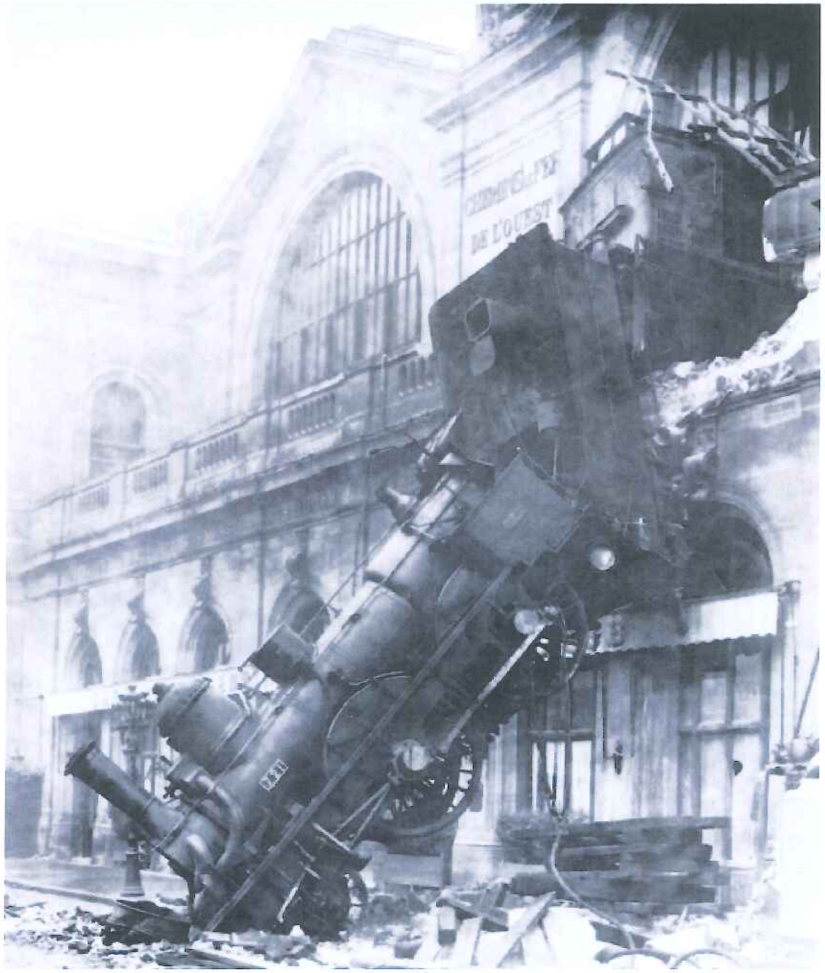
Lecture 8

(Ch4:1-2)

Topic 4: Newton's Laws of Motion



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College Physics, 11e
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Chris Vuille

BROOKS/COLE
CENGAGE Learning

Chapter 4:Force and Newton's Laws

- Force and Mass
- Newton's Laws of Motion

- Applications of Newton's Laws

- Uniform Circular Motion

- Friction and Drag

Chapter 4:Force and Newton's Laws
Force and Mass

- *The study of motion is "kinematics".*
- *Why is there motion is "dynamics".*
- *Kinematics + dynamics = "mechanics".*

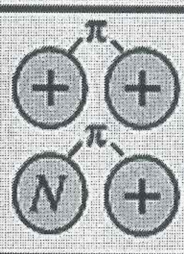
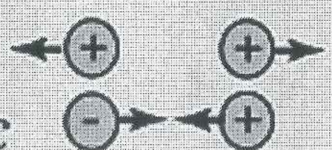
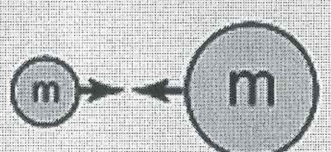
- *What is mass?*

Mass is a scalar quantity that describes the amount of matter within an object. At a deeper level, mass is given by the number and the type of atoms in an object.

- *What does mas do in mechanics?*

Mass determines the resistance to changes in motion, called **inertia.**

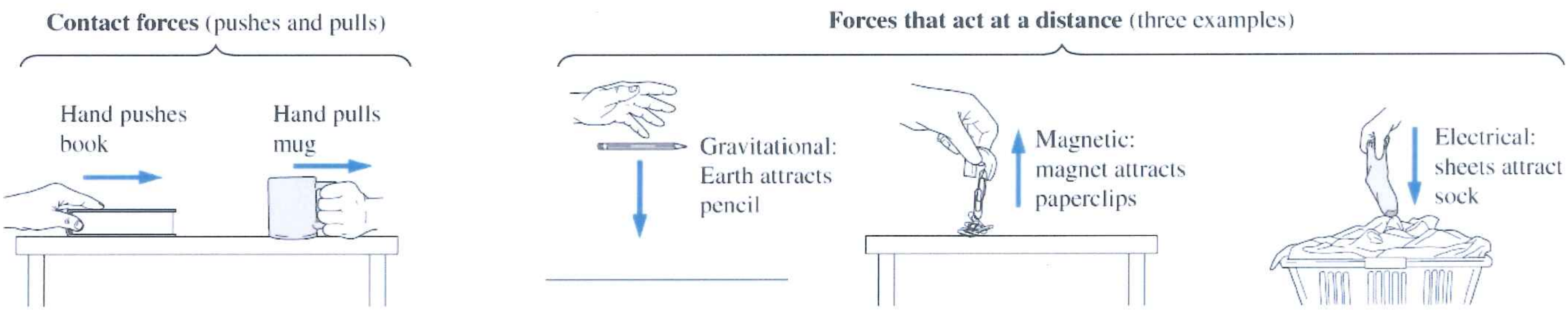
Fundamental Forces

Force		Strength	Range (m)	Particle
Strong	 Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	π, others mass > 0.1 GeV
Electro-magnetic		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	 neutrino interaction induces beta decay	10^{-5}	10^{-17} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity		6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

Chapter 4:Force and Newton's Laws Force and Mass

What are forces?

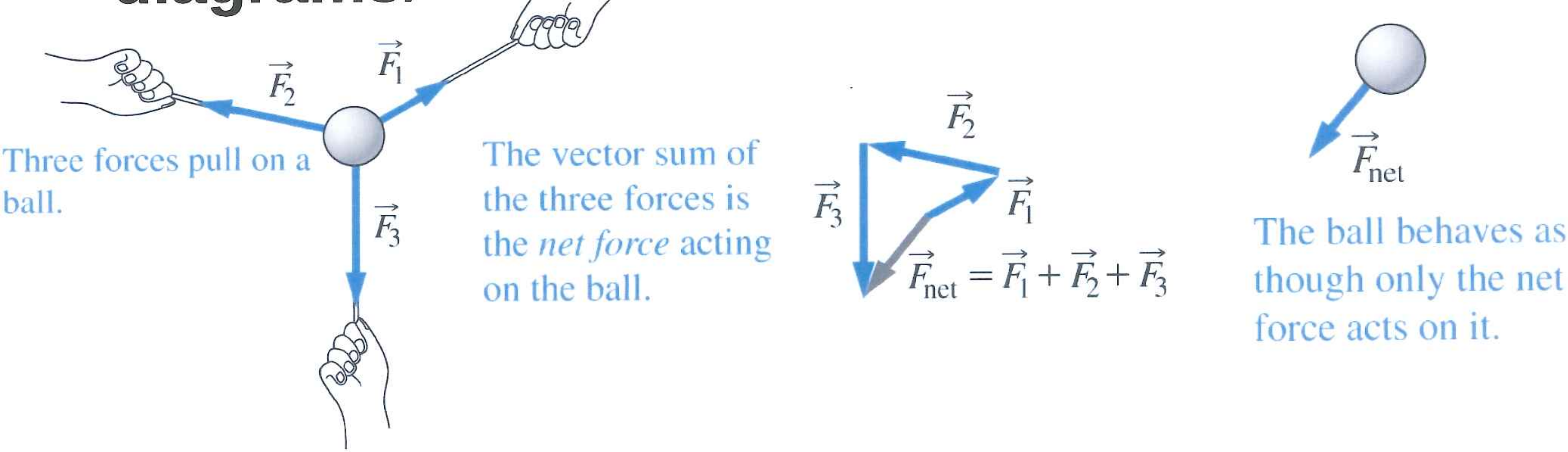
Forces are vector quantities with magnitude and direction that act during the interaction between objects.



Chapter 4:Force and Newton's Laws Net Force and Force Diagrams

If two or more forces act on an object, then we need to know their total magnitude and direction, called **net force***.*

It is simply the vector sum of all the forces involved and is treated like any other vector. Graphically, this is represented by **force diagrams***.*



Inertia

"The vis insita, or innate force of matter, is a power of resisting, by which every body, as much as in it lies, endeavours to persevere in its present state, whether it be of rest, or of moving uniformly forward in a right line."

Isaac Newton,
Mathematical Principles of Natural Philosophy, 1687

The greater an object's ***inertia****, the greater the force needed to change its motion.*

The Equivalence Principle

Inertia is equivalent to mass.

*The greater an object's **mass**, the greater the force needed to change its motion.*

mass - intrinsic characteristic of the body

Mass and Weight

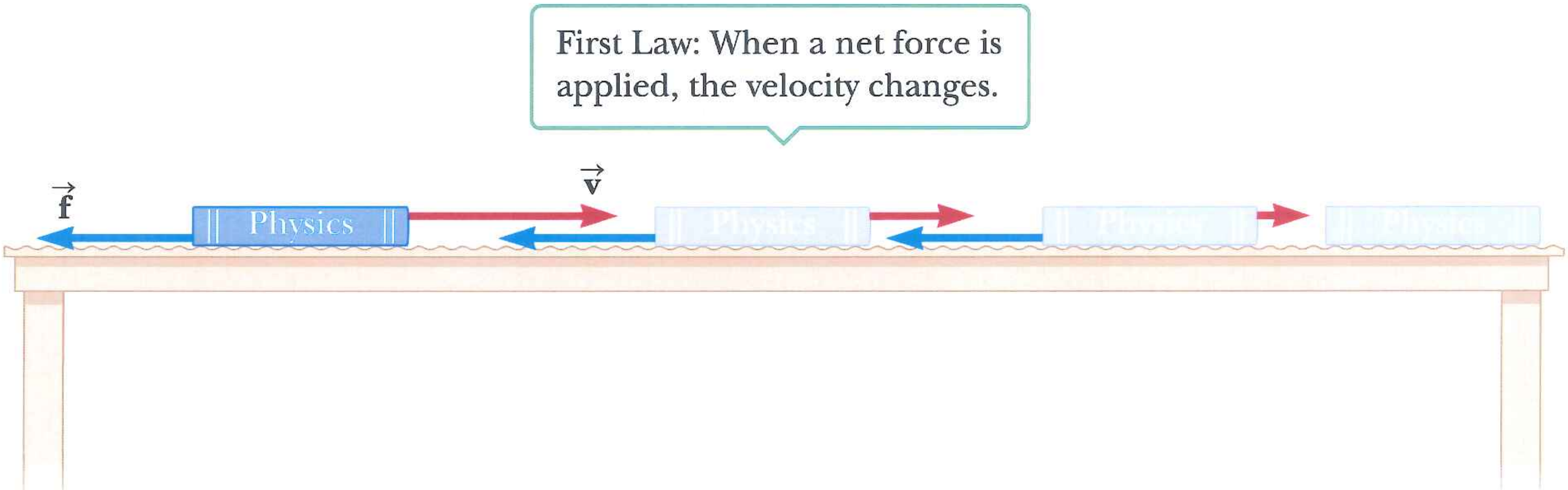
The mass of an object is a fundamental property of the object; a numerical measure of its inertia; a fundamental measure of the amount of matter in the object. Definitions of mass often seem circular because it is such a fundamental quantity that it is hard to define in terms of something else. All mechanical quantities can be defined in terms of mass, length, and time. The usual symbol for mass is m and its SI unit is the kilogram. While the mass is normally considered to be an unchanging property of an object, at speeds approaching the speed of light one must consider the increase in the relativistic mass.

The weight of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity, $w = mg$. Since the weight is a force, its SI unit is the newton. Density is mass/volume.

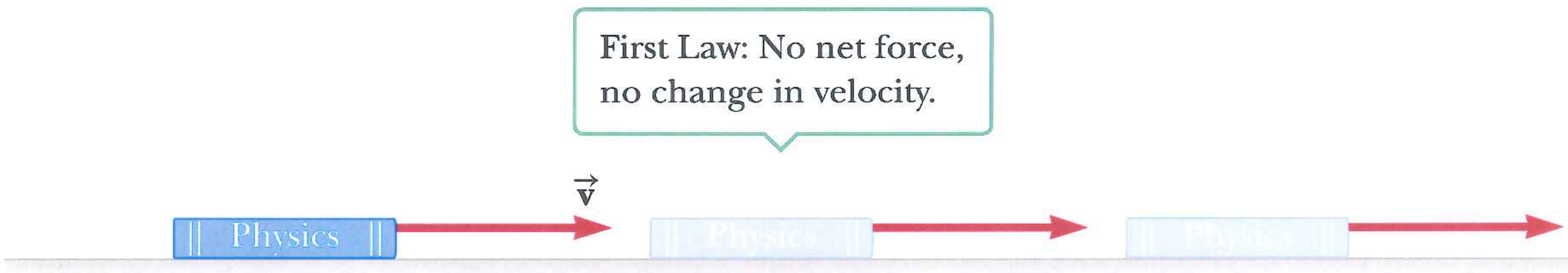
If an object has a mass of 1 kg on the earth, it would have a mass of 1 kg on the moon, even though it would weigh only one-sixth as much.

Weight Calculation

Newton's First Law



Newton's First Law



Newton's First Law

Newton's first law of motion: An object moves with a velocity that is constant in magnitude and direction unless a nonzero net force acts on it.

Chapter 4:Force and Newton's Laws
Newton's Second Law

"An object's acceleration and the net force acting on it are directly proportional."

$$\vec{F}_{net} = m \cdot \vec{a}\text{, in SI: } \frac{\mathrm{kg \cdot m}}{s^2} = 1\,\mathrm{N}$$

A consequence of the first and second laws is that acceleration (change of velocity in a unit of time) of an object requires a force, is proportional to the force and inversely proportional to the mass of the object.

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

Units of Force and Mass

$$1\ \text{N} \equiv 1\ \text{kg} \cdot \text{m/s}^2$$

$$1\ \text{N} = 0.225\ \text{lb}$$

Table 4.1 Units of Mass, Acceleration, and Force

System	Mass	Acceleration	Force
SI	kg	m/s^2	$\text{N} = \text{kg} \cdot \text{m/s}^2$
U.S. customary	slug	ft/s^2	$\text{lb} = \text{slug} \cdot \text{ft/s}^2$

1. The heaviest invertebrate is the giant squid, which is estimated to have a weight of about 2 tons spread out over its length of 70 feet. What is its weight in newtons?

4.1

$$w = (2\ \text{tons})\left(\frac{2\,000\ \text{lbs}}{1\ \text{ton}}\right)\left(\frac{4.448\ \text{N}}{1\ \text{lb}}\right) = \boxed{2\times10^4\ \text{N}}$$

7. Four forces act on an object, given by $\vec{\mathbf{A}} = 40.0$ N east, $\vec{\mathbf{B}} = 50.0$ north, $\vec{\mathbf{C}} = 70.0$ N west, and $\vec{\mathbf{D}} = 90.0$ N south.

a. What is the magnitude of the net force on the object?

Answer ↓

b. What is the direction of the force?

4.7 The net force has components: $F_x = A_x + B_x + C_x + D_x = 40.0\ \text{N} + 0 - 70.0\ \text{N} + 0 = -30.0\ \text{N}$ and $F_y = A_y + B_y + C_y + D_y = 0 + 50.0\ \text{N} + 0 - 90.0\ \text{N} = -40.0\ \text{N}$.

(a) The magnitude of the net force is

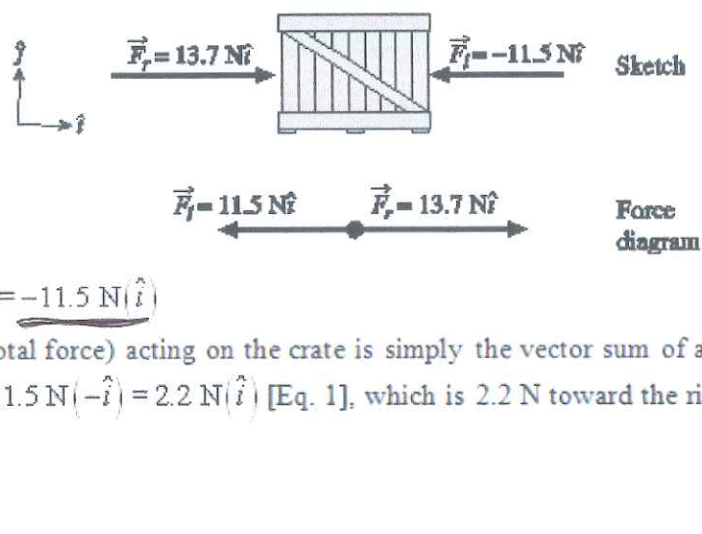
$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{(-30.0\ \text{N})^2 + (-40.0\ \text{N})^2} = \boxed{50.0\ \text{N}}$$

(b) The net force lies in the third quadrant so its direction is

$$\theta = \tan^{-1}\left(\frac{F_x}{F_y}\right) + 180° = \tan^{-1}\left(\frac{-30.0\ \text{km}}{-40.0\ \text{km}}\right) + 180° = \boxed{217°}$$

or 36.9° south of west.

29. **ORGANIZE AND PLAN** To find the net force acting on an object, we perform a *vector addition* of all the forces acting on the object. In this case there are only two forces, and they are anti-parallel (i.e., parallel but in opposite directions), so the vector addition is quite simple. We chose a coordinate system where the $\hat{i}$ direction is toward the right.



Known: $\vec{F}_r = 13.7\ \text{N}(\hat{i})$; $\vec{F}_l = -11.5\ \text{N}(\hat{i})$

SOLVE The net force (or total force) acting on the crate is simply the vector sum of all the forces acting on it, or $\vec{F}_{\text{net}} = \vec{F}_r + \vec{F}_l = 13.7\ \text{N}(\hat{i}) + 11.5\ \text{N}(-\hat{i}) = 2.2\ \text{N}(\hat{i})$ [Eq. 1], which is 2.2 N toward the right.

1kg is accelerated to 2 $\frac{m}{s^2}$ by a force applied at an angle of 20°. Find F_x, F_y and $|F|$.

1. We apply Newton's second law (specifically, Eq. 5-2).

   (a) We find the x component of the force is

   $$F_x = ma_x = ma\cos 20° = (1.00\,\mathrm{kg})(2.00\,\mathrm{m/s^2})\cos 20° = 1.88\ \mathrm{N}\ .$$

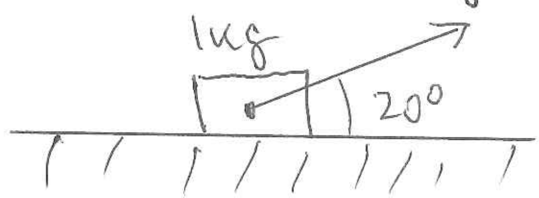
   (b) The y component of the force is

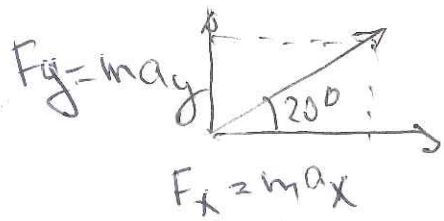
   $$F_y = ma_y = ma\sin 20° = (1.0\,\mathrm{kg})(2.00\,\mathrm{m/s^2})\sin 20° = 0.684\ \mathrm{N}\ .$$

   (c) In unit-vector notation, the force vector (in Newtons) is

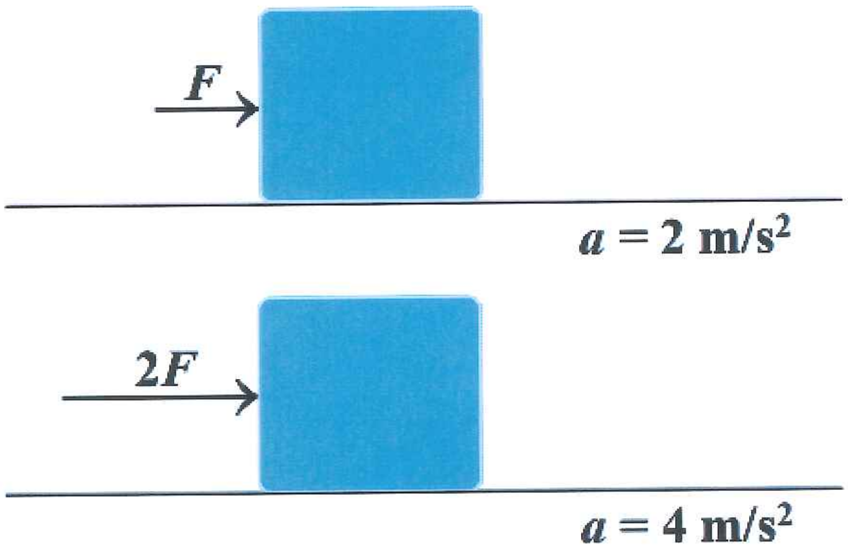
   $$\vec{F} = F_x\,\hat{\imath} + F_y\,\hat{\jmath} = 1.88\,\hat{\imath} + 0.684\,\hat{\jmath}\ .$$

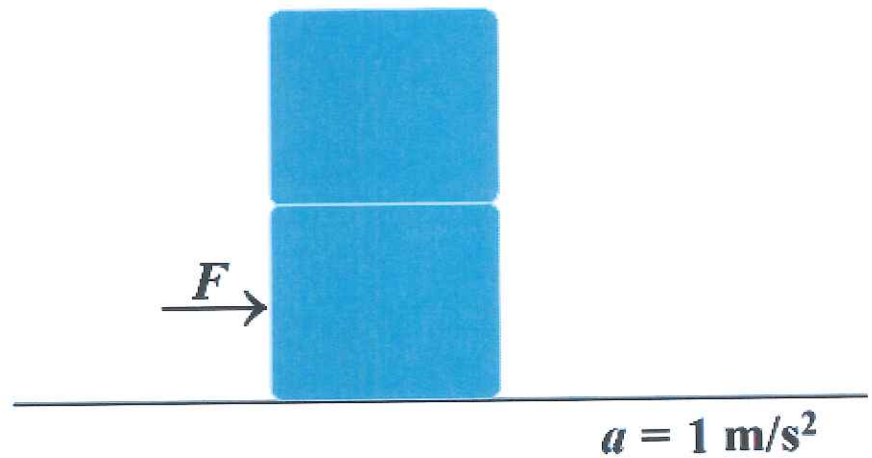
$$|\vec{F}| = \sqrt{F_x^2 + F_y^2} = \sqrt{1.88^2 + 0.684^2} \approx 2\,N$$





Newton's Second Law





acceleration directly proportional to net force

acceleration inversely proportional to mass

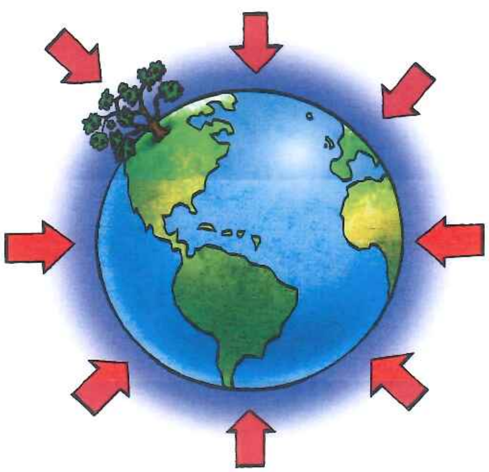
$$\vec{\mathbf{a}} = \frac{\Sigma\vec{\mathbf{F}}}{m} \qquad \Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

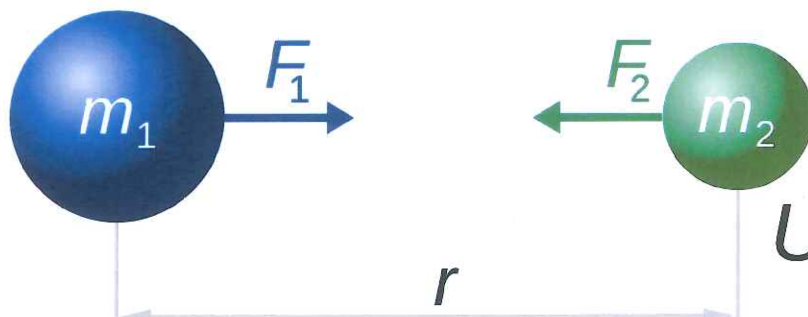
Chapter 4:Force and Newton's Laws
Weight and Gravitational Acceleration

*The force of gravity is called **weight**. This is what scales measure.*

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

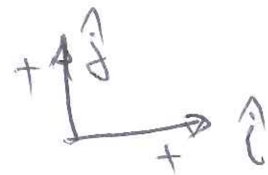
At Earth's surface, weight is directly proportional to the mass and is pointing towards the Earth.





Universal gravity

$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2} \qquad G = 6.674 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}.$$



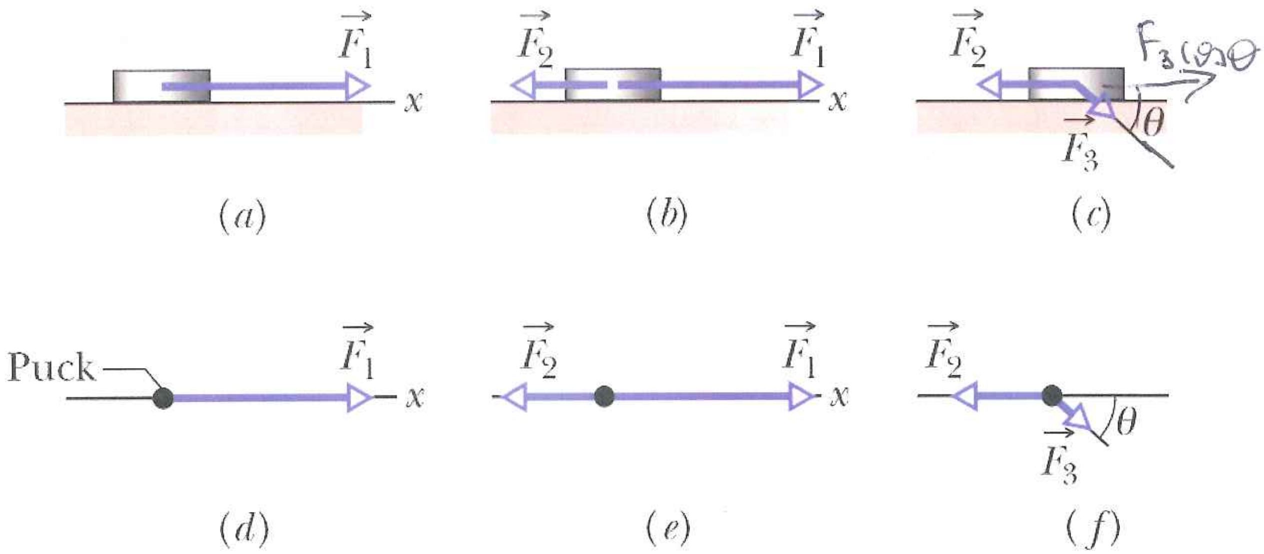
$m = 0.2\ kg$

$F_1 = 4\ N$

$F_2 = 2\ N$

$F_3 = 1\ N$

$\theta = 30°$



$$\vec{a}_x = \frac{\vec{F}_1}{m} = 20\ \frac{m}{s^2}$$

$$\vec{a}_x = \frac{\vec{F}_1 - \vec{F}_2}{m} = 10\ \frac{m}{s^2}$$

$$\vec{a}_x = \frac{F_3 \cos\theta - F_2}{m} = -5.7\ \frac{m}{s^2}$$

10. A 5.0-g bullet leaves the muzzle of a rifle with a speed of 320 m/s. What force (assumed constant) is exerted on the bullet while it is traveling down the 0.82-m-long barrel of the rifle?

4.10 The acceleration of the bullet is given by $a = \frac{v^2 - v_0^2}{2(\Delta x)} = \frac{(320 \text{ m/s})^2 - 0}{2(0.82 \text{ m})}$.

Then, $\sum F = ma = (5.0 \times 10^{-3} \text{ kg})\left[\frac{(320 \text{ m/s})^2}{2(0.82 \text{ m})}\right] = \boxed{3.1 \times 10^2 \text{ N}}$.

17. A force of 30.0 N is applied in the positive x-direction to a block of mass 8.00 kg, at rest on a frictionless surface.

a. What is the block's acceleration?

Answer

b. How fast is it going after 6.00 s?

4.17 **(a)** Solve the x-component of Newton's second law for the acceleration, a, to find

$$a = \frac{\Sigma F_x}{m} = \frac{30.0 \text{ N}}{8.00 \text{ kg}} = \boxed{3.75 \text{ m/s}^2}$$

(b) Use the time-dependent velocity equation from kinematics to find the block's speed after 6.00 s:

$$\begin{aligned} v &= v_0 + at \\ &= 0 + (3.75 \text{ m/s}^2)(6.00 \text{ s}) \\ &= \boxed{22.5 \text{ m/s}} \end{aligned}$$

14. **S** An object of mass m is dropped from the roof of a building of height h. While the object is falling, a wind blowing parallel to the face of the building exerts a constant horizontal force F on the object.

a. How long does it take the object to strike the ground? Express the time t in terms of g and h.

b. Find an expression in terms of m and F for the acceleration a_x of the object in the horizontal direction (taken as the positive x-direction).

c. How far is the object displaced horizontally before hitting the ground? Answer in terms of m, g, F, and h.

d. Find the magnitude of the object's acceleration while it is falling, using the variables F, m, and g.

4.14 (a) With the wind force being horizontal, the only vertical force acting on the object is its own weight, mg. This gives the object a downward acceleration of

$$a_y = \frac{\Sigma F_y}{m} = \frac{-mg}{m} = -g$$

The time required to undergo a vertical displacement $\Delta y = -h$, starting with initial vertical velocity $v_{0y} = 0$, is found from

$\Delta y = v_{0y}t + \frac{1}{2}a_y t^2$ as

$$-h = 0 - \frac{g}{2}t^2 \quad \text{or} \quad \boxed{t = \sqrt{\frac{2h}{h}}}$$

(b) The only horizontal force acting on the object is that due to the wind, so $\Sigma F_x = F$ and the horizontal acceleration will be $a_x = \frac{\Sigma F_x}{m} = \boxed{\frac{F}{m}}$.

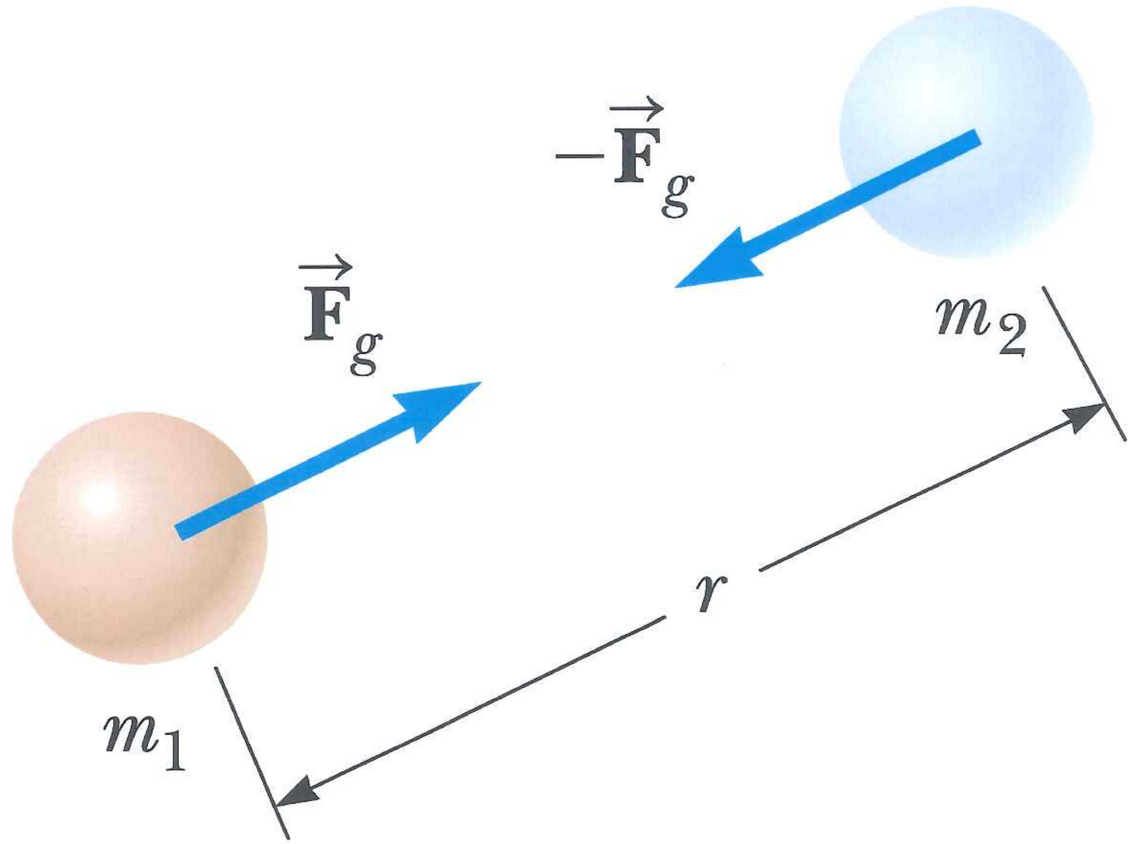
(c) With $v_{0x} = 0$, the horizontal displacement the object undergoes while falling a vertical distance h is given by $\Delta x = v_{0x}t + \frac{1}{2}a_x t^2$ as

$$\Delta x = 0 + \frac{1}{2}\left(\frac{F}{m}\right)\left(\sqrt{\frac{2h}{g}}\right)^2 = \boxed{\frac{Fh}{mg}}$$

(d) The total acceleration of this object while it is falling will be

$$a = \sqrt{a_x^2 + a_y^2} = \sqrt{(F/m)^2 + (-g)^2} = \boxed{\sqrt{(F/m)^2 + g^2}}$$

The Gravitational Force



$$F_g = G\frac{m_1 m_2}{r^2} \quad \text{where } G = 6.67\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}$$

Weight

$$w = mg$$

$$w_{\text{on Earth}} = (70.0\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 686\ \text{N}$$

$$w_{\text{in balloon}} = (70.0\ \text{kg})(9.76\ \text{m/s}^2)$$
$$= 683\ \text{N}$$

NASA/Eugene Cernan

Weight

$$w = mg \quad \text{SI unit: N}$$

$$w = G\frac{M_E m}{r^2}$$

$$g = G\frac{M_E}{r^2}$$

18. What would be the acceleration of gravity at the surface of a world with twice Earth's mass and twice its radius?

4.18 A planet's gravitational acceleration is given by

$$g_p = G\frac{M_p}{r_p^2}$$

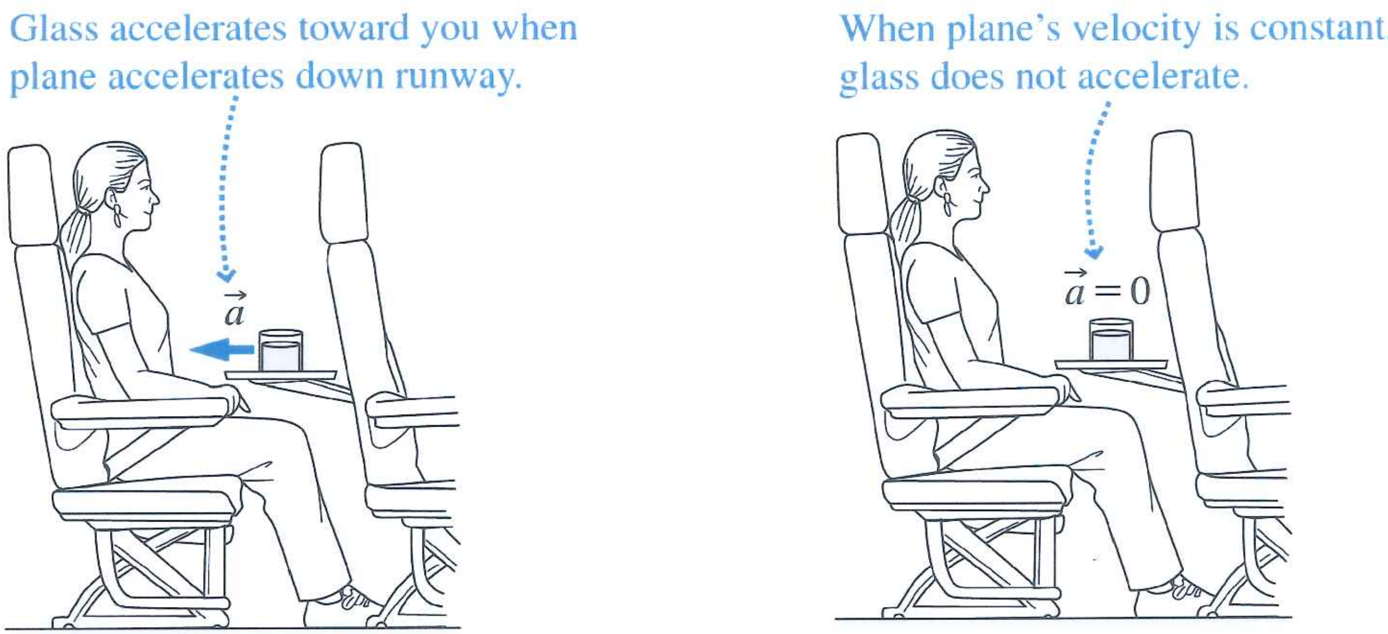
Construct the ratio with the gravitational acceleration on Earth to find

$$\frac{g_p}{g} = \frac{M_p / M_E}{\left(r_p / R_E\right)^2} = \frac{2}{2^2} = \frac{1}{2}$$

$$g_p = \tfrac{1}{2}g = \tfrac{1}{2}\left(9.80\ \text{m/s}^2\right)$$
$$= \boxed{4.90\ \text{m/s}^2}$$

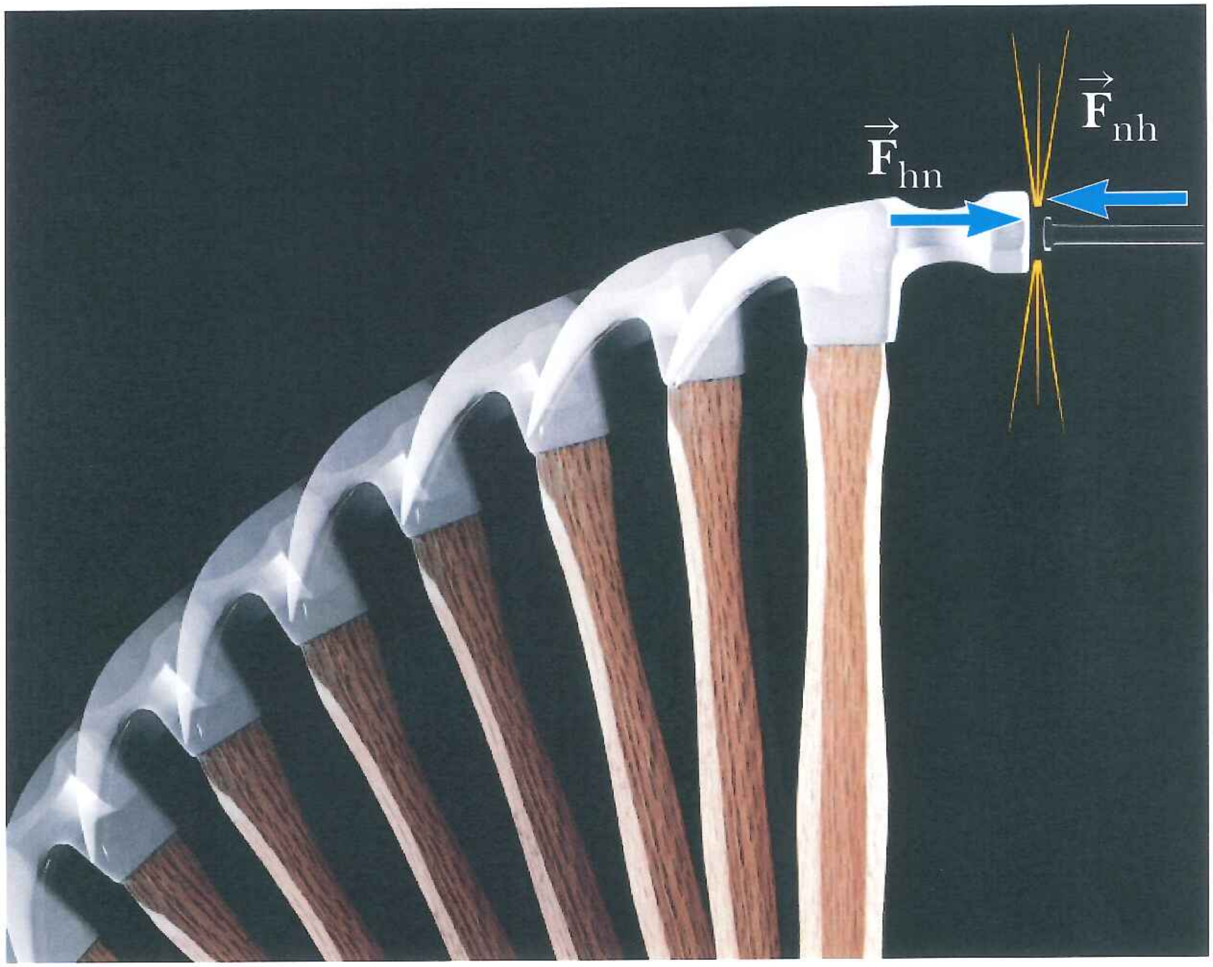
Chapter 4:Force and Newton's Laws
Inertial Reference Frames

The first and second laws hold true in **inertial reference frames***. This means that the reference frames are moving with constant velocity. Accelerated frames are* **noninertial***.*



(a) Noninertial reference frame   **(b)** Inertial reference frame

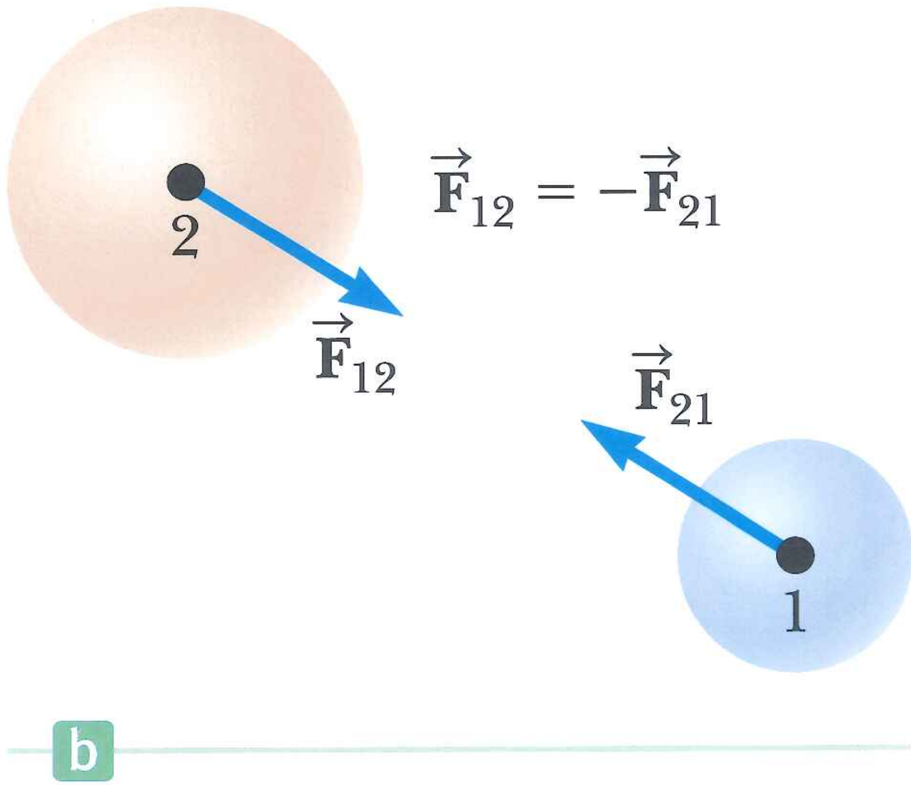
Newton's Third Law



Jim Gillmoure/CORBIS

a

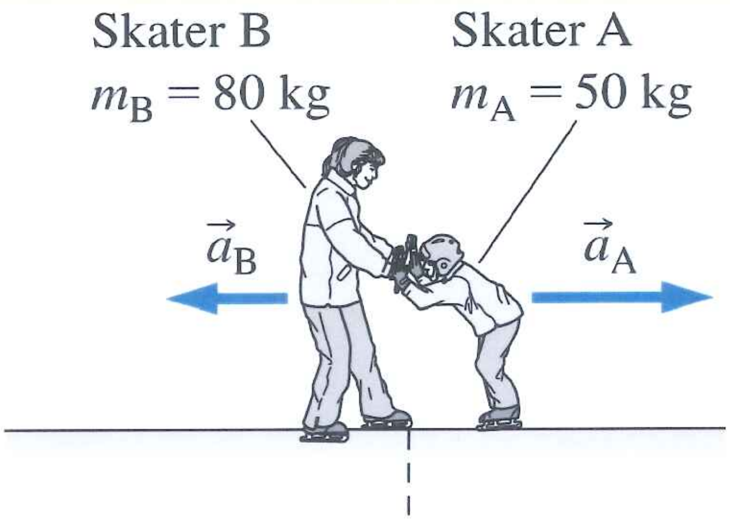
Newton's Third Law



The action force is equal in magnitude to the reaction force and opposite in direction. In all cases, the action and reaction forces act on different objects.

Chapter 4:Force and Newton's Laws
Newton's Third Law

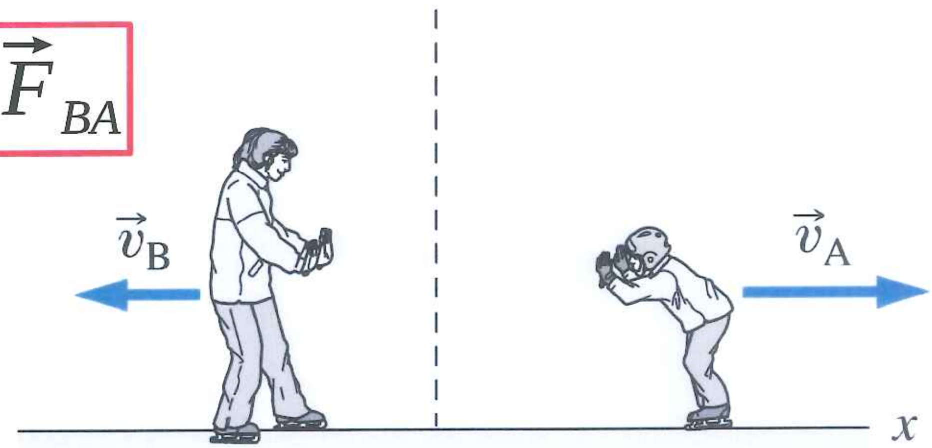
"When two objects (A and B) interact, the force that object A exerts on object B is equal in magnitude and opposite in direction to the force that B exerts on A."



(a) Skaters push off

Skaters accelerate in opposite directions: $m_A < m_B$, so $a_A > a_B$.

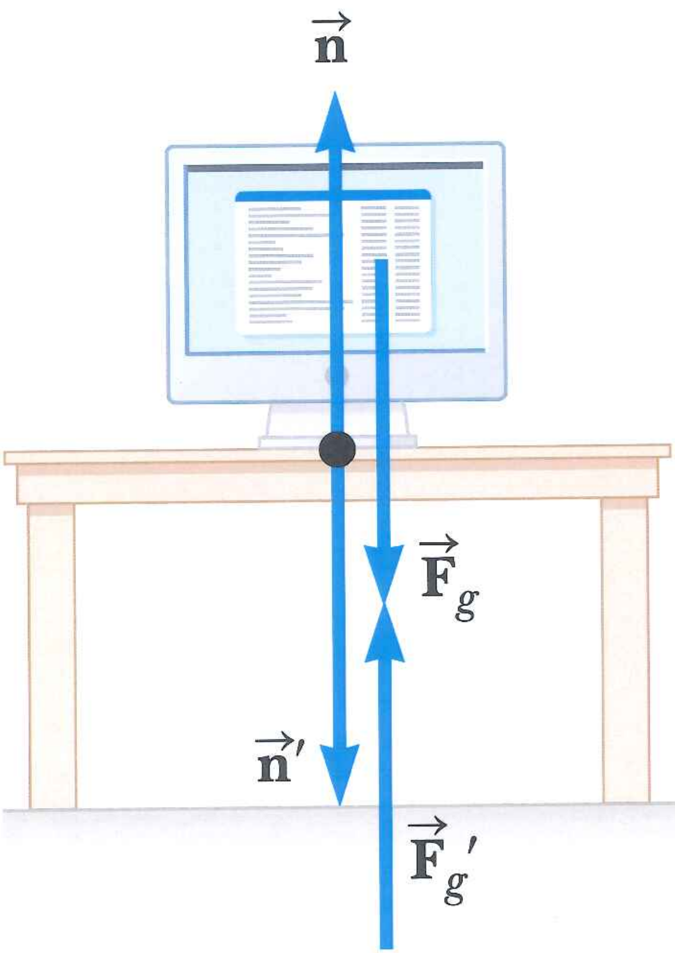
$$\vec{F}_{AB} = -\vec{F}_{BA}$$



(b) Motion after separation

After separation, smaller skater travels faster: $v_A > v_B$.

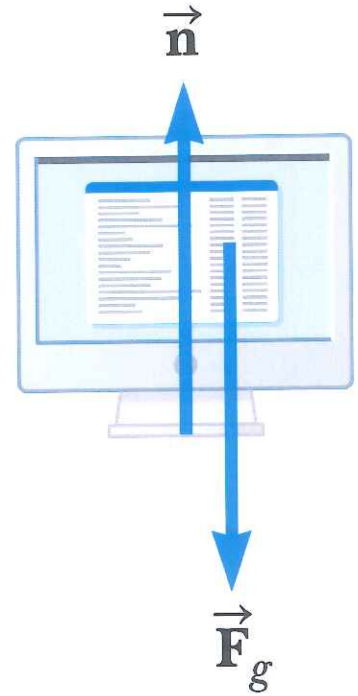
Newton’s Third Law



$$\vec{\mathbf{F}}_g = -\vec{\mathbf{F}}_g' \text{ and } \vec{\mathbf{n}} = -\vec{\mathbf{n}}'$$

$$m\vec{\mathbf{a}} = \vec{\mathbf{F}}_g + \vec{\mathbf{n}}$$

$$Fg = -mg \rightarrow n = mg$$



Think – Pair – Share

A small sports car collides head-on with a massive truck. Which vehicle experiences the greater acceleration?

1. the car
2. the truck
3. The accelerations are the same.

Think – Pair – Share

Which has a greater value, a newton of gold won on Earth or a newton of gold won on the Moon?

1. the newton of gold on the Earth
2. the newton of gold on the Moon
3. The value is the same, regardless.

Think – Pair – Share

True or False? If two identical planets, each with surface gravity g and volume V, coalesce into one planet with volume $2V$, the surface gravity of the new planet is $2g$.