

Chapter 4, Dynamics: Force and Newton's Laws of Motion

Newton's First Law of Motion (law of inertia)

If the net force exerted on an object is zero ($\Sigma F = 0$), the object will continue in a state of rest or in a state of motion at a constant speed along a straight line.

A force is a push or pull, either by contact or from a distance (field force). The net force on an object is the vector sum of all the forces acting on this object.

Inertial Reference Frame

... is one in which Newton's law of inertia is valid.

Inertia

a qualitative expression

Mass

a quantitative measure of the inertia of an object (measured in kilogram in SI)

Weight

gravitational force exerted on an object, expressed in newton (N)

Caveat: Laws refer to motion of point objects (small particles); forces refer to external forces.

Newton's Second Law of Motion

Newton's Second Law of Motion

The acceleration of an object as a result of a net external force is proportional to the net force and has a magnitude that is inversely proportional to the mass. The direction of the acceleration is the same as the direction of the net force.

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

Units for Mass, Acceleration, and Force

System	Mass	Acceleration	Force
SI	kg	m/s ²	newton (N)
CGS	g	cm/s ²	dyne (dyn)
BE	slug	ft/s ²	pound (lb)

$$1 \text{ lb} = 4.44 \text{ N}$$

$$1 \text{ N} = 10^5 \text{ dyn}$$

Vector Nature of Second Law

Breaking $\sum \vec{F} = m\vec{a}$ into its components (in 2D), we get $\sum F_x = ma_x$ and $\sum F_y = ma_y$

The acceleration in x-direction (y-direction) is related only to the x-components (y-components) of the external forces.

The motion along the x-direction can be treated independently of the motion/forces along the y-direction, and vice versa.

In a **free-body diagram**, all the forces exerted on “a single body” are graphically indicated. These forces sum up to **ma**. Note that the forces this body exerted on other objects are NOT included.

Newton’s Third Law of Motion

Newton’s Third Law of Motion (action-reaction)

Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body. For every action, there is an equal, but opposite, reaction.

For objects of finite dimensions, the action and reaction point in opposite directions, and are along the same line.

What if the objects move as a result?

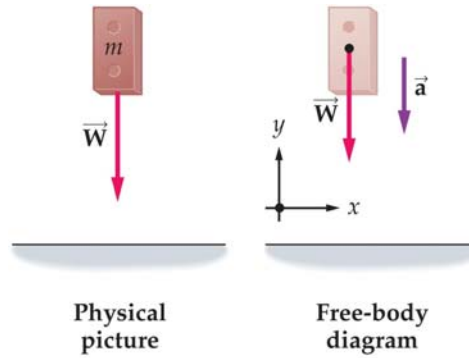
Third law always holds, whether objects are stationary, accelerating, moving away from each other, moving toward each other,

Weight

The weight of any object near the face is the gravitational force exerted by the earth on the object. Weight has the units of force (Newton) and points downward.

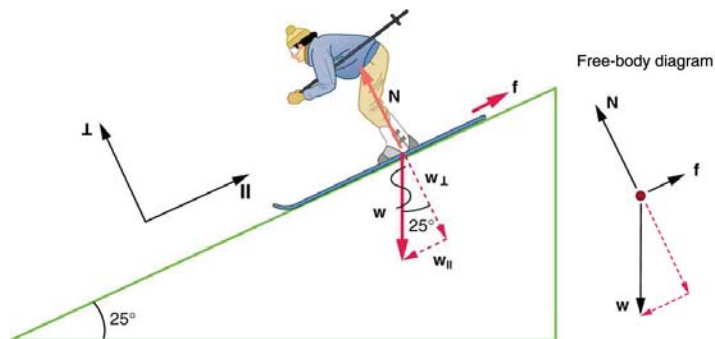
$$\vec{W} = m \vec{g}$$

$$g = 9.80 \text{ m/s}^2.$$

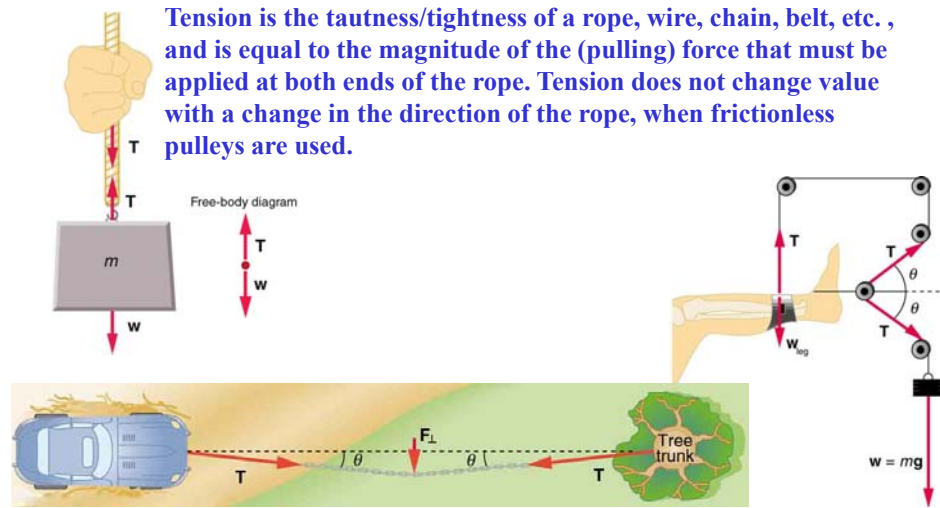


Normal Force

Normal force, n , is the component of the force normal to the surface that a surface exerts on an object with which it is in contact. It arises because rigid objects cannot yield/distort significantly.



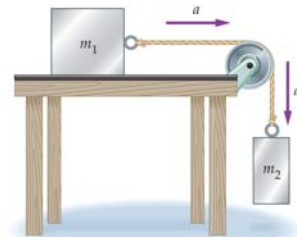
Tension



Connected Objects

- (1) Draw free body diagram for each object.
- (2) The total length of rope (wire, etc.) is constant.

(a) What is the acceleration of the blocks? (b) What is the tension in the string?



example

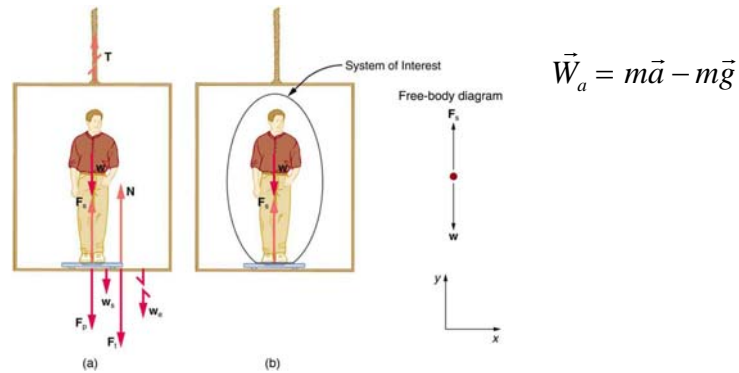
A force of magnitude 7.50 N pushes three boxes with masses of 1.30 kg, 3.20 kg and 4.90 kg, as shown. Find the magnitude of the contact force (a) between boxes 1 and 2, and (b) between boxes 2 and 3.



Interactive Figures

Apparent Weight

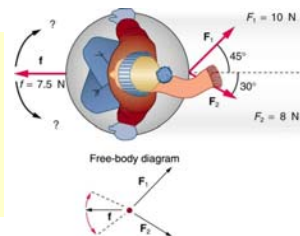
The apparent weight of an object is the total force, **except for the gravitational force**, an object receives (from the floor, wall, a bungee cord, a hook, a pushing hand, etc.).



Examples

47. A 2.50-kg fireworks shell is fired straight up from a mortar and reaches a height of 110 m. (a) Neglecting air resistance, calculate the shell's velocity when it leaves the mortar. (b) The mortar itself is a tube 0.450 m long. Calculate the average acceleration of the shell in the tube as it goes from zero to the velocity found in (a). (c) What is the average force on the shell in the mortar?

31. Two children pull a third child on a snow saucer sled exerting forces F_1 and F_2 . Find the acceleration of the 49.00-kg sled and child system. Note that the direction of the frictional force is unspecified, it will be in the opposite direction of the sum of F_1 and F_2 .



Summary of Chapter 4

- **Force:** a push or pull
- **Mass:** measures the difficulty in accelerating an object
- **Newton's first law:** if the net force on an object is zero, its velocity is constant
- **Inertial frame of reference:** one in which the first law holds
- **Newton's second law:**
$$\sum \vec{F} = m\vec{a}$$
- **Free-body diagram:** a sketch showing all the forces on an object

Summary of Chapter 4

- **Newton's third law:** If object 1 exerts a force \vec{F} on object 2, then object 2 exerts a force $-\vec{F}$ on object 1.
- **Contact forces:** an action-reaction pair of forces produced by two objects in physical contact
- **Newton's laws can be applied to each component of the forces independently**
- **Weight:** gravitational force exerted by the Earth on an object. On the surface of the Earth, $W = mg$
- **Apparent weight:** force felt from contact with a floor or scale
- **Normal force:** force exerted perpendicular to a surface by that surface