Newton's Laws

Physics

Big Picture

Newton's laws form the basis for all of mechanics and describe the effects of forces on an object's motion. Newton's laws can be applied to all sorts of problems in mechanics and even some in electrostatics. Anytime a force is involved, Newton's laws will determine the motion of the object the force is acting on.

Key Terms

Inertia: An object's resistance to changes in its motion.

Force: Any push or pull. SI unit: N

Normal Force (N): The reaction force exerted on an object by the surface that is supporting it. SI unit: N

Friction: The force that acts between moving materials. It always acts opposite the direction of the object's motion or applied force (if the object isn't moving). The frictional force is proportional to the coefficient of friction μ, which depends on the surface the object is moving over, and the normal force **N**. SI unit: N

Coefficient of Static Friction: Coefficient of friction used for objects at rest to determine how much force is required to make it begin moving.

Coefficient of Kinetic Friction: Coefficient of friction used for objects moving across a surface to determine the force resisting the motion.

Tension: Force on an object provided by a wire, string, cable, or similar object.

Newton's Laws

Newton's First Law

Known as law of **inertia**, it states that an object in motion tends to stay in motion and an object at rest tends to stay at rest unless acted on by an external force.

- This means that an object moving with a constant velocity, speed, and direction will continue moving with that velocity. An object that is not moving will not move unless there a force acts on it.
- The value of an object's inertia can be measured. Mass is the measure of an object's inertia while it is at rest.

Newton's Second Law

Explains how the force acting on an object will affect its motion. The acceleration **a** (change in velocity) of an object is directly proportional to the force **F** exerted on it and inversely proportional to the mass m (inertia) of the object. $\mathbf{F} = m\mathbf{a}$

- If there are multiple forces on the object, the acceleration is proportional to the *net* (overall) force.
- Any net force causes an acceleration, but only forces in the direction of motion causes a change in speed.
- Forces applied perpendicular to direction of motion will change the direction of motion, but not the speed.

Newton's Third Law

This law states that for any force exerted by one object on another, the other object exerts an equal force in the opposite direction on the first object. For example, if a person is pushing on a wall, the wall is also pushing back on them with an equal force in the opposite direction.

- This law holds for all situations in which objects come into contact, even when the objects are accelerating.
- While it seems like the third law would prevent the object from moving because the reaction force would cancel the initial force, the two forces act on different objects so there is still a net force on the individual objects.
- Pairs of forces described by the third law must be: the same type of force, exerted on two different objects, and equal in magnitude in opposite directions.

Free Body Diagrams

The forces on an object are often visualized using a free body diagram (FBD). FBDs are useful for looking at the different types of forces acting on an object.

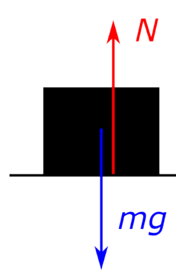
Be careful when assigning signs. For each of the x- and y-components, remember which direction is positive and which is negative. Typically the "downward" direction is assigned as the negative direction, but you do not have to follow this convention as long as your signs are consistent.

Mass on a Table

Gravity is a force that acts on all objects. Near the surface of the Earth, the force due to gravity (F_g) is equal to mg, where g is approximately 9.8 m/s^2.

- mg is what we call the weight of an object. It is not the same thing as mass!

Normal force (**N**) can be understood using Newton's third law. It is the force opposing gravity so that the net force on both objects (the mass and the table) is zero. $N = mg$

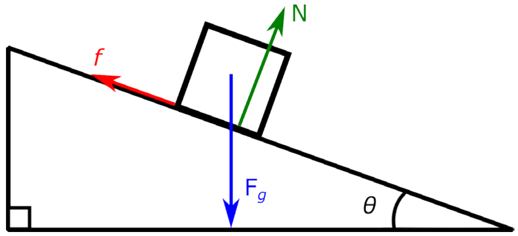


Newton's Laws cont.

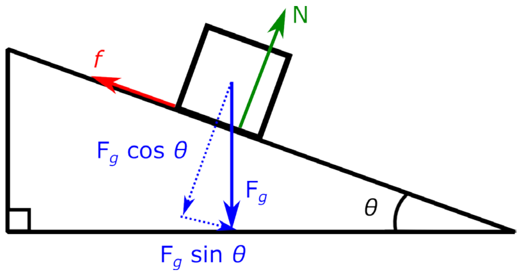
Free Body Diagrams (cont.)

Objects on a Ramp

Another type of problem is an object on a ramp or tilted table. The normal force is still perpendicular to the table, but gravity is always pointing straight down.

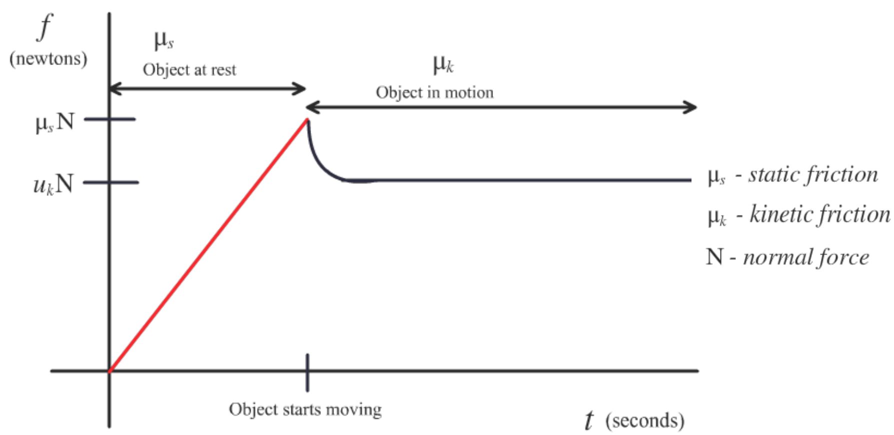


Gravity can be decomposed into its *x*- and *y*-components (relative to the ramp), as shown below. Because of Newton's third law, we know that $N = mg \cos \theta$.



Friction force is always in the opposite direction of motion. In the ramp example, gravity pulls the object down the ramp, so friction acts in the opposite direction (up the ramp), impeding the object's motion.

- There are two friction coefficients: the **coefficient of static friction** (μ_s) and the **coefficient of kinetic friction** (μ_k). The static coefficient is always greater than the kinetic coefficient, which is why it takes less force to keep an object sliding along the ground than it does to make it start moving. The graph below shows the magnitude of the friction force over time while resisting an external force.

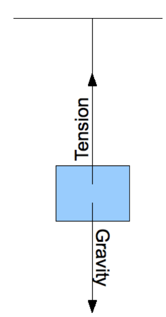


- $\mu_s N$ is the static friction the block needs to overcome before it can move.
- If the block is not moving, we can calculate the magnitude of static friction.
- If the block is moving, use the kinetic coefficient to calculate kinetic friction.

Tension

For objects attached to a string (or similar string-like objects), the force provided by the string is called **tension**. This could be an object hanging from a string or an object being pulled by a string.

- Usually the string is assumed to have no mass - this means that we can assume the string will perfectly transfer energy from one end of the string to the other.
- The total force on a massless string must always be zero. This means that every point along the string feels two equal and opposite tension forces.
- If the string is angled, make sure to decompose the tension force into components.



Newton's Laws Problem Guide

Important Equations

$\mathbf{F} = m\mathbf{a}$	**F** - force	m - mass	**a** - acceleration
$f = \mu N$	f - force of friction	μ - coefficient of friction	N - normal force

Example

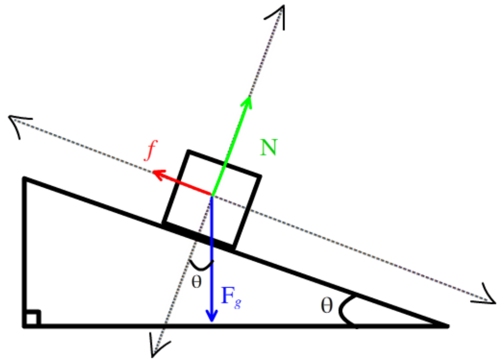
Equilibrium problems (where there is no net force) are the most common type of problem involving Newton's laws.

Example

A block of mass m is at rest on an incline of angle θ. Solve for the the coefficient of static friction (μ) in terms of m, g, and θ.

Solution

The first step in any problem involving Newton's laws is to draw an FBD of the situation and carefully label all the forces involved. The FBD on the right shows all the forces all drawn from a single point instead of from where they're acting so that it's easier to visualize the axes. In these sort of problems it is best to angle the coordinate system so that the x-axis is parallel to the incline. This forces us to break the weight vector into its components. Since the object is in equilibrium, the weight vector's components can be matched to the normal force and friction.



Here is the mathematical process to solve this problem:

$$f = \mu N \qquad \text{start with the equation for friction}$$

$$f = \mu mg\cos\theta \qquad \text{substitute the } y\text{-component of the weight vector } (mg\cos\theta) \text{ for } N$$

$$mg\sin\theta = \mu mg\cos\theta \qquad \text{substitute the } x\text{-component of the weight vector } (mg\sin\theta) \text{ for } f$$

$$\mu = \frac{mg\sin\theta}{mg\cos\theta} \qquad \text{solve for } \mu$$

$$\mu = \frac{\sin\theta}{\cos\theta} \qquad \text{simplify the result}$$

$$\mu = \tan\theta$$

Notes