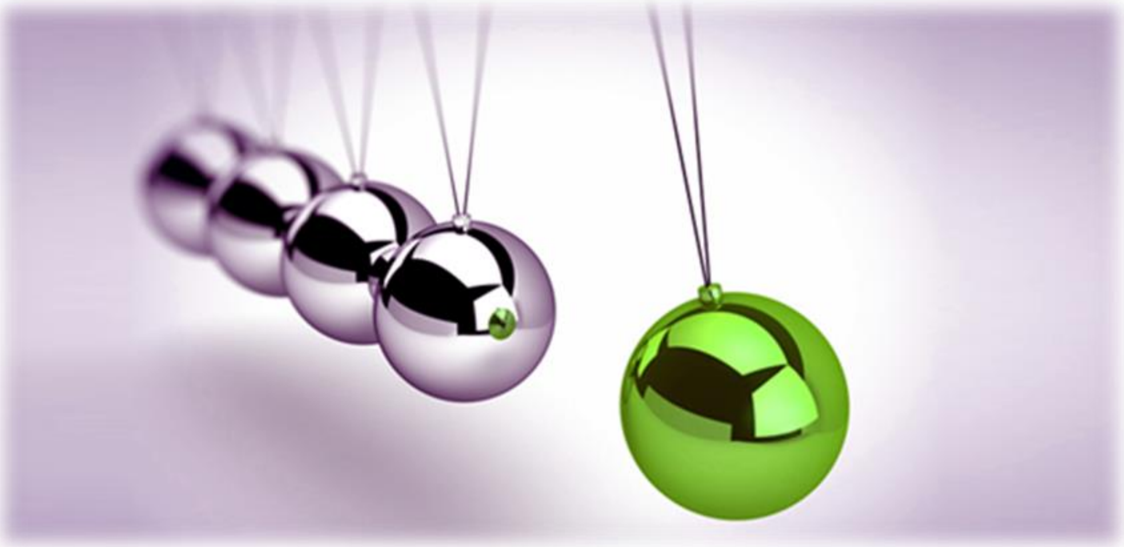
PHYSICS I - MECHANICS
The LAWS of MOTION



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CHAPTER 5. The LAWS of MOTION

Learning Objectives

5.1 Force and Interactions

5.2 Newton's First Law and Inertial Frames

5.3 Mass

5.4 Newton's Second Law

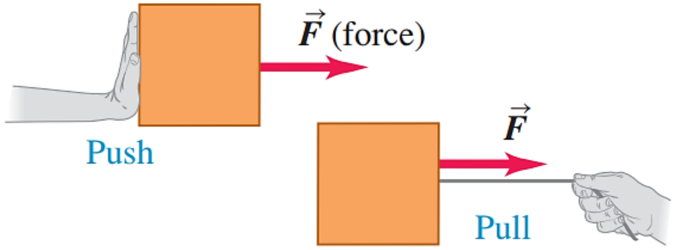
5.5 The Gravitational Force and Weight

5.6 Newton's Third Law

5.1 Force and Interactions

Force:

- A force is an interaction between two objects or between an object and its environment.
- A force is a push or a pull.
- A force is a vector quantity, with magnitude and direction.



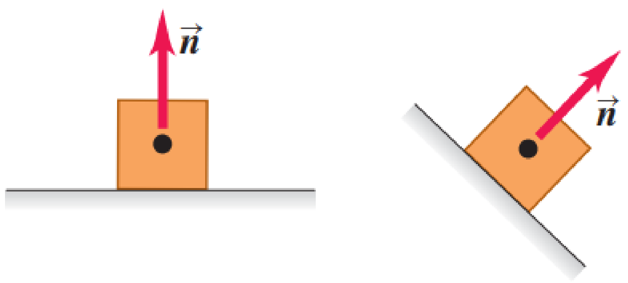
To describe a force vector , we need to describe the *direction* in which it acts as well as its *magnitude,* the quantity that describes "how much" or "how hard" the force pushes or pulls.

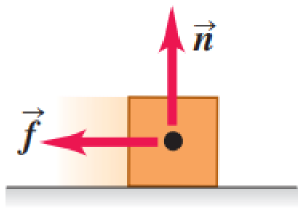
SI unit of the magnitude of ***force*** is the *newton*, abbreviated N

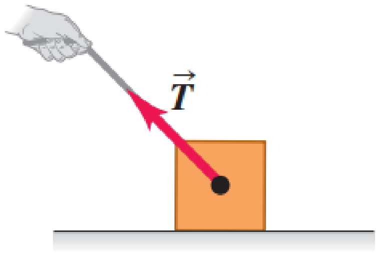
5.1 Force and Interactions

Interactions:

When a force involves direct contact between two bodies, such as a push or pull that you exert on an object with your hand, we call it a ***contact force***.







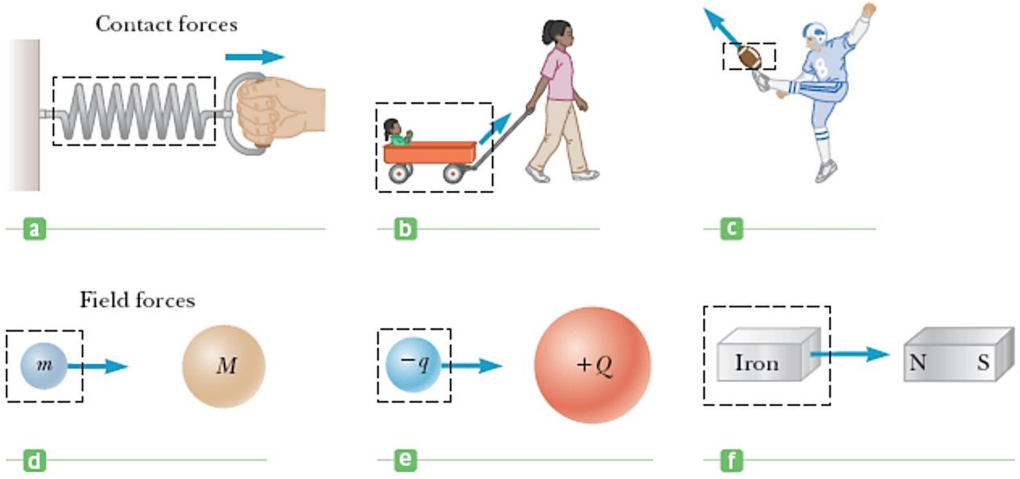
Normal force $\vec{n}$: When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface

Friction force $\vec{f}$: In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.

Tension force $\vec{T}$: A pulling force exerted on an object by a rope, cord, etc.

Pulling of a coiled spring, pulling of a cart and kicking a football are the class of ***contact forces***. They involve physical contact between two objects.

The ***field forces***, do not involve physical contact between two objects but instead act through empty space.



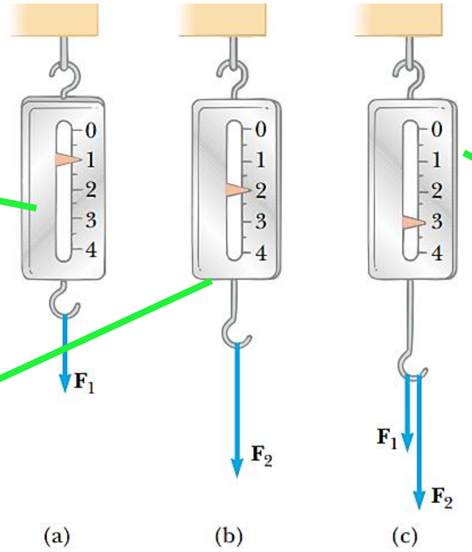
5.1 Force and Interactions

The instrument for measuring force magnitudes is the *spring balance.*

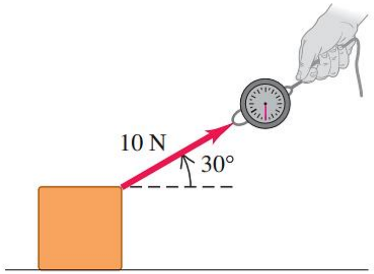
We can calibrate the spring by defining:

a reference force $\mathbf{F_1}$ as the force that produces a pointer reading of 1.00 cm.

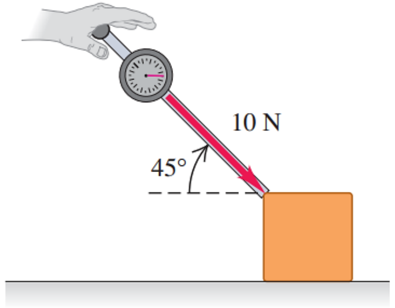
a different downward force $\mathbf{F_2}$ whose magnitude is twice that of the reference force $\mathbf{F_1}$ the pointer moves to 2.00 cm.



the combined effect of the two collinear forces is the sum of the effects of the individual forces.



A 10-N pull directed 30° above the horizontal

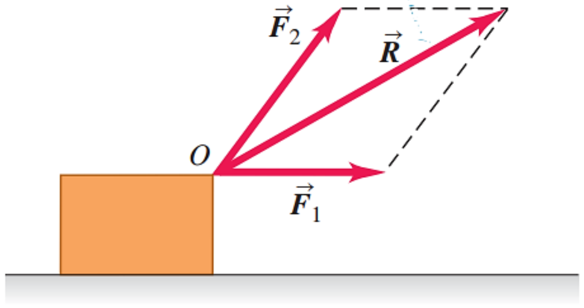


A 10-N push directed 45° below the horizontal

5.1 Force and Interactions

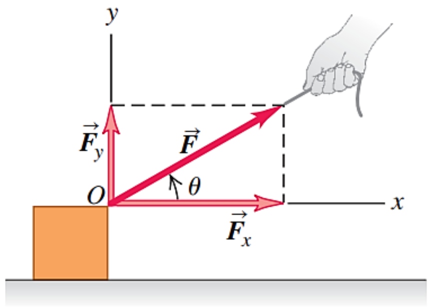
Superposition of Forces

When two forces $\vec{F}_1$ and $\vec{F}_2$ act at the same time at the same point on a body the effect on the body's motion is the same as if a single force $\vec{R}$ were acting equal to the vector sum of the original forces:

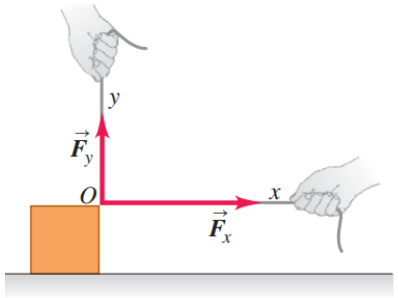


superposition of forces $$\vec{R} = \vec{F}_1 + \vec{F}_2$$

The force $\vec{F}$, which acts at an angle θ from the x-axis, may be replaced by its rectangular component vectors $\vec{F}_x$ and $\vec{F}_y$.



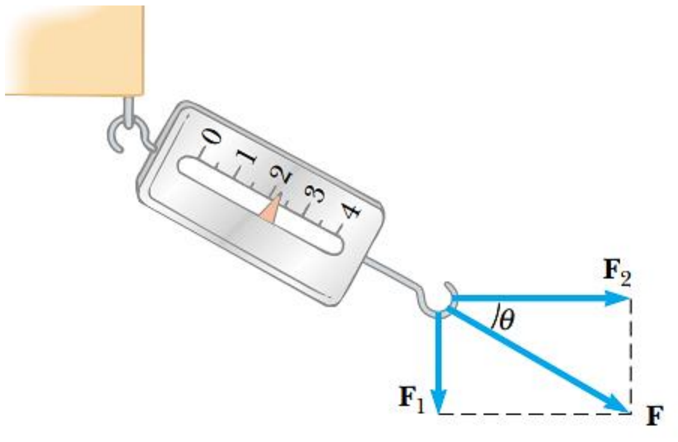
Component vectors: $\vec{F}_x$ and $\vec{F}_y$
Components: $F_x = F cos\theta \; and \; F_y = F sin\theta$



Component vectors $\vec{F}_x$ an $\vec{F}_y$ together have the same effect as original force $\vec{F}$

5.1 Force and Interactions

Superposition of Forces

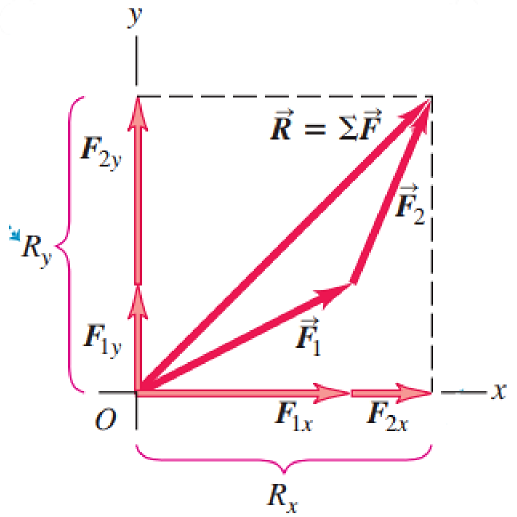


$\mathbf{F}_1$ downward and $\mathbf{F}_2$ horizontal

$$|\vec{F}| = \sqrt{F_1^2 + F_2^2} = \sqrt{1^2 + 2^2} = \sqrt{5} = 2.24\ N$$

$$\theta = tan^{-1}\left(-\frac{1}{2}\right) = tan^{-1}(-0.50) = -26.6°$$

Because forces have been experimentally verified to behave as vectors, you must use the rules of vector addition to obtain the net force on an object.



$$\boxed{\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots = \sum \vec{F}}$$

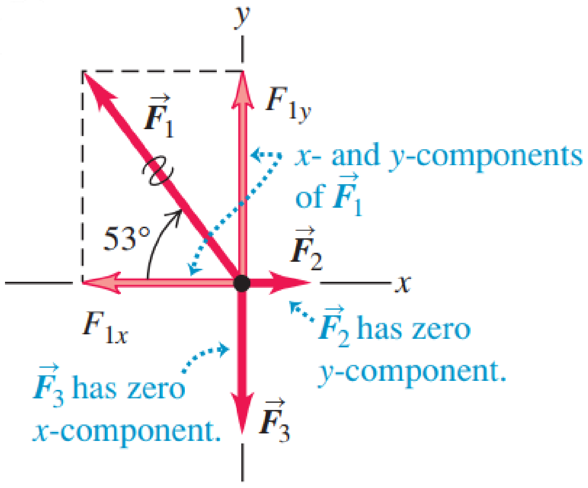
$$\boxed{R_x = \sum F_x \qquad R_y = \sum F_y}$$

$$\boxed{R = \sqrt{R_x^2 + R_y^2}}$$

5.1 Force and Interactions

Example:

Figure shows the horizontal force applies to an object. The forces have magnitudes $F_1 = 250\ N$, $F_2 = 50\ N$ and $F_3 = 120\ N$. Find the *x*- and *y*-components of the net force on the object, and find its magnitude and direction.



Solution:

$$\theta_1 = 180° - 53° = 127°, \theta_2 = 0°,\ \theta_3 = 270°$$

net force $\vec{R} = \sum\vec{F}$ has components

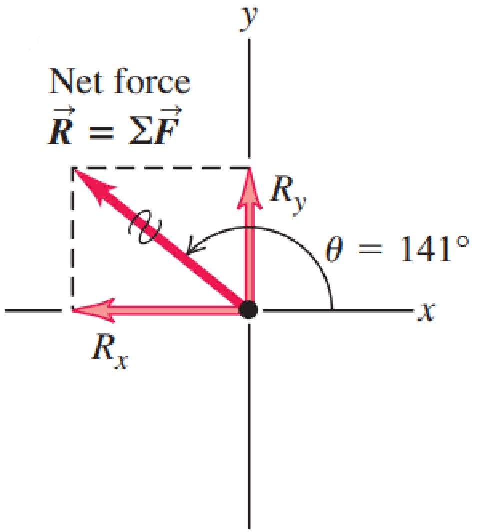
$$F_{1x} = (250\ \text{N})\cos 127° = -150\ \text{N}$$
$$F_{1y} = (250\ \text{N})\sin 127° = 200\ \text{N}$$
$$F_{2x} = (50\ \text{N})\cos 0° = 50\ \text{N}$$
$$F_{2y} = (50\ \text{N})\sin 0° = 0\ \text{N}$$
$$F_{3x} = (120\ \text{N})\cos 270° = 0\ \text{N}$$
$$F_{3y} = (120\ \text{N})\sin 270° = -120\ \text{N}$$

$$R_x = F_{1x} + F_{2x} + F_{3x} = (-150\ \text{N}) + 50\ \text{N} + 0\ \text{N} = -100\ \text{N}$$
$$R_y = F_{1y} + F_{2y} + F_{3y} = 200\ \text{N} + 0\ \text{N} + (-120\ \text{N}) = 80\ \text{N}$$

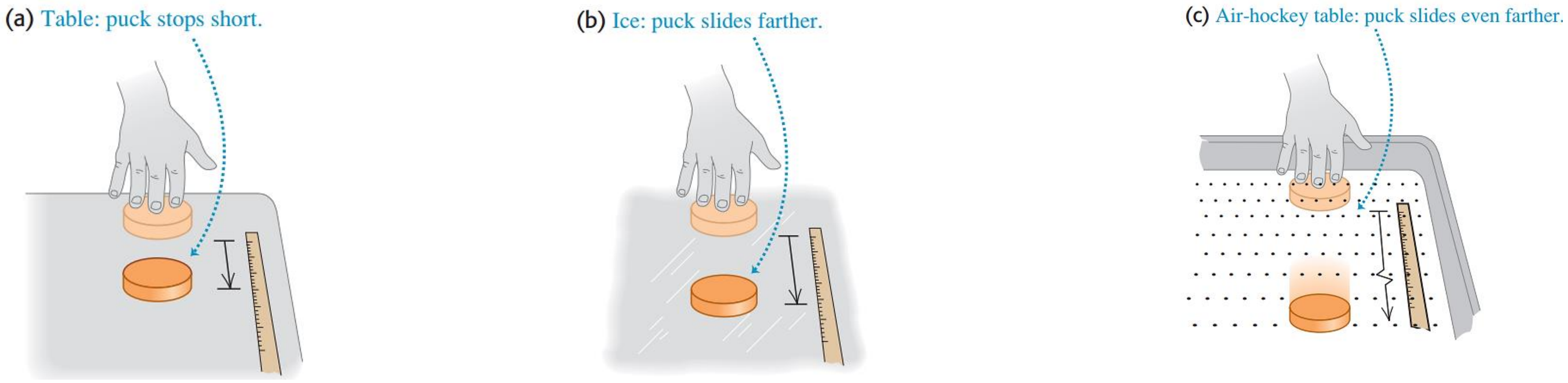
$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{(-100\ \text{N})^2 + (80\ \text{N})^2} = 128\ \text{N}$$

$$\theta = \arctan\frac{R_y}{R_x} = \arctan\left(\frac{80\ \text{N}}{-100\ \text{N}}\right) = \arctan(-0.80)$$

$$\theta = -39° + 180° = 141°$$



5.2 Newton’s First Law and Inertial Frames

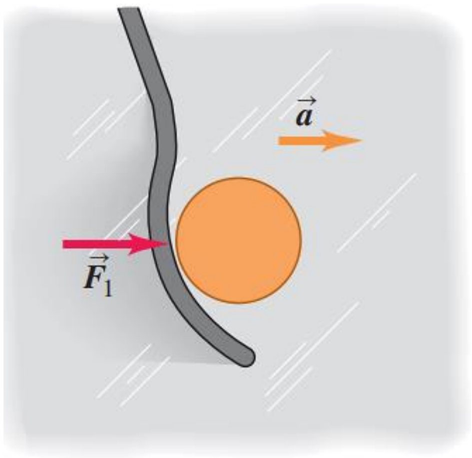


Newton’s First Law:

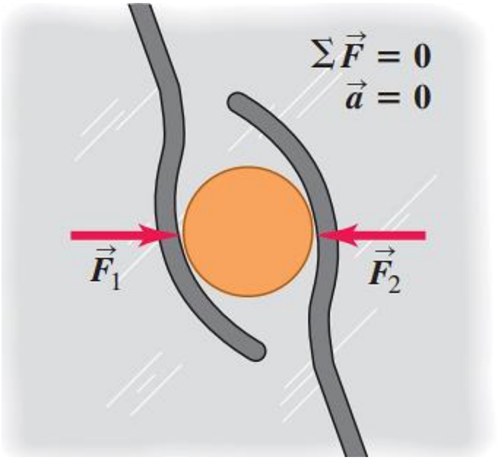
An object at rest will stay at rest, and an object in motion will stay in motion at constant velocity, unless acted upon by an unbalanced force.

- ✓ In simpler terms, we can say that when no force acts on an object, the acceleration of the object is zero.
- ✓ If nothing acts to change the object’s motion, then its velocity does not change.

5.2 Newton's First Law and Inertial Frames



A puck on a frictionless surface accelerates when acted on by a single horizontal force.



An object acted on by forces whose vector sum is zero behaves as though no forces act on it.

$$\vec{F}_2 = -\vec{F}_1$$

$$\sum \vec{F} = \vec{F}_1 + \vec{F}_2 = \vec{F}_1 + \left(-\vec{F}_1\right) = 0$$

$$\sum \vec{F} = 0 \qquad \text{(body in equilibrium)}$$

$$\sum F_x = 0 \qquad \sum F_y = 0 \qquad \text{(body in equilibrium)}$$

5.2 Newton’s First Law and Inertial Frames

Inertial Frames

From the first law, we conclude that any isolated object (one that does not interact with its environment) is either at rest or moving with constant velocity.

If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration. Such a reference frame is called an *inertial frame of reference*.

Inertia is the tendency of an object to resist changes in its velocity: whether in motion or motionless.

Any reference frame that moves with constant velocity relative to an inertial frame is itself an inertial frame. When the train accelerates, however, you are observing the puck from a noninertial reference frame.

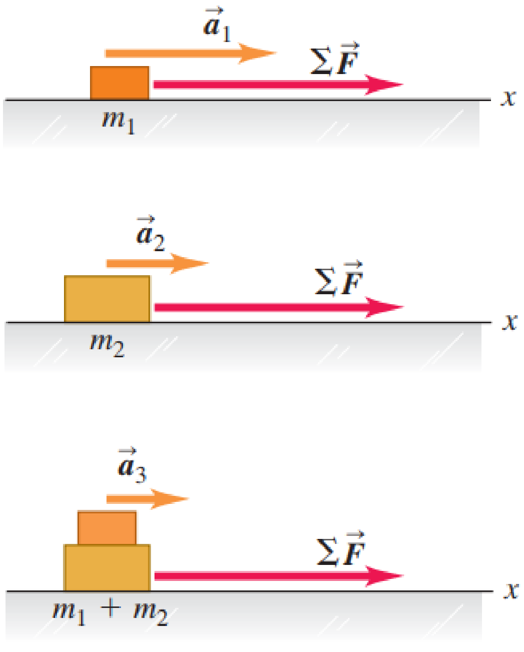
5.3 Mass

The First Law states that all objects have inertia. The more mass an object has, the more inertia it has (and the harder it is to change its motion).

Mass is that property of an object that specifies how much resistance an object exhibits to changes in its velocity.

$\sum \vec{F}$ → 3 kg → 4 m/s^2

$\sum \vec{F}$ → 6 kg → 2 m/s^2



$$m_1 a_1 = m_2 a_2$$

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

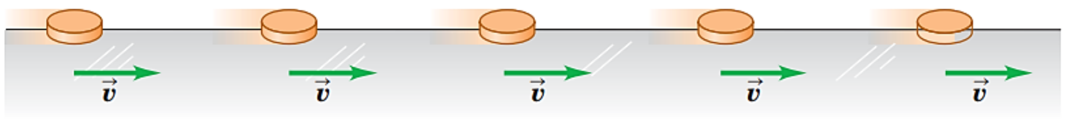
$$\left|\sum \vec{F}\right| = (m_1 + m_2)a_3$$

- ✓ Mass is an inherent property of an object.
- ✓ Mass is independent of the object's surroundings.
- ✓ Mass is a scalar quantity.

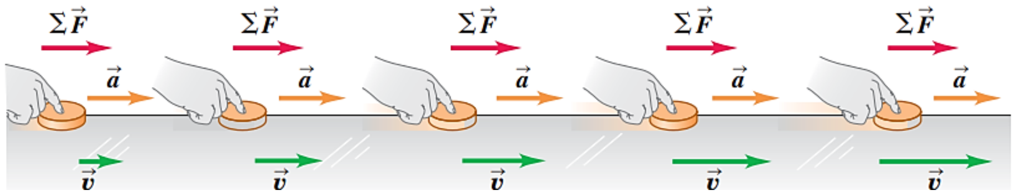
5.4 Newton's Second Law

Newton's second law answers the question of what happens to an object that has a nonzero resultant force acting on it.

(a) A puck moving with constant velocity (in equilibrium): $\sum\vec{F} = 0,\ \vec{a} = 0$

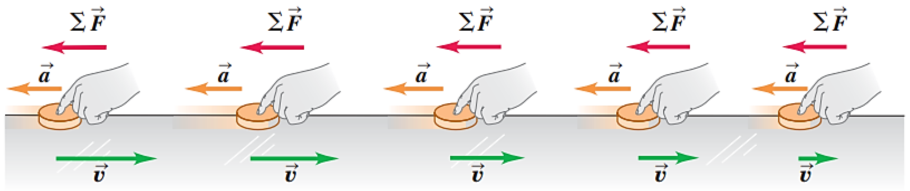


(b) A constant net force in the direction of motion causes a constant acceleration in the same direction as the net force.



We apply a constant horizontal force to a sliding. Then $\sum\vec{\boldsymbol{F}}$ is constant. During the time the force is acting, the velocity of the puck changes at a constant rate; the puck moves with constant acceleration.

(c) A constant net force opposite the direction of motion causes a constant acceleration in the same direction as the net force.

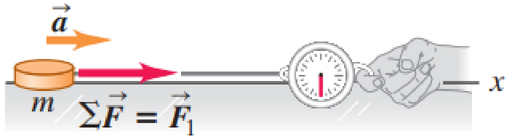


We reverse the direction of the force on the puck so that acts opposite to $\vec{\boldsymbol{v}}$. In this case as well, the puck has an acceleration; the puck moves more and more slowly to the right.

A net force acting on a body causes the body to accelerate in the same direction as the net force.

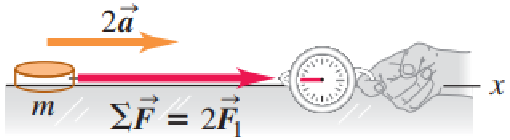
5.4 Newton's Second Law

(a) A constant net force $\Sigma\vec{F}$ causes a constant acceleration $\vec{a}$.



When you exert some horizontal force F on the block, it moves with some acceleration **a**.

(b) Doubling the net force doubles the acceleration.



If you apply a force twice as great, you find that the acceleration of the block doubles.

For any given body, the magnitude of the acceleration is directly proportional to the magnitude of the net force acting on the body.

$$\boxed{\sum \vec{F} = m\vec{a} \qquad \text{(Newton's second law of motion)}}$$

Newton's second law :

If a net external force acts on a body, the body accelerates. The direction of acceleration is the same as the direction of the net force. The mass of the body times the acceleration of the body equals the net force Vector.

5.4 Newton's Second Law

Mass and Force

The ratio of the magnitude $\left|\sum \vec{\boldsymbol{F}}\right|$ of the net force to the magnitude $a = |\vec{\boldsymbol{a}}|$ of the acceleration is constant, regardless of the magnitude of the net force. We call this ratio the *mass* of the body and denote it by m.

$$m = \frac{\left|\sum \vec{\boldsymbol{F}}\right|}{a} \qquad \left|\sum \vec{\boldsymbol{F}}\right| = \mathrm{ma}$$

We can use this standard kilogram, to define the **newton:**

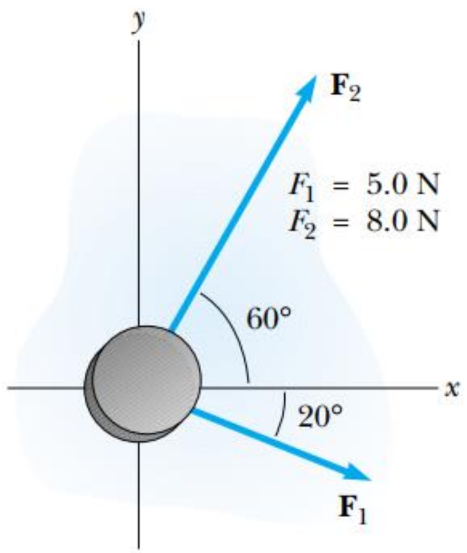
One newton is the amount of net force that gives an acceleration of 1 meter per second squared to a body with a mass of 1 kilogram.

$$1\ newton = (1\ kilogram)(1\ meter\ per\ second\ squared) \qquad 1\ N = 1\ kg \cdot m/s^2$$

5.4 Newton's Second Law

Example:

A hockey puck having a mass of 0.30 kg slides on the horizontal, frictionless surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting the forces on the puck shown in figure. The force $\mathbf{F_1}$ has a magnitude of 5.0 N, and the force $\mathbf{F_2}$ has a magnitude of 8.0 N. Determine both the magnitude and the direction of the puck's acceleration.



Solution:

$$\sum F_x = F_{1x} + F_{2x} = F_1 \cos(-20°) + F_2 \cos 60°$$
$$= (5.0\ \text{N})(0.940) + (8.0\ \text{N})(0.500) = 8.7\ \text{N}$$

$$\sum F_y = F_{1y} + F_{2y} = F_1 \sin(-20°) + F_2 \sin 60°$$
$$= (5.0\ \text{N})(-0.342) + (8.0\ \text{N})(0.866) = 5.2\ \text{N}$$

Now we use Newton's second law in component form to find the *x* and *y* components of the puck's acceleration:

$$a_x = \frac{\Sigma F_x}{m} = \frac{8.7\ \text{N}}{0.30\ \text{kg}} = 29\ \text{m/s}^2$$

$$a_y = \frac{\Sigma F_y}{m} = \frac{5.2\ \text{N}}{0.30\ \text{kg}} = 17\ \text{m/s}^2$$

The acceleration has a magnitude of

$$a = \sqrt{(29)^2 + (17)^2}\ \text{m/s}^2 = 34\ \text{m/s}^2$$

and its direction relative to the positive x axis is

$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right) = \tan^{-1}\left(\frac{17}{29}\right) = 30°$$

5.5 The Gravitational Force and Weight

Mass and weight are two different quantities.

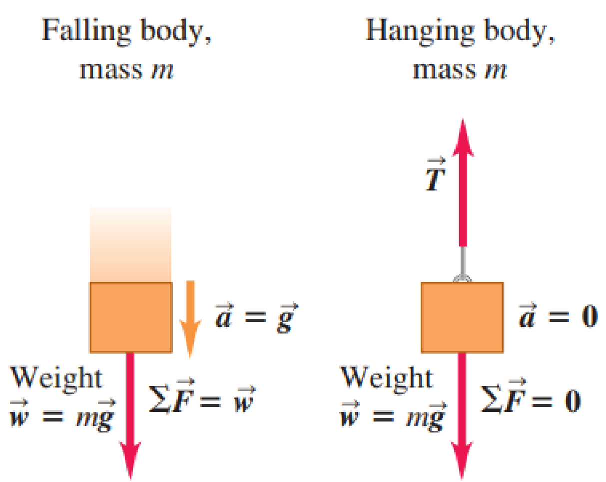
The weight of an object is equal to the magnitude of the gravitational force exerted on the object and varies with location.

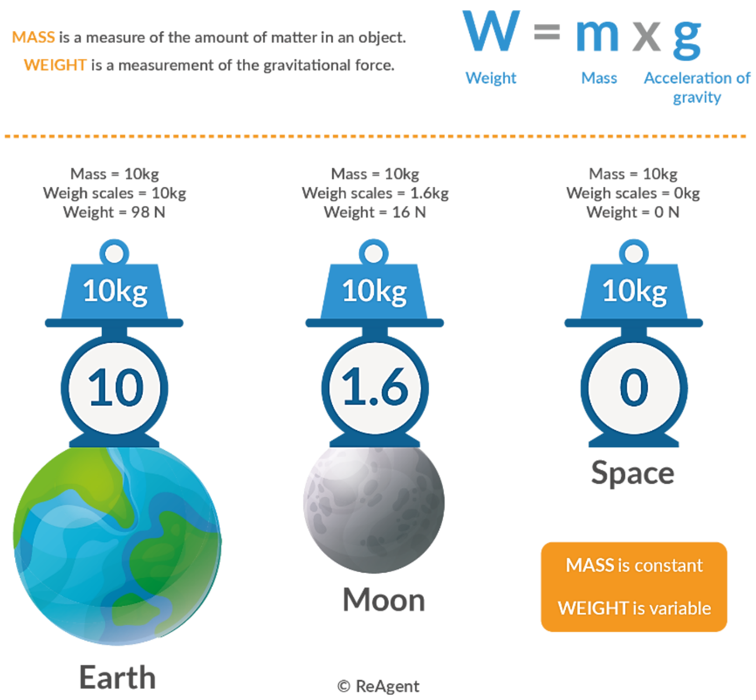
The attractive force exerted by the Earth on an object is called the gravitational force Fg.

This force is directed toward the center of the Earth, and its magnitude is called the weight of the object.

The force that makes the body accelerate downward is its weight

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





5.5 Newton’s Third Law

For every force acting on an object, there is an equal force acting in the opposite direction.

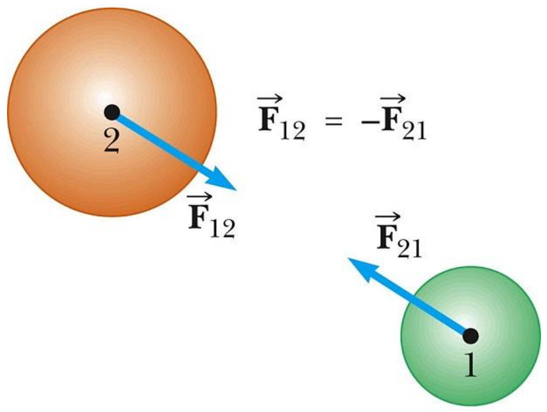
Right now, gravity is pulling you down in your seat, but Newton’s Third Law says your seat is pushing up against you with equal force. This is why you are not moving.

There is a balanced force acting on you– gravity pulling down, your seat pushing up.

Newton’s third law :

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.

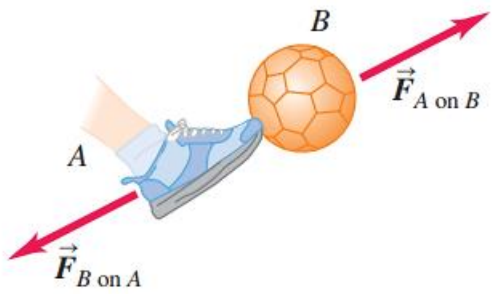
$$\vec{F}_{12} = -\vec{F}_{21}$$



Note on notation: $\vec{F}_{AB}$ is the force exerted by A on B.

5.5 Newton's Third Law

In the statement of Newton's third law, "action" and "reaction" are the two opposite forces we sometimes refer to them as an **action–reaction** pair.



The reaction of a rocket is an application of the third law of motion. Various fuels are burned in the engine, producing hot gases.

The hot gases push against the inside tube of the rocket and escape out the bottom of the tube. As the gases move downward, the rocket moves in the opposite direction.