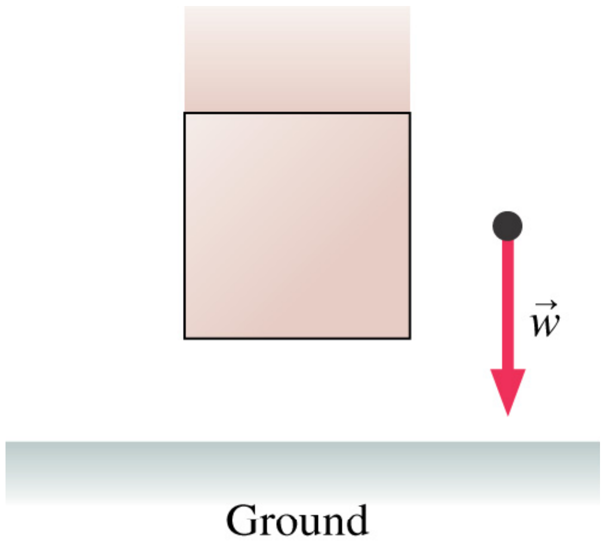
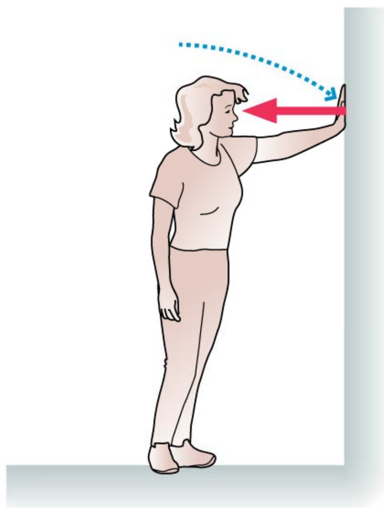
Force and Motion: Newton's Laws

Readings: Chapter 5 (2^{nd} edition)

Force: Properties

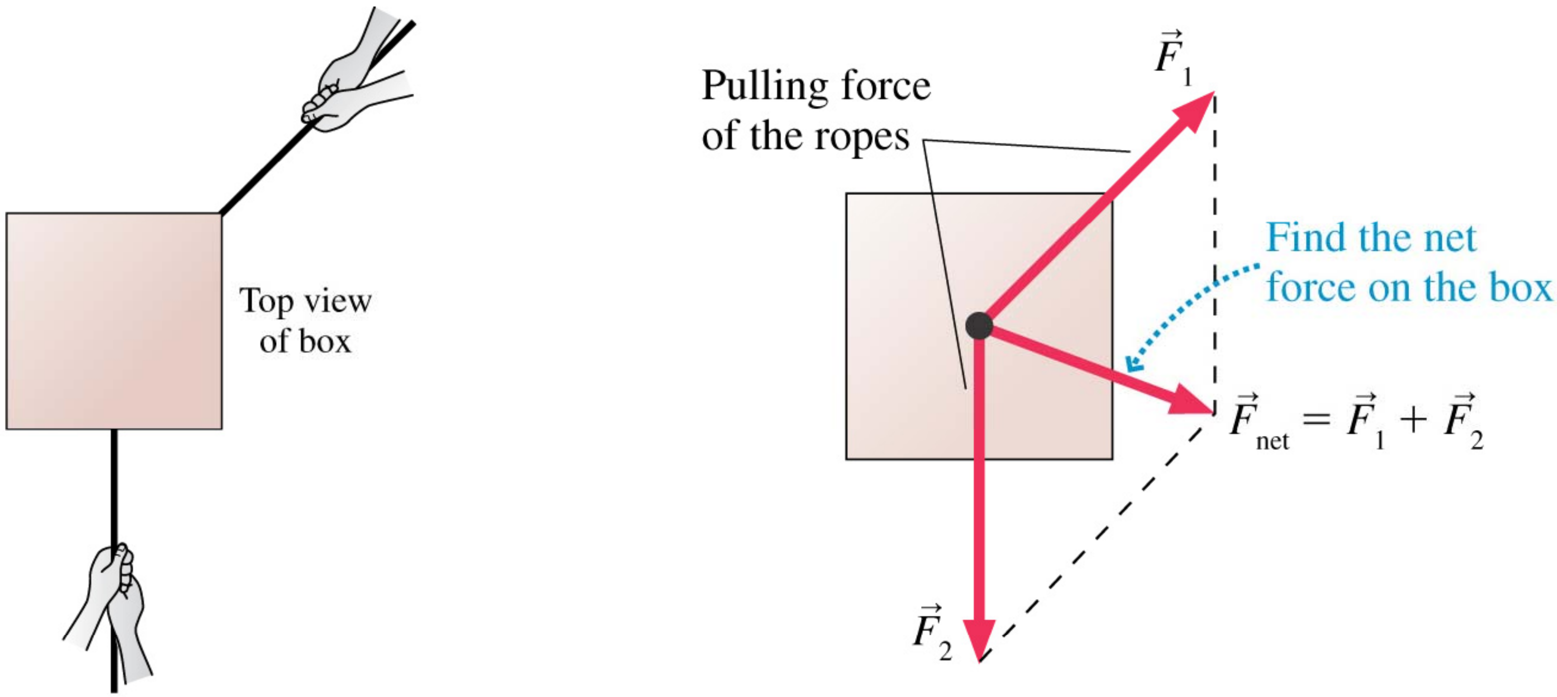
1. Push or Pull
2. Acts on an object
3. Force is a vector
4. Force is either a contact force or long range force





Force: Properties

Force is a vector – The net force is the vector sum of the individual forces



How can we find the individual force?

Major Forces:

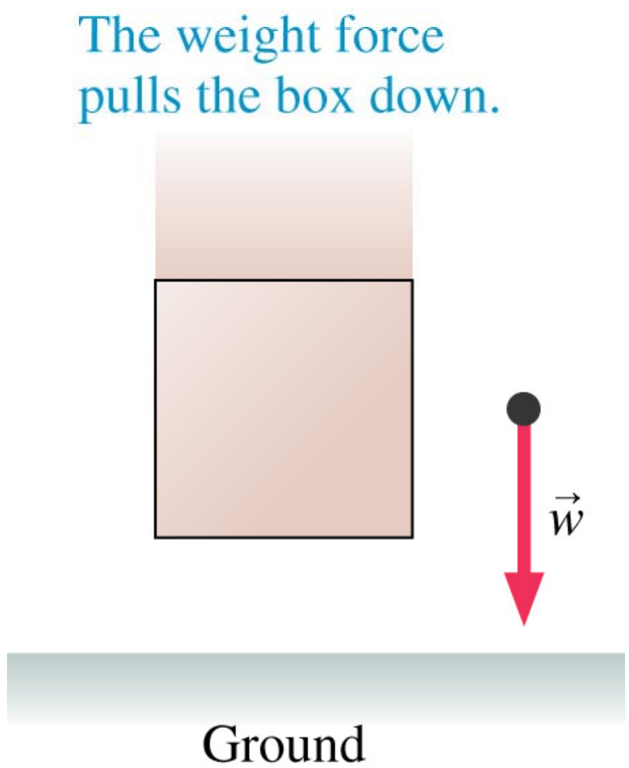
1. **Weight – gravitational force**

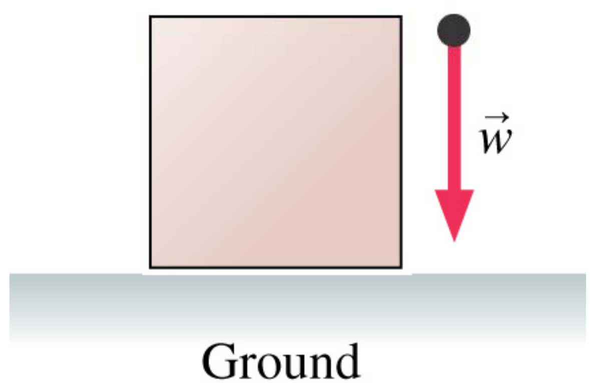
pulls the objects down – determines its direction

magnitude: $$\vec{w} = m\vec{g}$$

m **- Mass of the object**

$$g = 9.8\frac{m}{s^2}$$ **- free-fall acceleration**





Major Forces:

1. **Weight – gravitational force** $\vec{w} = m\vec{g}$

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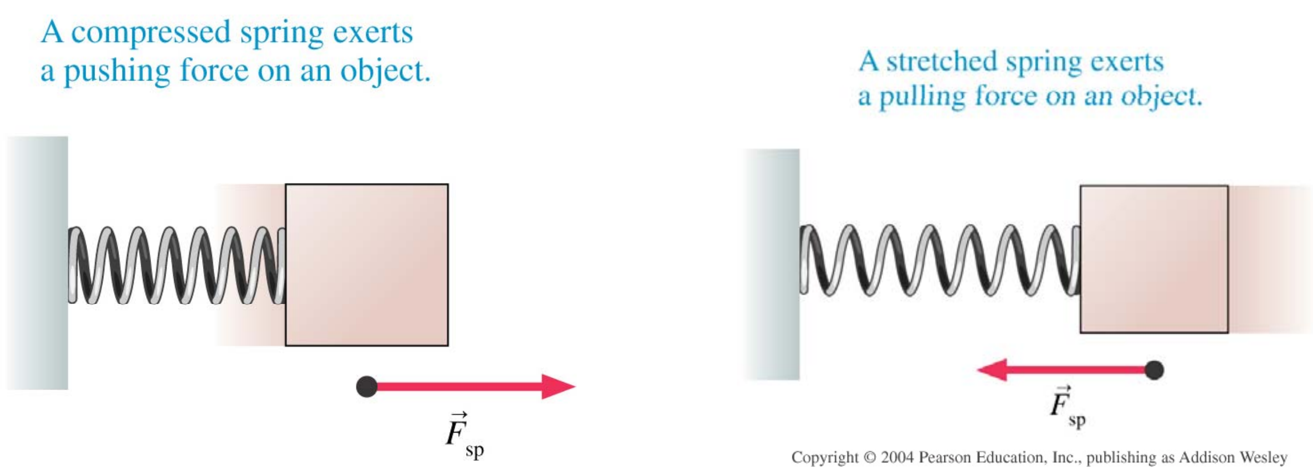
2. **Spring Force** $F_{sp} = kx$

k **- coefficient, which depends only on geometric parameters of the spring**

$x = |\Delta l|$ **- change in the length of the spring**



Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
2. Spring Force $F_{sp} = kx$

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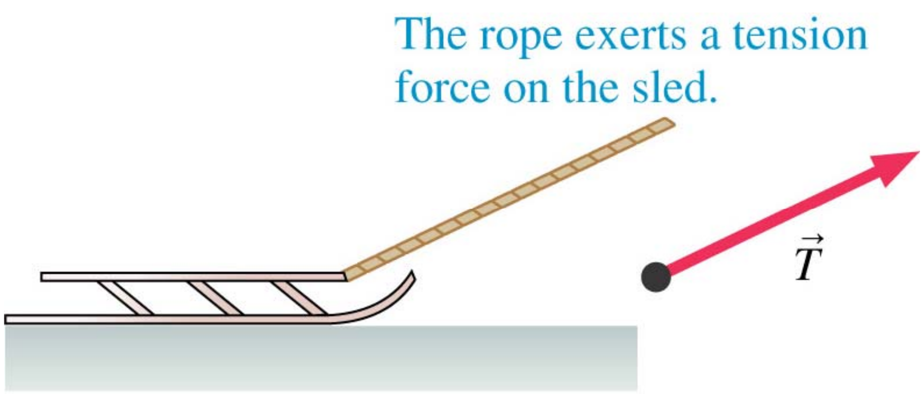
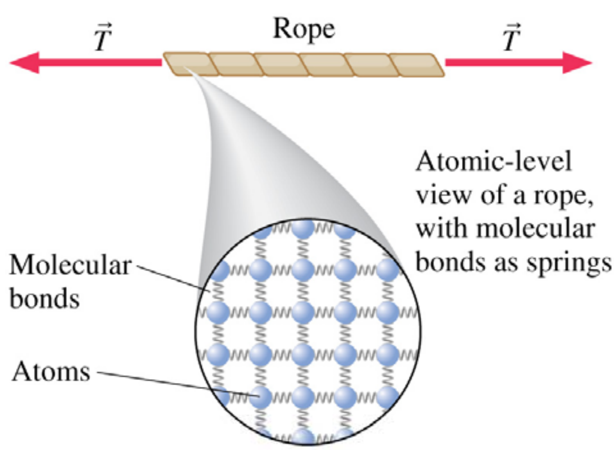
3. Tension Force $\vec{T}$

   direction is always in the direction of the rope

   magnitude - usually found from the condition of equilibrium





Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
2. Spring Force $F_{sp} = kx$
3. Tension Force $\vec{T}$

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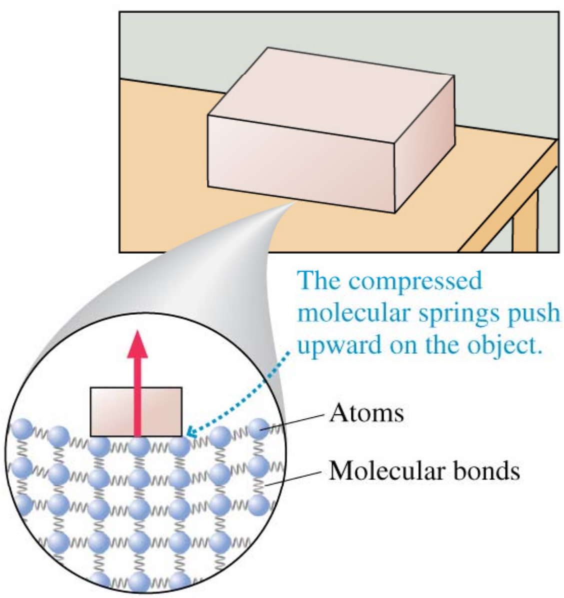
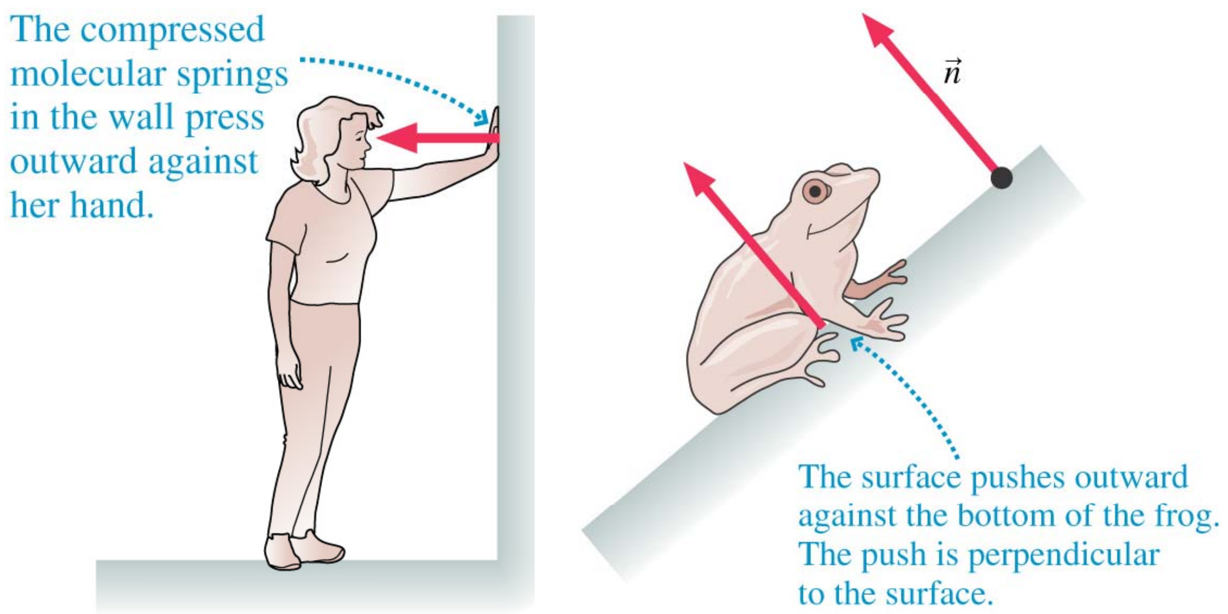
4. Normal Force $\vec{n}$

direction is always perpendicular to the surface

magnitude - usually found from the condition of equilibrium





Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
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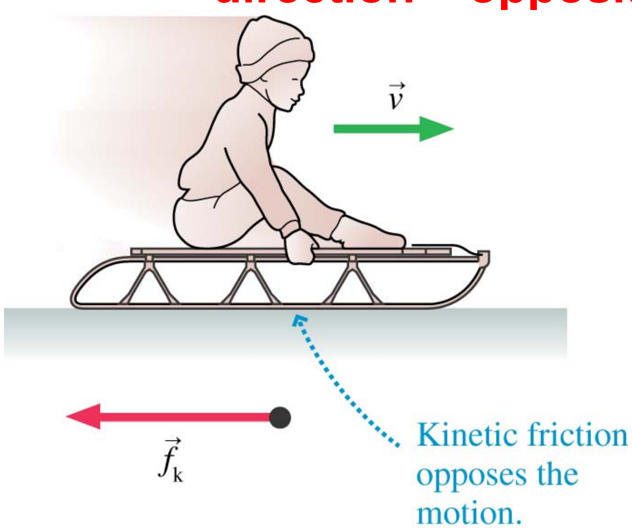
5. Friction

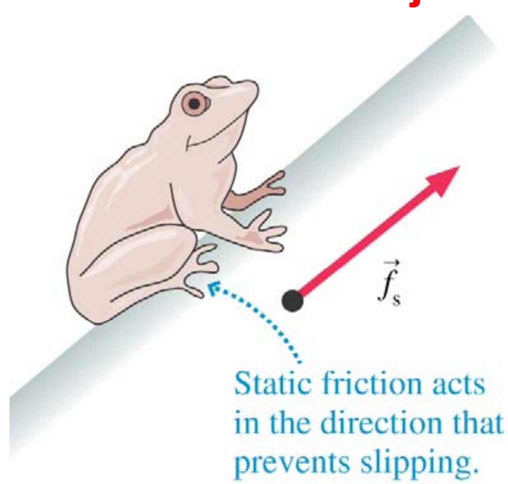
- Kinetic friction – opposes the motion $\vec{f}_k$

direction – opposite the velocity vector

- static friction – prevent the motion of the object $\vec{f}_s$

direction – opposite the direction in which the object would move





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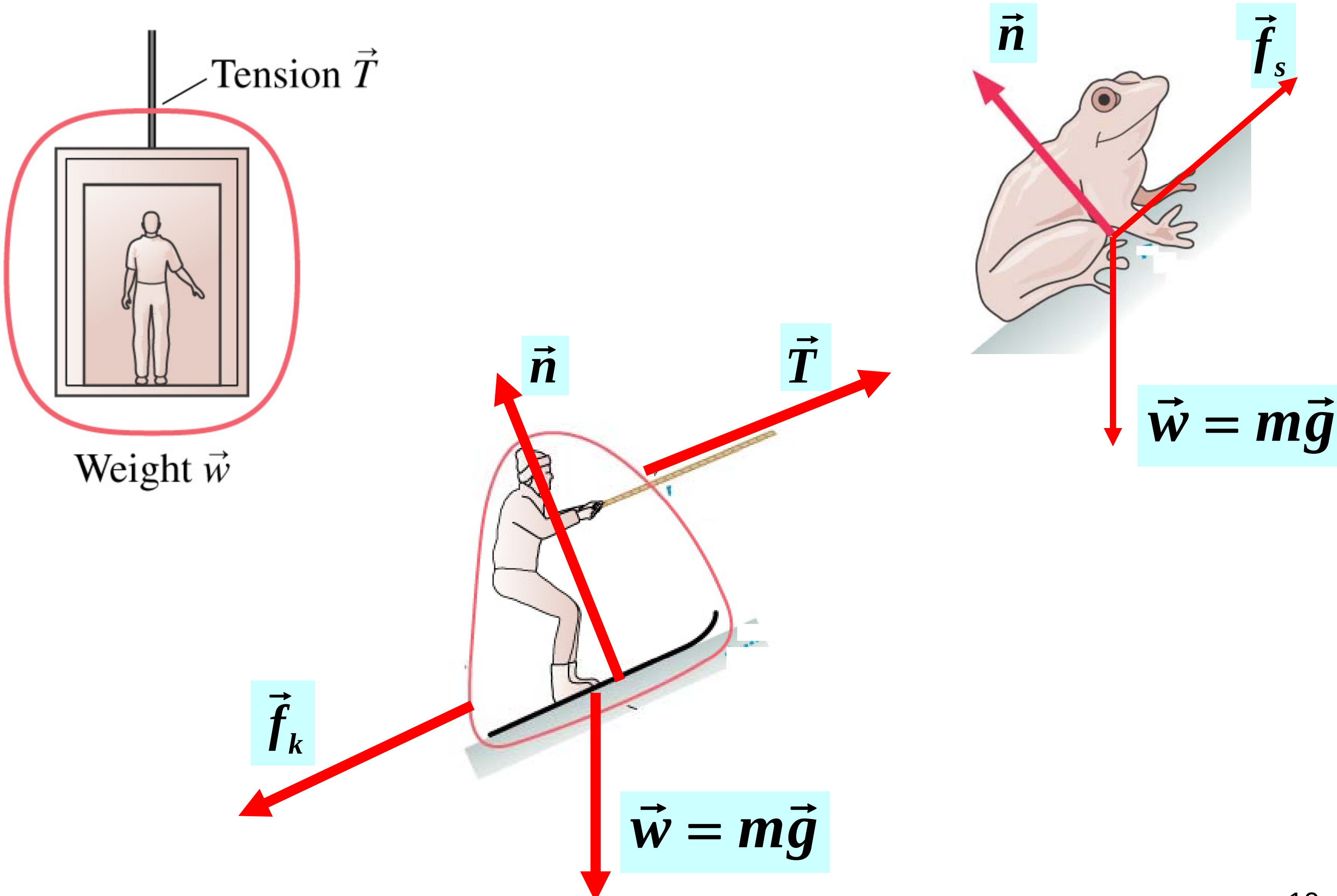
5. Friction

   - kinetic friction $\vec{f}_k$

   - static friction $\vec{f}_s$

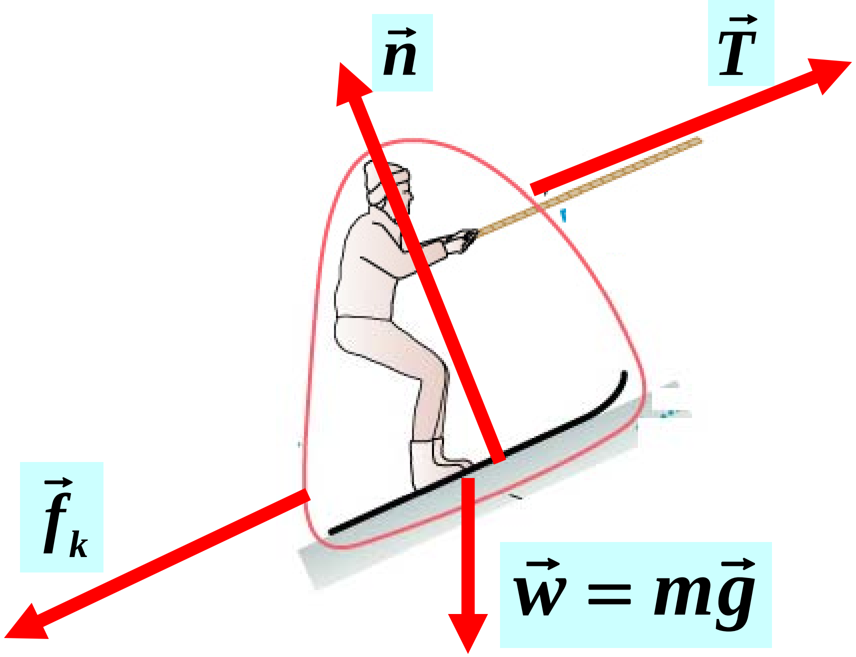
Force Identification



Newton's Second Law

An object of mass m subject to forces $\vec{F}_1, \vec{F}_2, \ldots$ will undergo an acceleration given by

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



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$$\vec{a} = \frac{\vec{w} + \vec{n} + \vec{T} + \vec{f}_k}{m}$$

Newton's Second Law

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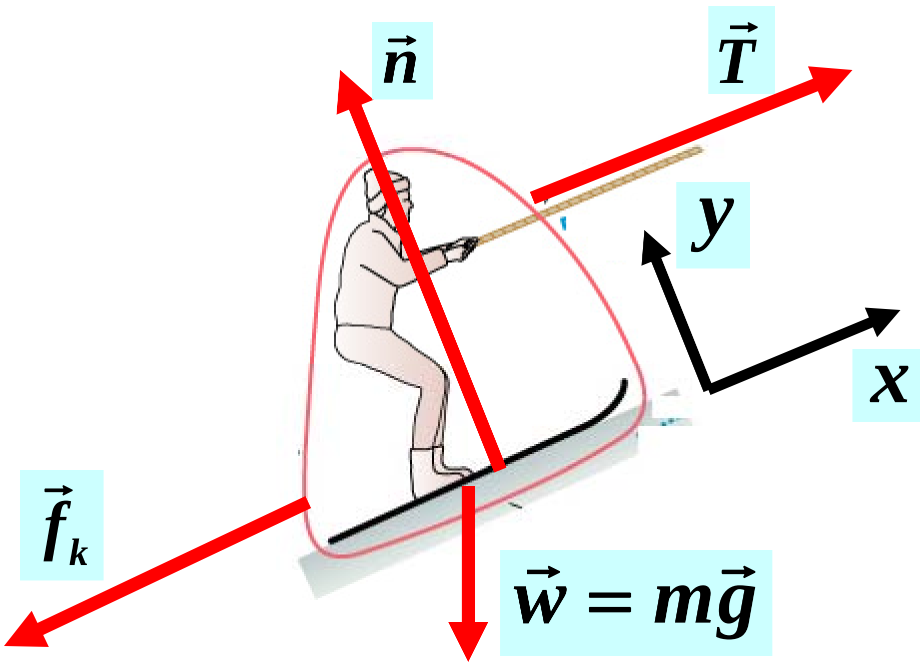


It is convenient to introduce coordinate system and write the Newton's second law in terms of vector components

No motion in y-direction:

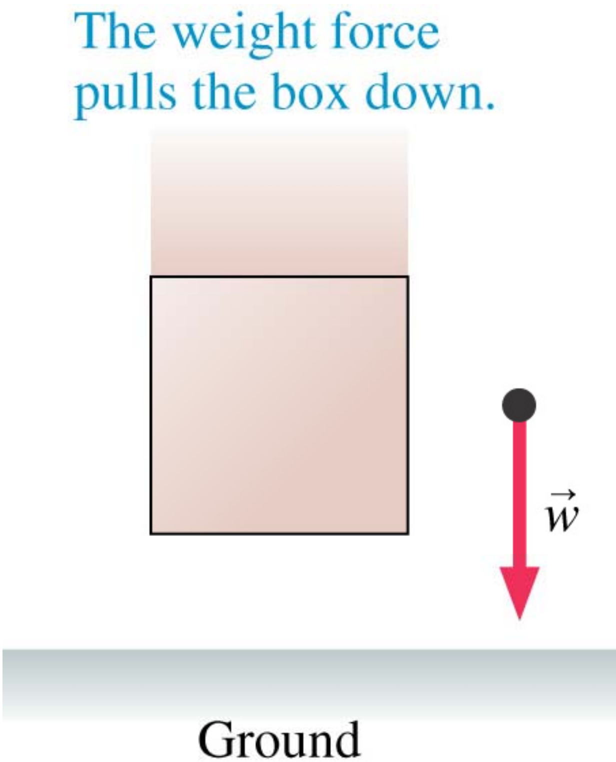
$$a_y = 0$$

$$w_y + n = 0$$

For motion in x-direction:

$$ma_x = w_x + T - f_k$$

Free-fall motion



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

Then from the second Newton's law:

$$\vec{a} = \frac{\vec{w}}{m} = \frac{m\vec{g}}{m} = \vec{g}$$

$$g = 9.8\,\frac{m}{s^2}$$

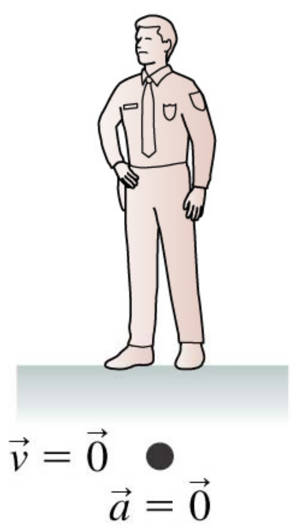
The acceleration is the same for all objects (does not depend on the mass of the object)

Newton's First Law

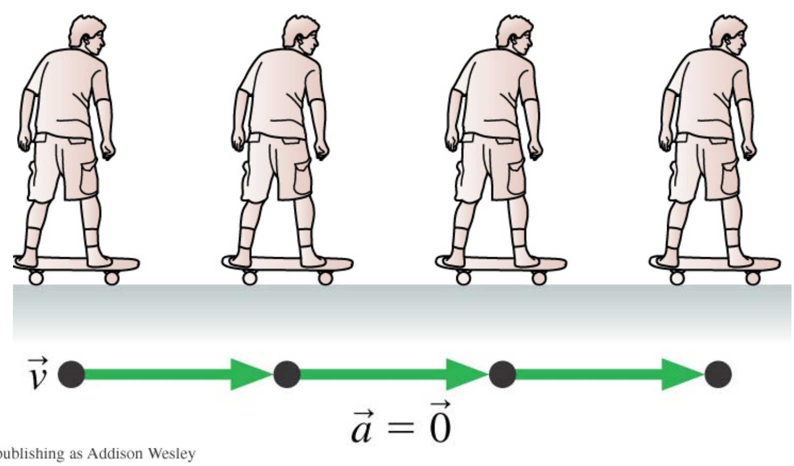
An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

$\vec{F}_{net} = 0$ **then** $\vec{a} = 0$ **velocity is constant**

Static equilibrium



Dynamic equilibrium



Inertial reference frames

Inertial reference frame is the coordinate system in which Newton's laws are valid.

The earth is an inertial reference frame

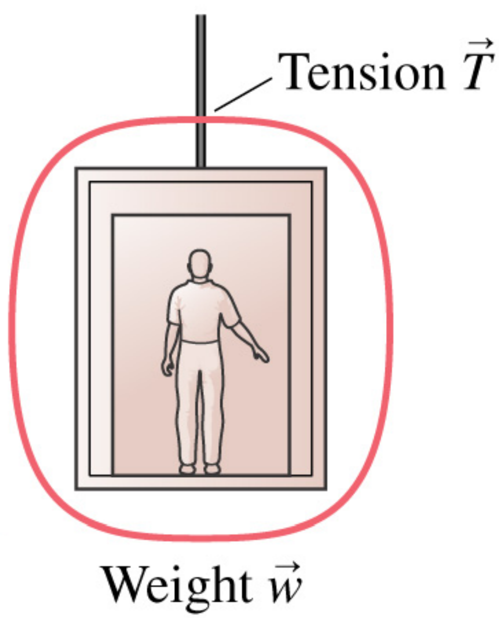
Any other coordinate systems, which are traveling with constant velocity with respect to the earth is an inertial reference frame

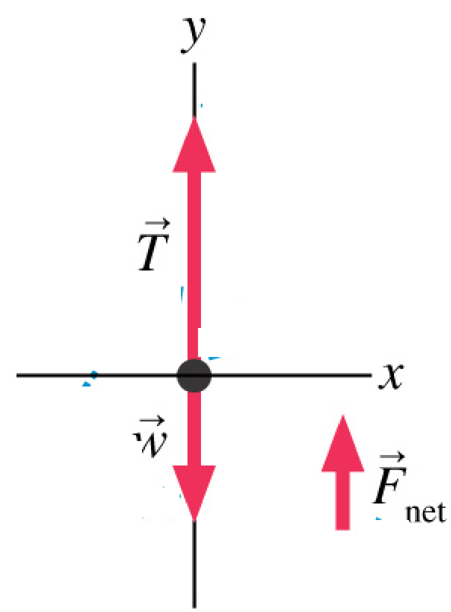
Car traveling with constant velocity is an inertial reference frame

Car traveling with acceleration is NOT an inertial reference frame (violation of Newton's law)

Free-Body Diagram

1) Object – as a particle
2) Identify all the forces
3) Find the net force (vector sum of all individual forces)
4) Find the acceleration of the object (second Newton's law)
5) With the known acceleration find kinematics of the object





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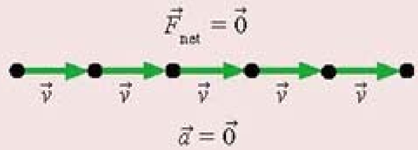


The first law tells us that no "cause" is needed for motion. Uniform motion is the "natural state" of an object.

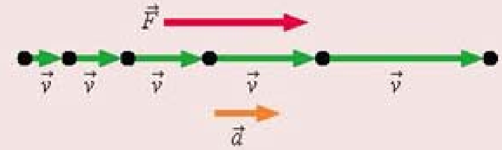
Newton's laws are valid only in inertial reference frames.

Newton's Second Law

An object with mass m will undergo acceleration

$$\vec{a} = \frac{1}{m}\vec{F}_{net}$$

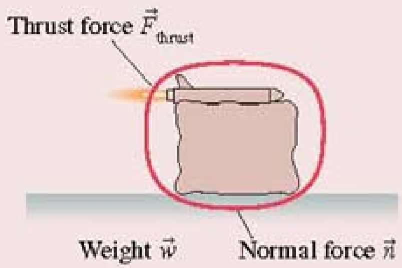
where $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all the individual forces acting on the object.



The second law tells us that a net force causes an object to accelerate. This is the connection between force and motion that we are seeking.

Identifying Forces

Forces are identified by locating the points where the environment touches the system. These are points where contact forces are exerted. In addition, objects with mass feel a long-range weight force.



Free-Body Diagrams

A free-body diagram represents the object as a particle at the origin of a coordinate system. Force vectors are drawn with their tails on the particle. The net force vector is drawn beside the diagram.