Chapter 5: The Laws of Motion

PHY0101/PHY(PEN)101

Dynamics: What might cause one object to remain at rest and another object to accelerate?

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Outline

5.1 The Concept of Force
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
5.7 Some Applications of Newton's Laws
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The Concept of Force

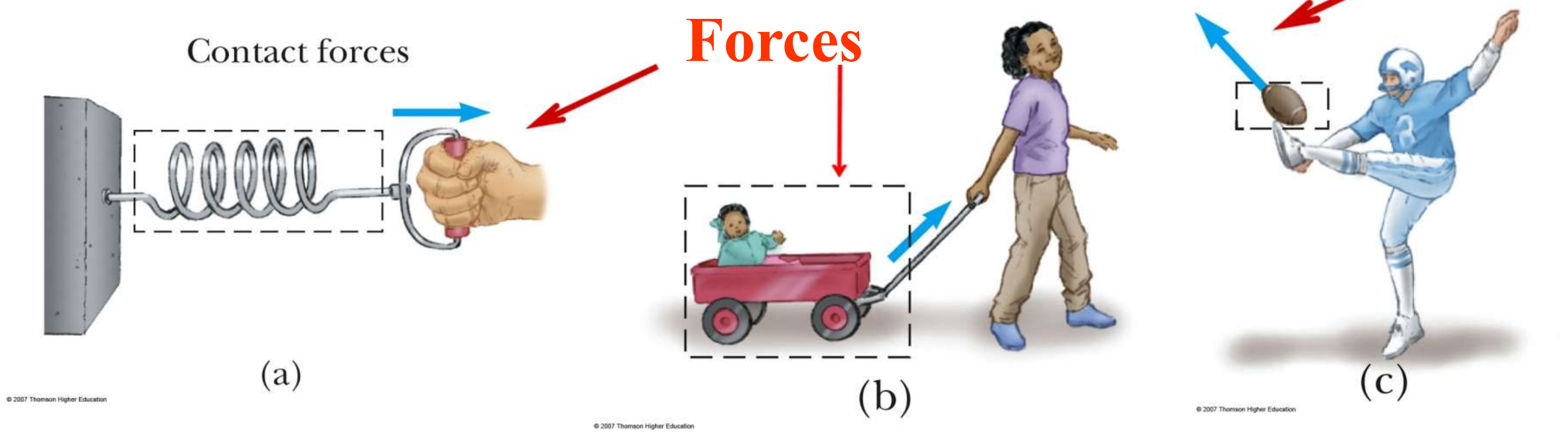
- What force (if any) causes the Moon to orbit the Earth? Newton answered this and related questions by stating that forces are what cause any change in the velocity of an object. We can think of force as that which causes an object to accelerate.
- The net force acting on an object is defined as the vector sum of all forces acting on the object. If the net force acting on the object is zero, the object either remains at rest or continues to move with constant velocity.
- When the velocity of an object is constant (including when the object is at rest), the object is said to be in equilibrium.

Examples of Forces

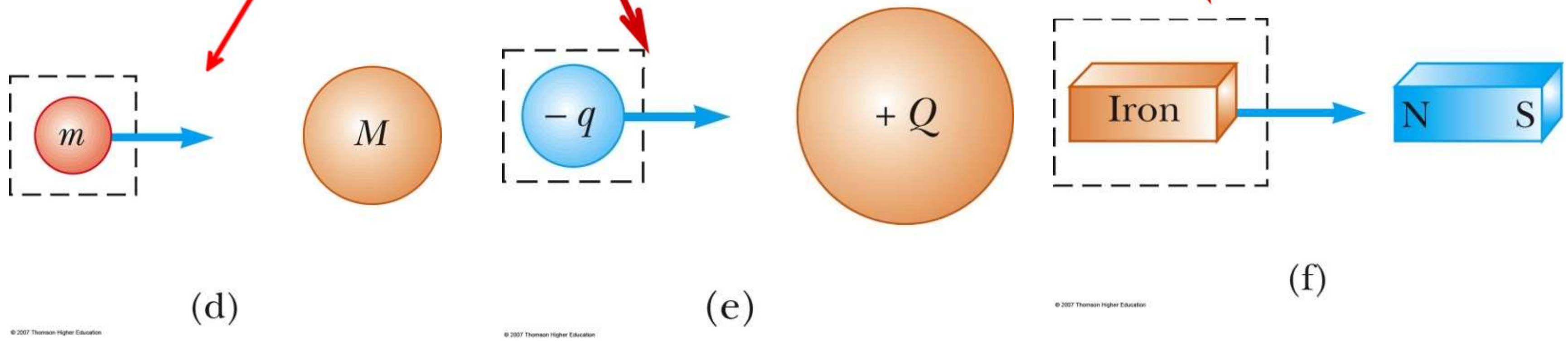
"Contact" Forces

"Pulling" Forces

"Pushing" Force



"Field" Forces (Physics II)

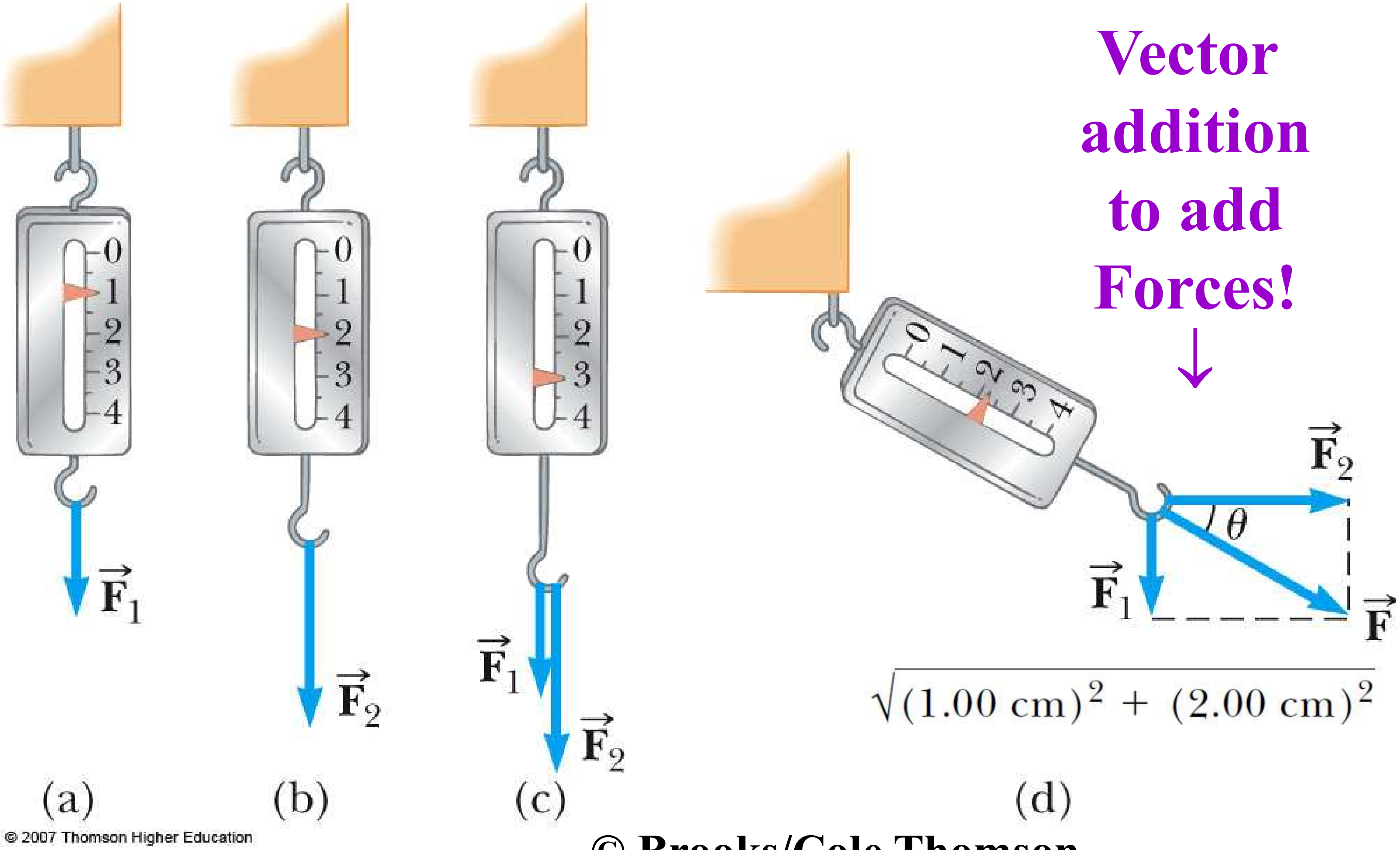


Classes of Forces

- **Contact forces** involve ***physical contact*** between two objects
  - Examples (in pictures):
    spring force, pulling force, pushing force
- **Field forces** act through empty space.
  - No physical contact is required.
  - Examples (in pictures):
    gravitation, electrostatic, magnetic

*When examined at the atomic level, all the forces we classify as contact forces turn out to be caused by electric (field) forces of the type illustrated in Figure 5.1e.

Measurement of Forces:
Spring Scale



The 4 Fundamental Forces of Nature

The Sources of these forces: In order of decreasing strength

- **Strong Nuclear Force:**
  – Binds nuclei together. Still being researched.
- **Electromagnetic Force:**
  – E&M phenomena. Chemical forces. Most everyday forces. Maxwell, Coulomb, Ampere, Faraday, ...
- **Weak Nuclear Force:**
  – Nuclear decay. Fermi, Bethe & others. Still being researched.
- **Gravitational Force:**
  – Newton ("classical" mechanics)
  – Einstein (general relativity)

The 4 Fundamental Forces of Nature

The Sources of these forces: In order of decreasing strength

TABLE 32–1 The Four Forces in Nature

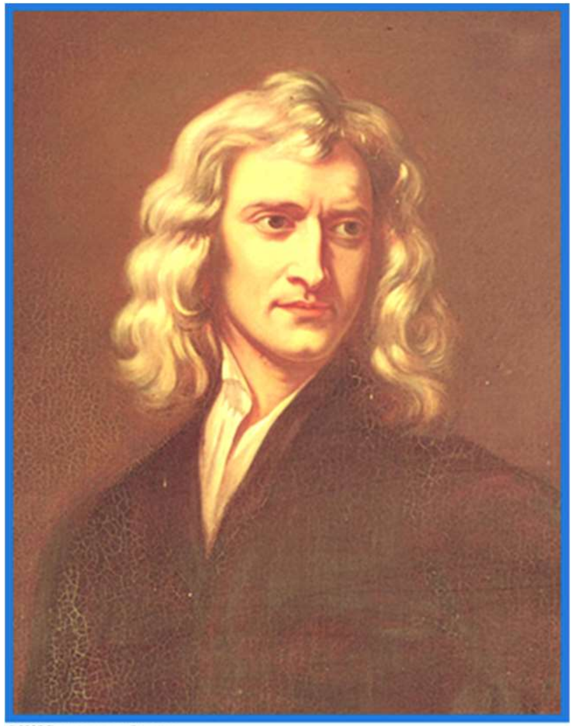
Type	Relative Strength (approx., for 2 protons in nucleus)	Field Particle
Strong nuclear	1	Gluons† (mesons)
Electromagnetic	10^{-2}	Photon
Weak nuclear	10^{-6}	$W^{\pm}$ and Z^0
Gravitational	10^{-38}	Graviton (?)

† Until the 1970s, thought to be mesons, but now gluons (see Section 32–10).

Newton's First Law

An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

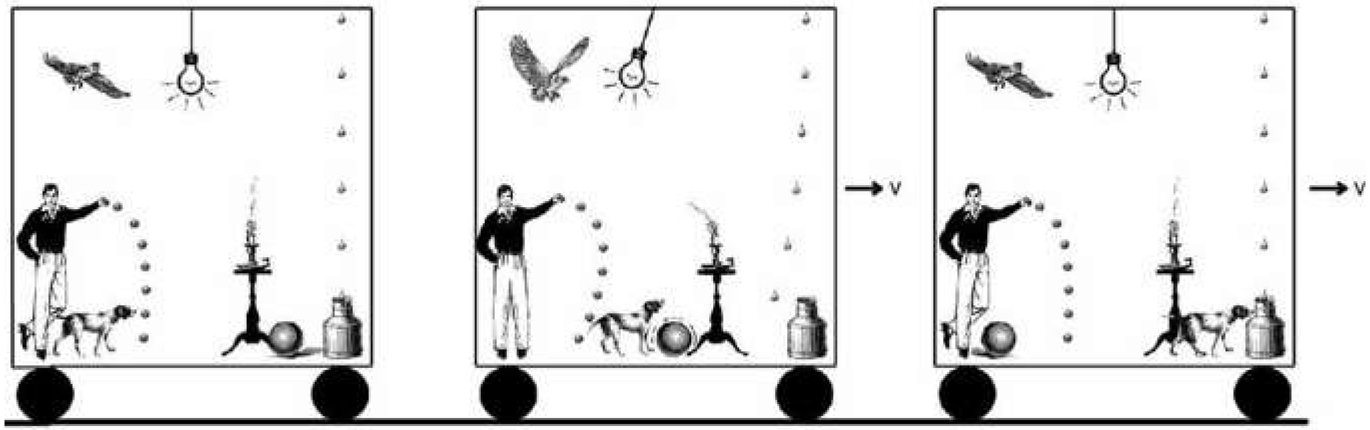
A spacecraft drifting through empty space with its engine turned off will keep moving forever—it would *not* seek a "natural state" of rest.



"Keep on doing what it is doing"

Inertial Frames

- 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.**
- 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.



A. Carriage standing still B. carriage accelerating C. carriage moving uniformly

5.3 Mass

- Mass is a property of an object that specifies how much resistance an object exhibits to changes in its velocity.
- The greater the mass of an object, the less that object accelerates under the action of a given applied force.
- Mass is an inherent property of an object and is independent of the object's surroundings and of the method used to measure it. Also, **mass is a scalar quantity**.

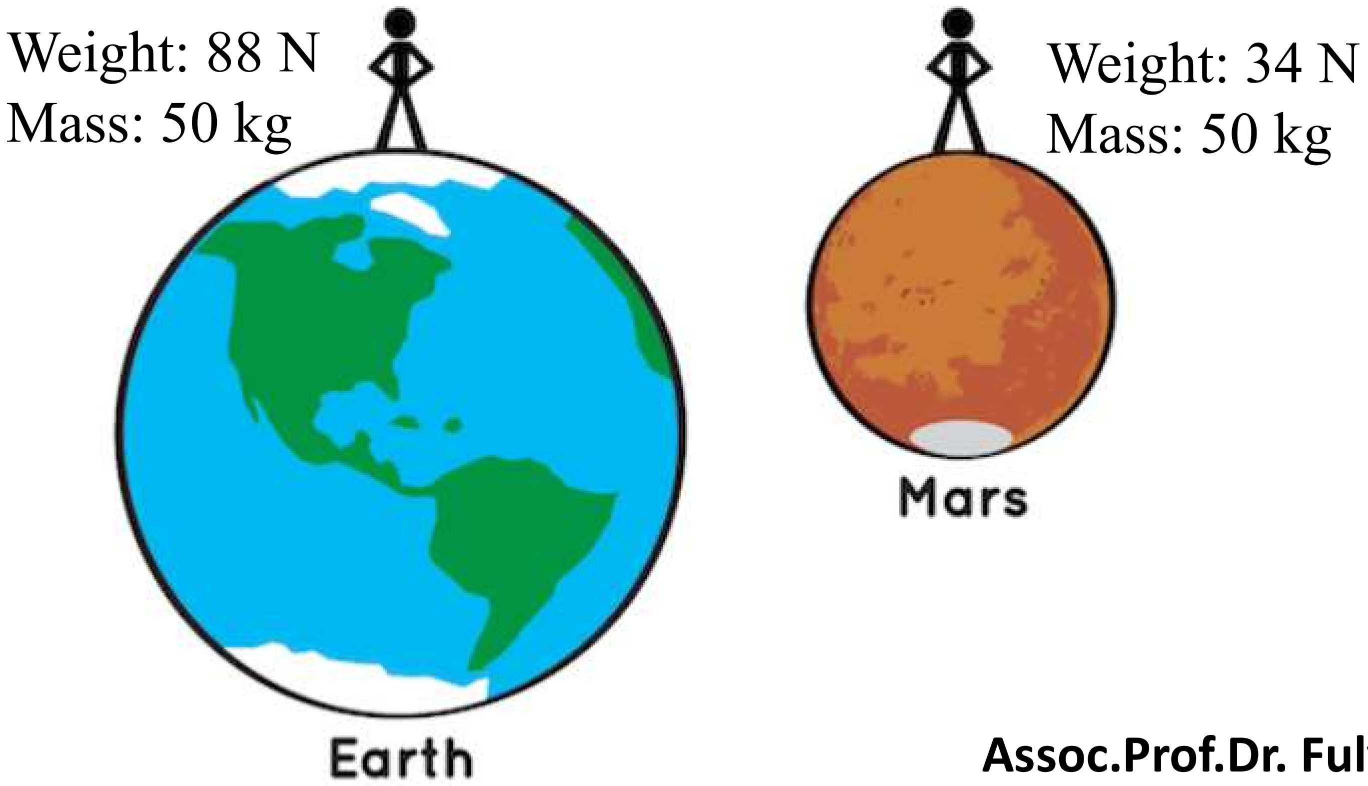
The ratio of the two masses is defined as the *inverse* ratio of the magnitudes of the accelerations produced by the force.

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

$\boldsymbol{a}$ $\qquad$ $\boldsymbol{a/10}$

Mass and weight are two different quantities.

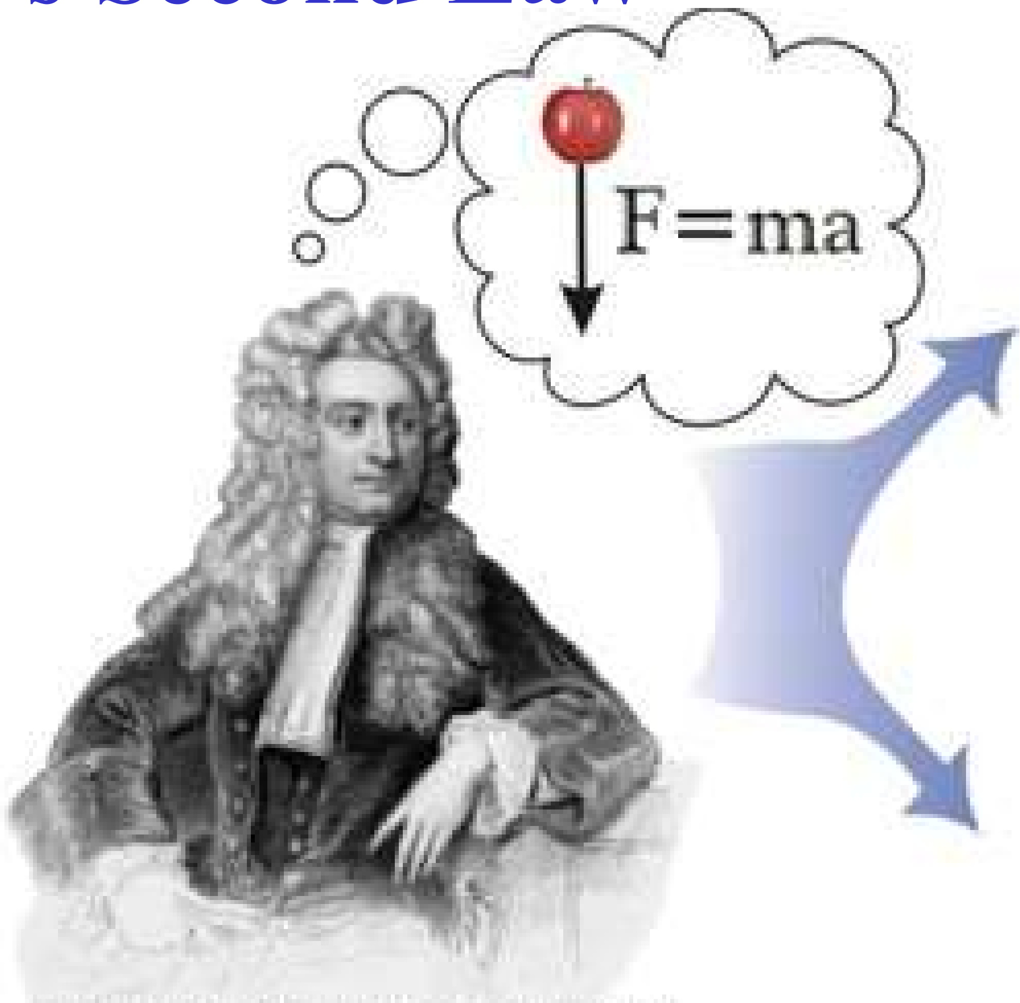
The weight of an object is equal to the magnitude of the gravitational force exerted on the object and varies with location.



5.4 Newton's Second Law

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

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



Portrait source: U.S. Centennial of Flight Commission
http://www.centennialofflight.gov/essay/Dictionary/newton/DI36.htm

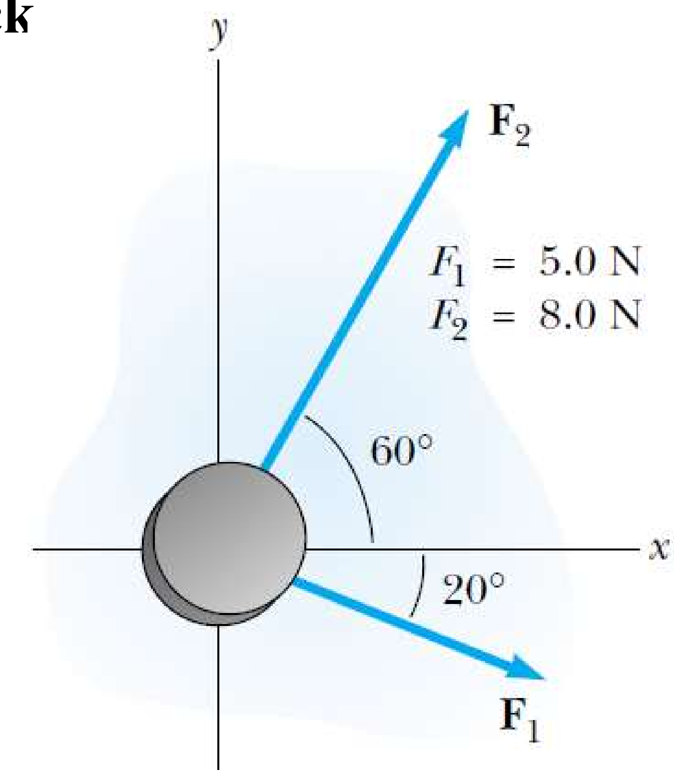
$$\vec{F}_{net} = \sum \vec{F} = m\vec{a}$$

- The SI unit of force is the newton, which is defined as the force that, when acting on an object of mass 1 kg, produces an acceleration of 1 m/s^2.

Example 5.1 An Accelerating Hockey Puck

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.

Determine both the magnitude and the direction of the puck's acceleration.



Solution: $\sum F_x = F_{1x} + F_{2x} = F_1 \cos(-20°) + F_2 cos60°$

$$= 5 \times 0.94 + 8 \times 0.5 = 8.7 \text{ N}$$

$$\sum F_y = F_{1y} + F_{2y} = F_1 \sin(-20°) + F_2 sin60°$$

$$= 5 \times -0.342 + 8 \times 0.866 = 5.2 \text{ N}$$

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

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

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

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

5.5 The Gravitational Force and Weight

- The attractive force exerted by the Earth on an object is called the gravitational force F_g. This force is directed toward the center of the Earth, and its magnitude is called the weight of the object.

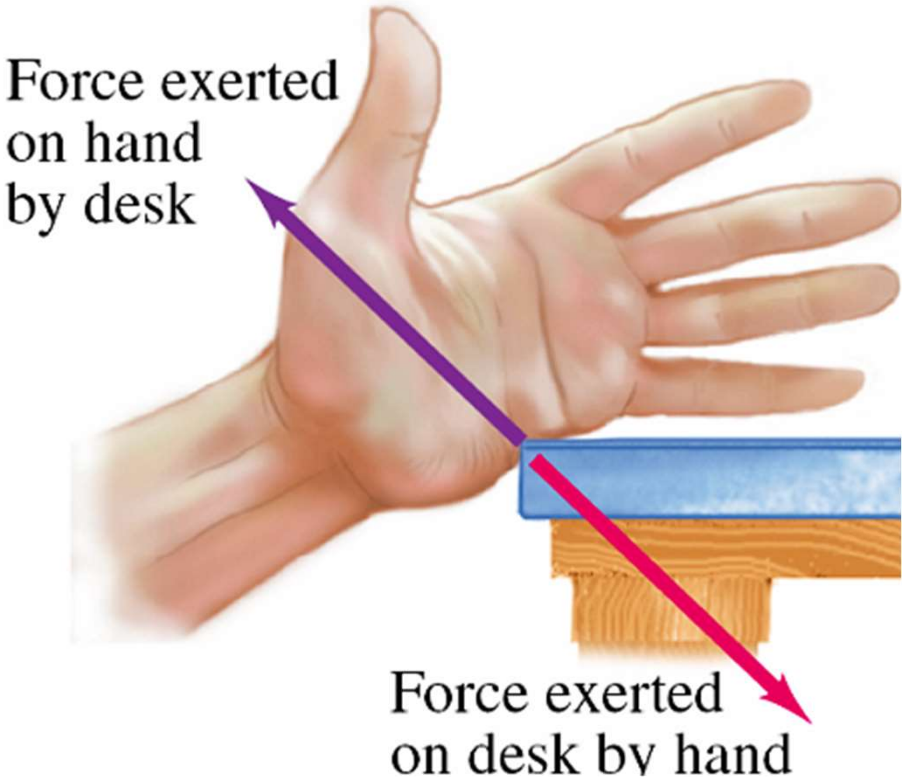
$$\mathbf{F}_g = m\mathbf{g}$$

- The student's weight in a location where g=9.80 m/s^2 is F_g =686 N. At the top of a mountain, however, where g=9.77 m/s^2, the student's weight is 684 N.

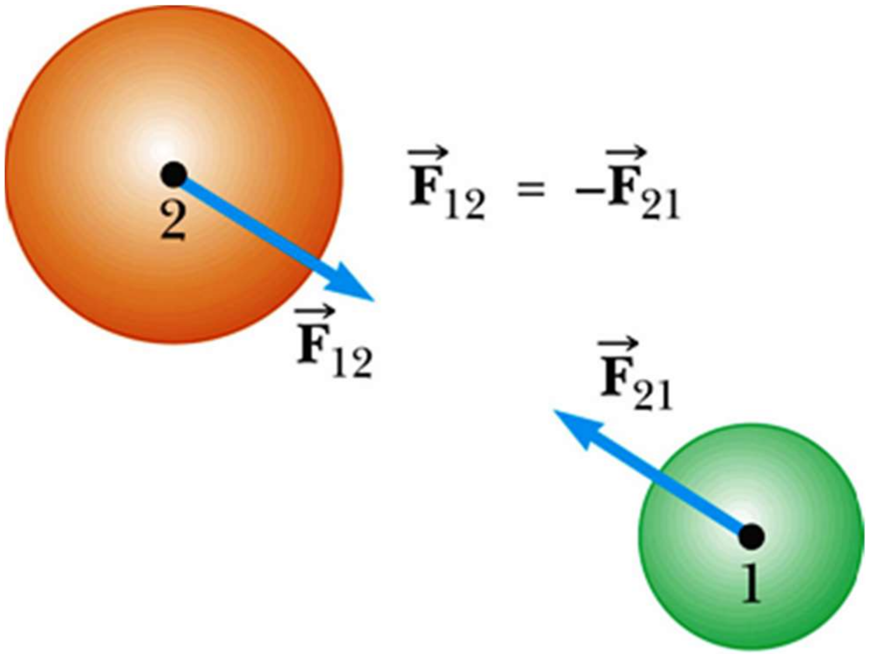
Newton's 3rd Law

Newton's 3[rd] Law:

"Whenever one object exerts a force on a second object, the second exerts an equal force in the opposite direction on the first."

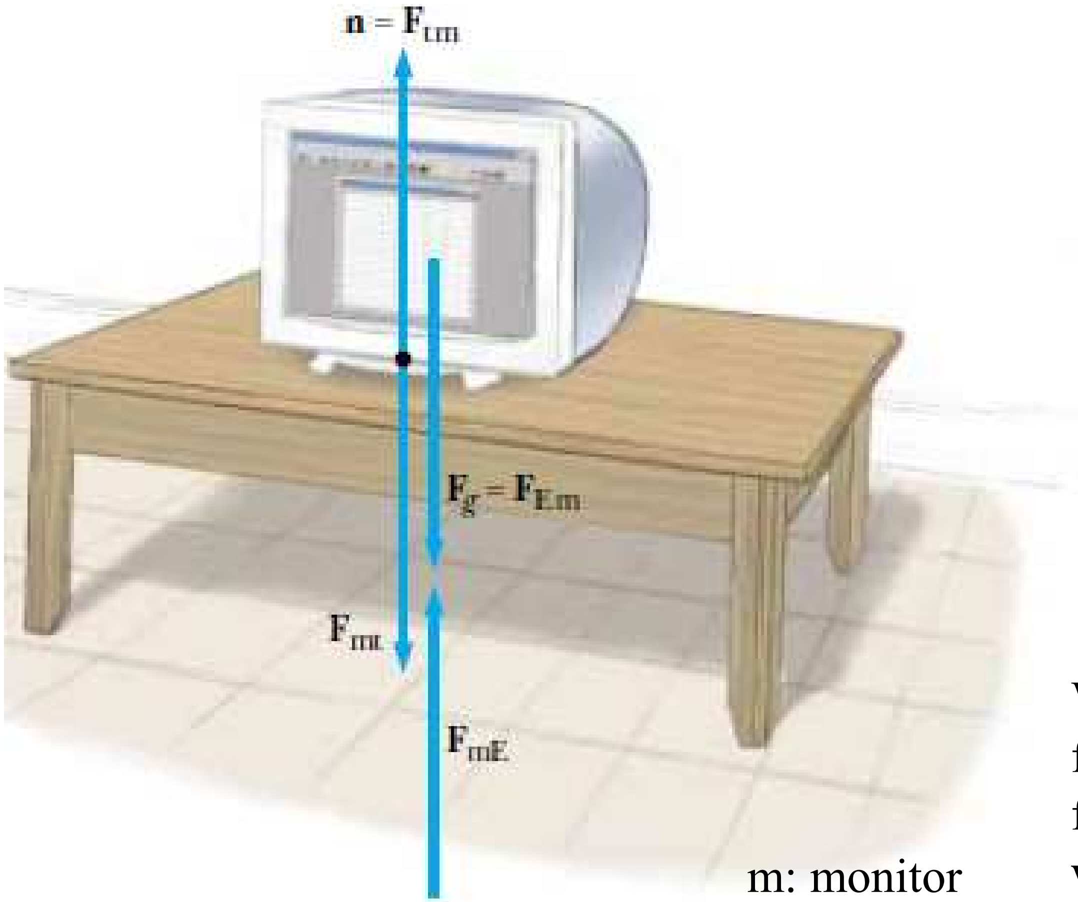


If your hand pushes against the edge of a desk (***the force vector shown in red***), the desk pushes back against your hand (***this force vector is shown in purple***, to remind us that this force acts on a ***DIFFERENT*** object).



Forces always occur in pairs, or that a single isolated force cannot exist.

The force that object 1 exerts on object 2 may be called the *action force* and the force of object 2 on object 1 the *reaction force*.



m: monitor
t: table
E: Earth

When analyzing an object subject to forces, we are interested in the net force acting on one object, which we will model as a particle. Thus, a free-body diagram helps us to isolate only those forces on the object and eliminate the other forces from our analysis.

$$\Sigma \mathbf{F} = \mathbf{n} - m\mathbf{g} = 0$$

Rocket propulsion can be explained using

Newton's Third Law

Hot gases from combustion spew out of the tail of the rocket at high speeds. The reaction force is what propels the rocket.

Note:

The rocket doesn't need anything to "push" against.