$$

$$F_\perp = F_g \cos\theta$$

Inclined Planes



- **The parallel component $F_\parallel$ of the weight causes the object to slide down the plane.**
- **The perpendicular component $F_\perp$ of the weight contributes to frictional losses (if any) due to surface roughness.**