Chapter 5

1

The laws of motion

The Laws of Motion

2

Kinematic: the description of an object in motion included its position, velocity, and acceleration.

Dynamic: studies the causes of motion.

Two main factors need to be addressed to answer questions about why the motion of an object will change.

- Forces acting on the object
- The mass of the object

Will start with three basic laws of motion, formulated by sir Isaac Newton

Force $(\vec{F})$

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Forces are what cause an acceleration.

Forces are vectors.

SI units: Newton

Classes of Forces

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Contact forces

- involve physical contact between two objects
  - Pull or Push

Field forces

- act through empty space
  - No physical contact is required
    - The gravitational force
    - The electric force
    - The magnetic force

Fundamental Forces

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- Gravitational force: Between objects
- Electromagnetic forces: Between electric charges
- Nuclear force: Between subatomic particles
- Weak forces: Arise in certain radioactive decay processes
- Note: These are all field forces.

Newton's First Law

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"In the absence of external forces, an object at rest remains at rest, and an object in motion remains in motion with constant velocity."

Mathematically:

$$\sum \vec{F} = 0$$

Objects in equilibrium are:

- at rest and remains at rest,
- moving with constant velocity.

Newton's First Law

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Newton's First Law describes what happens in the absence of a force. Does not describe zero net force

Also tells us that when no force acts on an object, the acceleration of the object is zero

Can conclude that any isolated object is either at rest or moving at a constant velocity

The First Law also allows the definition of force.

Inertia and Mass

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Inertia: is the tendency of an object to resist any attempt to change its velocity.

Mass is the measure of inertia.

- Mass is a scalar quantity.
- Mass is a basic quantity.
- The SI unit of mass is kg.

Masses can be defined in terms of the accelerations produced by a given force acting on them:

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

The magnitude of the acceleration acting on an object is inversely proportional to its mass.

Mass vs. Weight

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Mass and weight are two different quantities.

Weight is equal to the magnitude of the gravitational force exerted on the object.

- Weight will vary with location.
- $W_{Earth} = 120\ N;\ W_{Moon} \cong 20\ N$
- $m_{Earth} = 2\ kg;\ m_{Moon} = 2\ kg$

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Newton's Second Law

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

Mathematically,

$$\vec{a} = \frac{\sum \vec{F}}{m} \quad \Leftrightarrow \quad \sum \vec{F} = m\vec{a}$$

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Newton's Second Law

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$\sum \vec{F}$ is the net force

- This is the vector sum of all the forces acting on the object.
- May also be called the total force, resultant force.
- The SI unit of force is the Newton (N).
- $1\,N = 1\ kg.m/s^2$

Newton's Second Law can be expressed in terms of components:

- $\sum F_x = ma_x$
- $\sum F_y = ma_y$
- $\sum F_z = ma_z$

Newton's Third Law

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"If two objects interact, the force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1."

Mathematically:

$\vec{F}_{12} = -\vec{F}_{21}$

- Note on notation: $\vec{F}_{AB}$ is the force exerted *by* A *on* B.
- One of the forces is the action force, the other is the reaction force.
- It doesn't matter which is considered the action and which the reaction.

Action-Reaction

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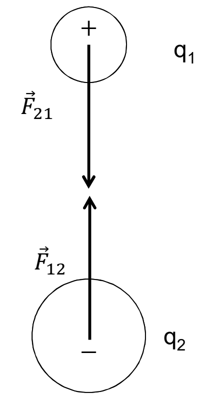
The force $\vec{F}_{12}$ exerted by charge 1 on charge 2 is equal in magnitude and opposite in direction to $\vec{F}_{21}$ exerted by charge 2 on charge 1.

$$\vec{F}_{12} = -\vec{F}_{21}$$



Action-Reaction

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The action and reaction forces are:

- of the same magnitude
- in opposite directions
- acting on different objects
- of the same type.

Some Particular Forces

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- The Gravitational Force
- The Normal Force
- Forces of Tension
- Forces of Friction

The Gravitational Force

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The gravitational force, $\vec{F_g}$, is the force that the earth exerts on an object.

This force is directed toward the center of the earth (downward).

From Newton's Second Law:

$$\vec{F_g} = m\vec{g}$$

Its magnitude is called the weight of the object.

- $Weight = |\vec{F_g}| = mg$
- SI units of weight is Newton
- Kilogram is not a unit of weight.

More About Weight

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Because it is dependent on g, the weight varies with location.

- g, and therefore the weight, is less at higher altitudes.
- This can be extended to other planets.

Weight is not an inherent property of the object.

- The weight is a property of a *system* of items: the object and the Earth.

The Normal Force, $\vec{n}$

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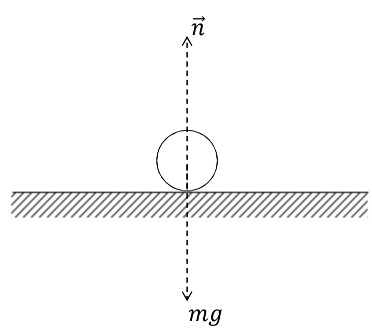
Whenever an object rests on a surface, the surface pushes on the object with a force called the normal force.

Normal means perpendicular.

The normal force is the force that prevents the object from falling through the surface.

It is always perpendicular to the surface.

It isn't always equals the weight.



Forces of Tension, $\vec{T}$

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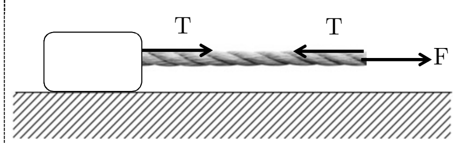
When a rope is attached to a body and pulled, the rope is said to be in tension.

The rope's function is to transfer force between two bodies.

The tension in the rope is defined as the force that the rope exerts on the body.



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Forces of Friction

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When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion.

This resistance is called the force of friction.

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Forces of Friction

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Friction is proportional to the normal force.

- $f_s \leq \mu_s n$
- $f_k = \mu_k n$

These equations relate the magnitudes of the forces; they are not vector equations.

For static friction, the equals sign is valid only when the surfaces are on the verge of slipping.

Use the inequality for static friction if the surfaces are not on the verge of slipping.

μ is the coefficient of friction

- $\mu_s > \mu_k$
- $0 < \mu_s \leq 1$
- $0 < \mu_k < 1$

Forces of Friction

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The coefficient of friction depends on the surfaces in contact.

The force of static friction is generally greater than the force of kinetic friction.

The direction of the frictional force is opposite the direction of motion and parallel to the surfaces in contact.

The coefficients of friction are nearly independent of the area of contact.

Static Friction

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Static friction acts to keep the object from moving.

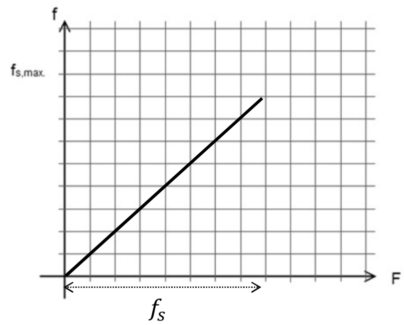
As long as the object is not moving, $f_s = F$

If $\vec{F}$ increases, so does $\vec{f_s}$

If $\vec{F}$ decreases, so does $\vec{f_s}$

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

The equality holds when the surfaces are on the verge of slipping.



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Kinetic Friction

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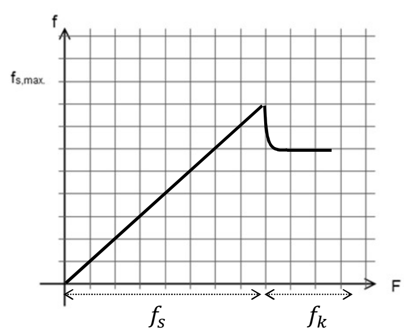
The force of kinetic friction acts when the object is in motion.

$f_k = \mu_k n$



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Some Coefficients of Friction

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TABLE 5.1 *Coefficients of Friction*

	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

Friction in Newton's Laws Problems

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Friction is a force, so it simply is included in the $\sum \vec{F}$ in Newton's Laws.

The rules of friction allow you to determine the direction and magnitude of the force of friction.