Lecture 11

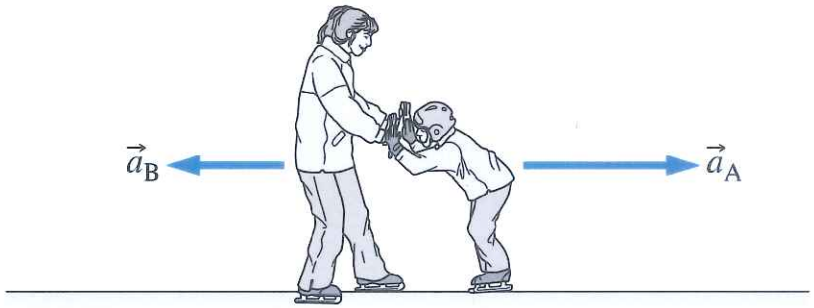
(Ch4:4-5)

Chapter 4:Force and Newton's Laws Summary

Newton's first law: *zero net force implies constant velocity.*

Newton's second law: *Net force is proportional to acceleration.*

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

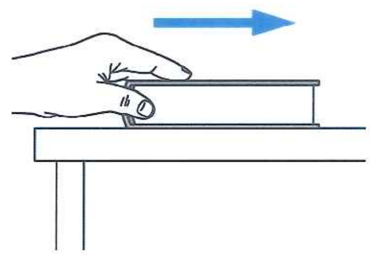


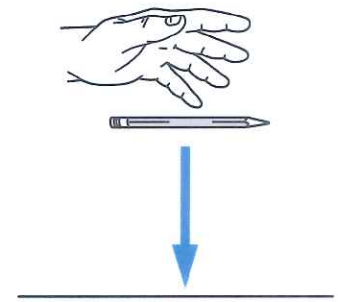
Newton's third law: *Forces between objects come in pairs of equal magnitudes and opposite directions*

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

Chapter 4:Force and Newton's Laws Summary

Force *is an interaction between two objects, such as a pull or push, or action at a distance (electric and magnetic forces).*





Mass *generates inertia and resits to changes of motion.*

Net force: $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \ldots + \vec{F}_n$

F_1, F_2 on 24kg cart so $a = -5.17\frac{m}{s^2}\hat{i} + 2.5\frac{m}{s^2}\hat{j}$

$\vec{F}_1 = 32N(\hat{i}) - 48N\hat{j}$ $F_2 = ?$

49. ORGANIZE AND PLAN We can use Newton's second law to solve this problem. Since this problem involves forces and an acceleration with multiple components, we must be careful when treating the components.

Known: $\vec{F}_1 = 32\text{ N}(\hat{i}) + 48\text{ N}(-\hat{j})$; $\vec{a} = 5.17\text{ m/s}^2(-\hat{i}) + 2.5\text{ m/s}^2(\hat{j})$; $m = 24\ kg$

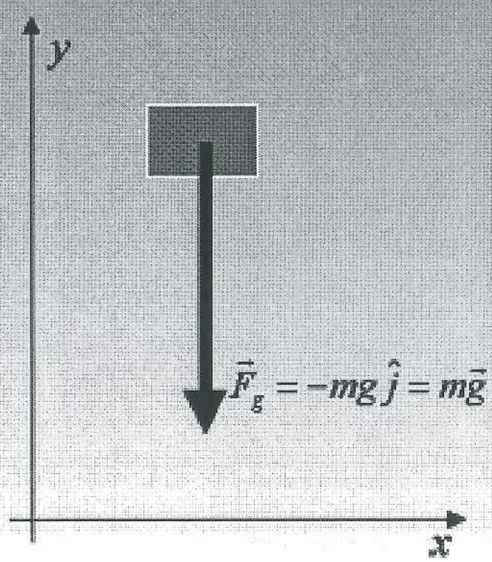
SOLVE Newton's second law gives [Eq. 1]

$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 = m\vec{a}$$

$$\vec{F}_2 = m\vec{a} - \vec{F}_1 = (24\text{ kg})\left[5.17\text{ m/s}^2(-\hat{i}) + 2.5\text{ m/s}^2(\hat{j})\right] - \left[32\text{ N}(\hat{i}) + 48\text{ N}(-\hat{j})\right] = 156\text{ N}(-\hat{i}) + 108\text{ N}(\hat{j})$$

REFLECT Since there were 2 components for the force and the acceleration, care was needed to treat each component individually.

Gravitational Force



$$\vec{g} = -g\,\hat{j}$$

- The gravitational force $\vec{F}_g$ is the attractive force between a mass and another mass.
- $\vec{F}_g$ is directed toward the center of the earth.
- $\vec{F}_g$ results in a downward acceleration of magnitude $g = 9.8\ m/s^2$.
- The gravitational force actually varies with the distance from the center of the earth, but we will usually assume it to be constant.

Figure 4.12

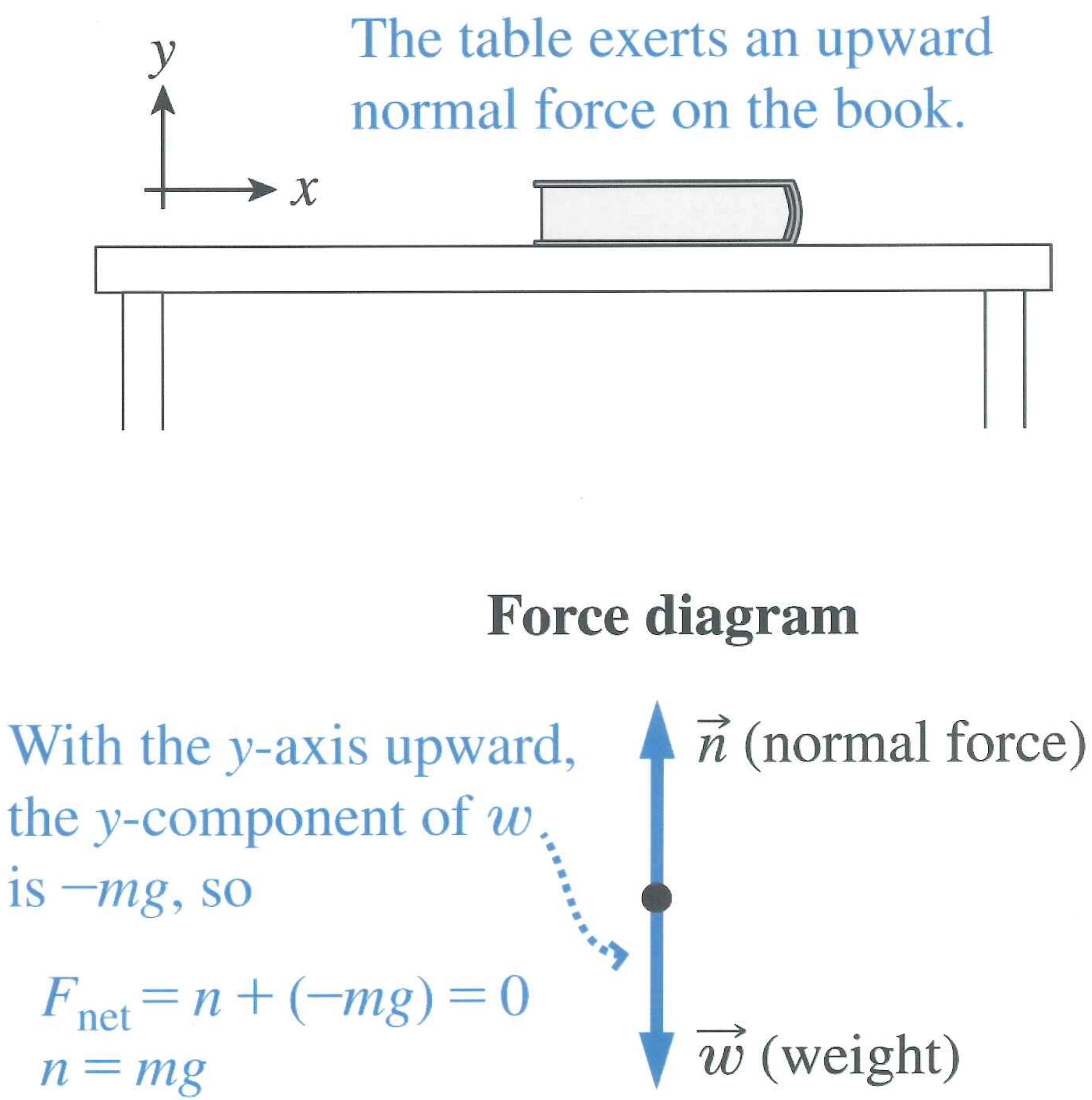
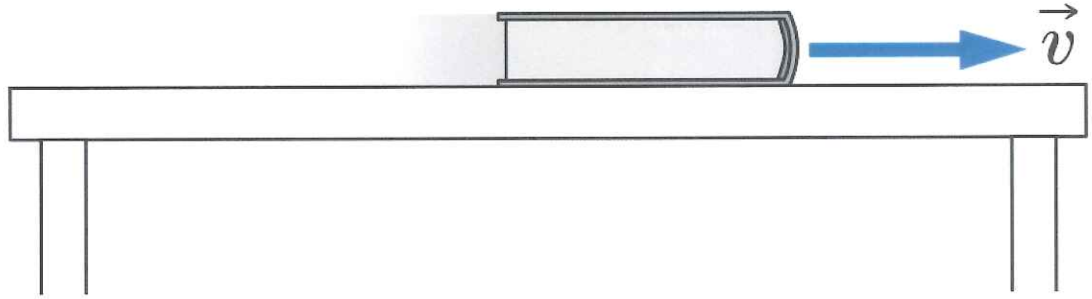

The table exerts an upward normal force on the book.
y
x
Force diagram
With the y-axis upward, the y-component of w is −mg, so
$F_{net} = n + (-mg) = 0$
$n = mg$
$\vec{n}$ (normal force)
$\vec{w}$ (weight)

Figure 4.18

Friction

The sliding book experiences kinetic friction.



Force diagram

The force of kinetic friction is opposite the book's velocity.

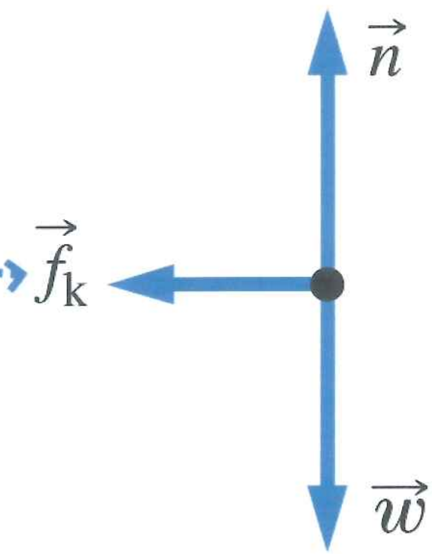
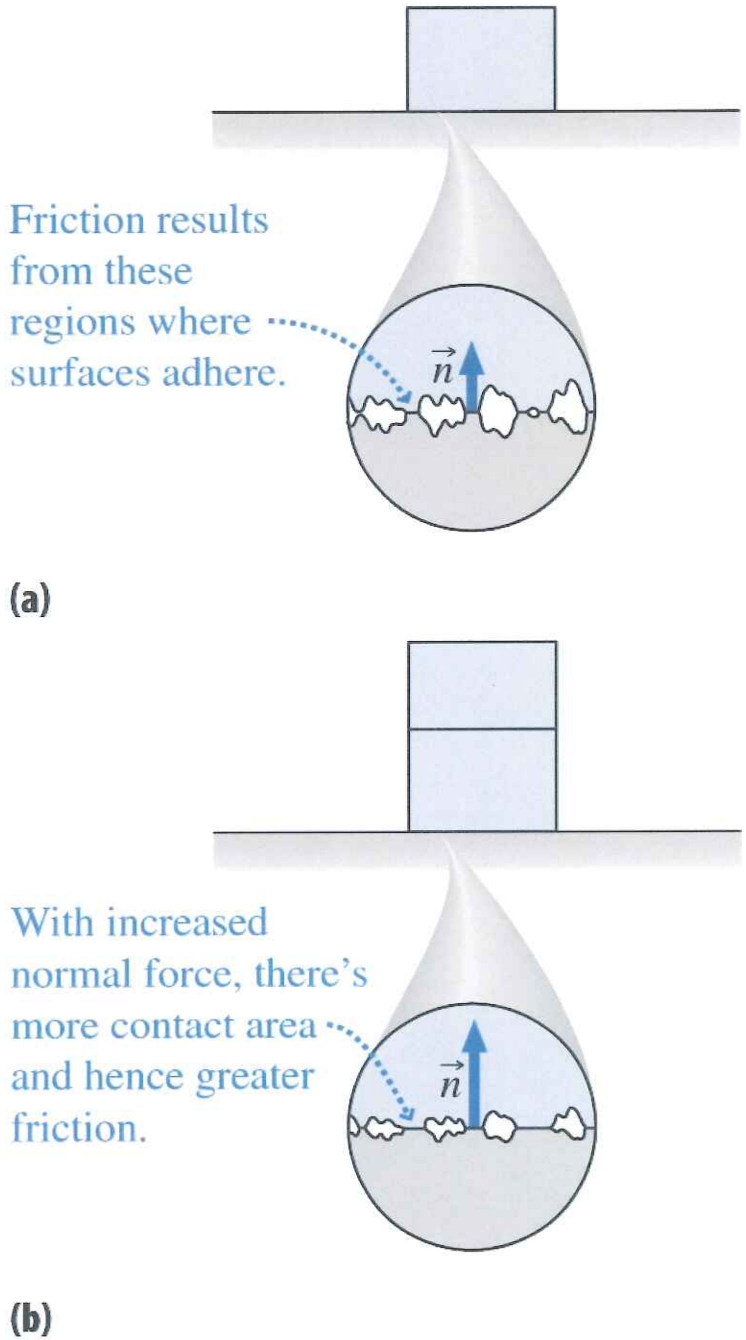


Figure 4.19



Origin of friction

$f_K = \mu_K n$

$n = |\vec{n}|$ normal force

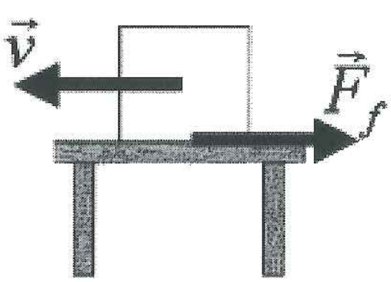
Table 4.1

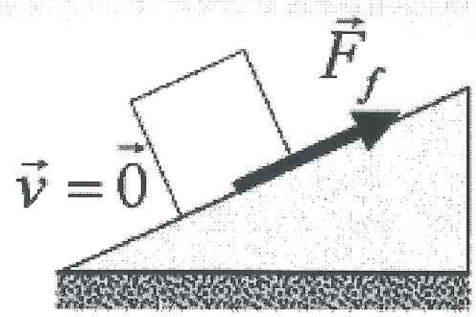
TABLE 4.1 Approximate Coefficients of Friction for Selected Materials

Materials	Coefficient of kinetic friction μ_k	Coefficient of static friction μ_s
Rubber on concrete (dry)	0.80	1.0
Rubber on concrete (wet)	0.25	0.30
Wood on snow (snowboard/ski)	0.06	0.12
Steel on steel (dry)	0.60	0.80
Steel on steel (oiled)	0.05	0.10
Wood on wood	0.20	0.50
Steel on ice (speed skating)	0.006	0.012
Teflon on Teflon	0.04	0.04
Human synovial joints	0.003	0.10

Friction

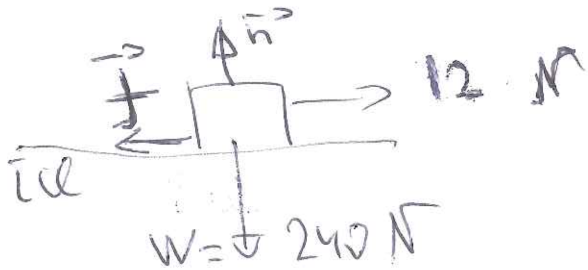
- Friction is a *contact force* which acts between two surfaces in contact.
- The direction of the frictional force is parallel to the surfaces and *opposes relative motion* or imminent relative motion.





4. A forward force of 12 N is used to pull a 240-N sled at constant velocity on a frozen pond. The coefficient of friction is:

1) 0.5
2) 0.05
3) 2
4) 0.2



along $\vec{x}$ →

$12N - f_k = m a = 0$

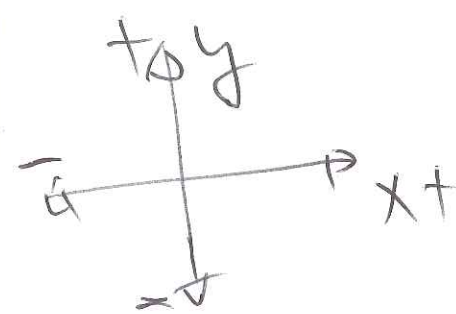
$12N = f_k = \mu_k n$; $|\vec{n}| = |\vec{w}| = 240N$

$= \mu(240N)$

$\frac{12N}{240N} = \mu$

$0.05 = \mu$

along $\vec{y}$ direction



29. A dockworker loading crates on a ship finds that a 20.0-kg crate, initially at rest on a horizontal surface, requires a 75.0-N horizontal force to set it in motion. However, after the crate is in motion, a horizontal force of 60.0 N is required to keep it moving with a constant speed. Find the coefficients of static and kinetic friction between crate and floor.

4.29 When the block is on the verge of moving, the static friction force has a magnitude $f_s = (f_s)_{max} = \mu_s n$.

Since equilibrium still exists and the applied force is 75.0 N, we have

$$\Sigma F_x = 75.0\text{ N} - f_s = 0 \qquad \text{or} \qquad (f_s)_{max} = 75.0\text{ N}$$

In this case, the normal force is just the weight of the crate, or $n = mg$.

Thus, the coefficient of static friction is

$$\mu_s = \frac{(f_s)_{max}}{n} = \frac{(f_s)_{max}}{mg} = \frac{75.0\text{ N}}{(20.0\text{ kg})(9.80\text{ m/s}^2)} = \boxed{0.383}$$

After motion exists, the friction force is that of kinetic friction, $f_k = \mu_k n$.

Since the crate moves with constant velocity when the applied force is 60.0 N, we find that $\Sigma F_x = 60.0\text{ N} - f_k = 0$ or $f_k = 60.0\text{ N}$. Therefore, the coefficient of kinetic friction is

$$\mu_k = \frac{f_k}{n} = \frac{f_k}{mg} = \frac{60.0\text{ N}}{(20.0\text{ kg})(9.80\text{ m/s}^2)} = \boxed{0.306}$$

Chapter 4:Force and Newton's Laws Friction and Drag

- *Friction and Drag are forces that are opposite to the direction of movement.*
- *Friction appears from the interaction between an object and the surface it is traveling on. There are three kinds of friction:*
    - Kinetic friction $\vec{f}_k$
    - Rolling friction $\vec{f}_r$
    - Static friction $\vec{f}_s$
- *Drag appears when an object interacts with the environment surrounding it as it moves; either gas or liquid.*

Drag forces

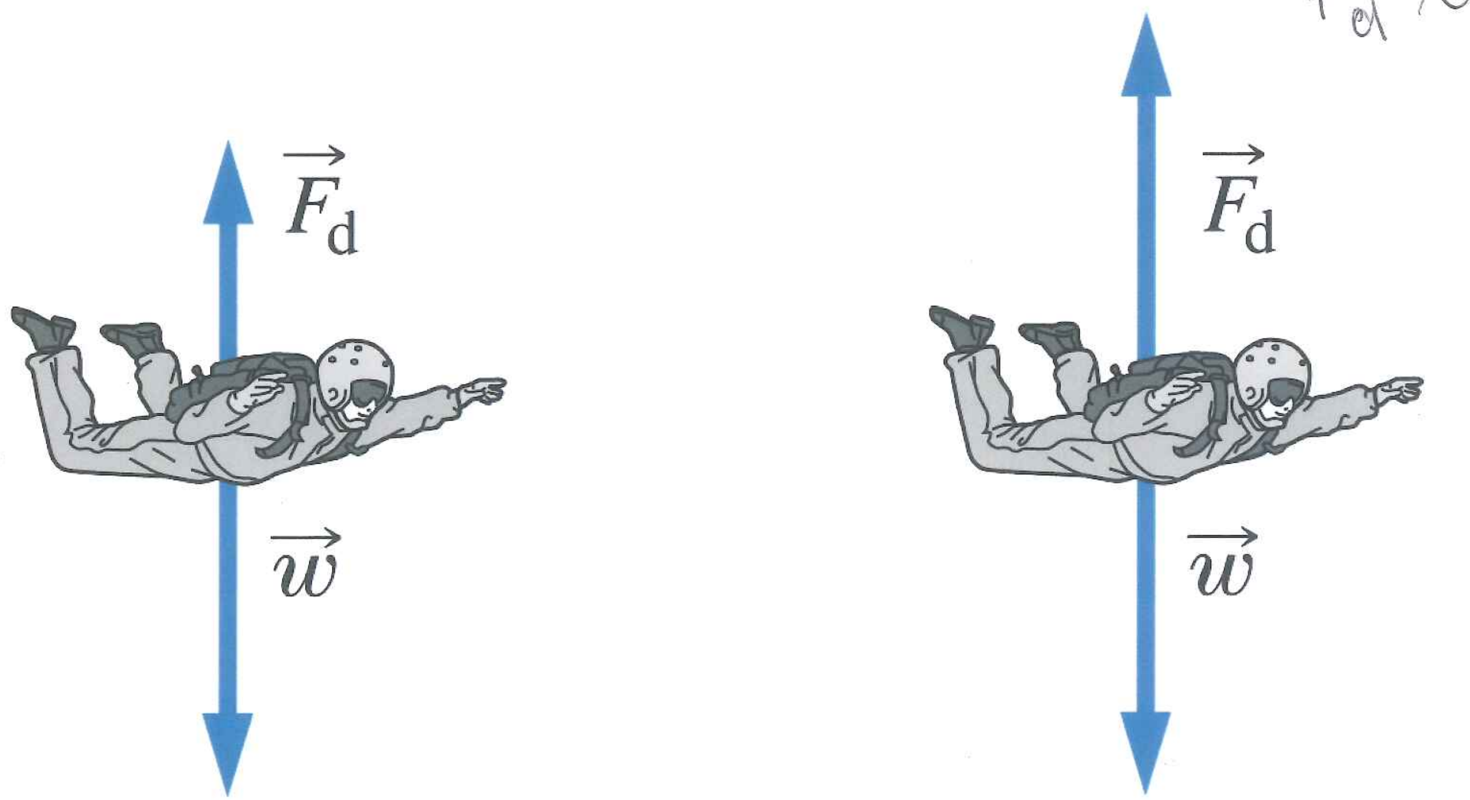
Figure 4.26

Early in fall, upward drag force is less than skydiver's weight, so skydiver accelerates.

Later in fall, drag force equals weight, so skydiver's velocity is constant.

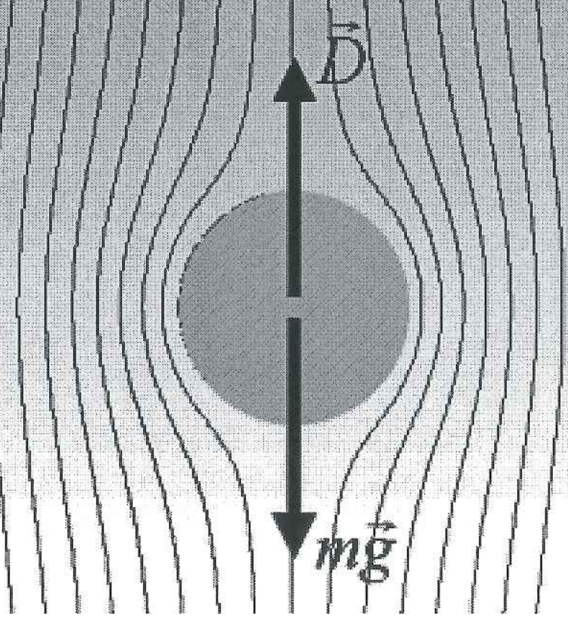
$F_d \sim V^2$ Area

Area



$F_d < w$ $F_d = w$

Drag Force and Terminal Speed



$$D = \tfrac{1}{2} C \rho A v^2$$ $C \sim [0, 1]$

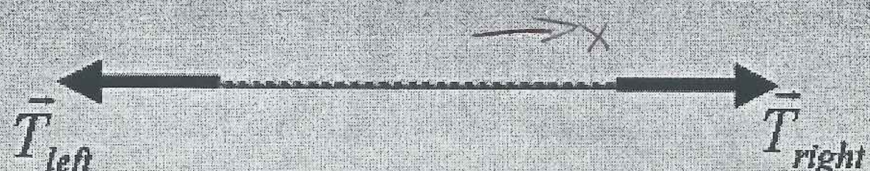
When the drag D balances the gravitational force, a falling body falls at a constant terminal speed: $\vec{D} - \vec{F}_g = m\vec{a}$ ($\vec{a} \to 0$)

$$\tfrac{1}{2} C \rho A v_t^2 - mg = 0$$

$$v_t = \sqrt{\frac{2mg}{C \rho A}}$$

Tension

- Tension is a pulling force which tends to stretch a body.
- For *ideal, massless bodies* ($m = 0$) the tension is constant along the body.



What is the relationship between the tension on the left and the tension on the right of this ideal rope?

$$\vec{T}_{right} - \vec{T}_{left} = ma = (0)a$$

$$\vec{T}_{right} = \vec{T}_{left} = \vec{T}$$

The tensions at the ends of an *ideal, massless* rope are equal.

88. An inventive child wants to reach an apple in a tree without climbing the tree. Sitting in a chair connected to a rope that passes over a frictionless pulley (Fig. P4.88), the child pulls on the loose end of the rope with such a force that the spring scale reads 250 N. The child's true weight is 320 N, and the chair weighs 160 N. The child's feet are not touching the ground.

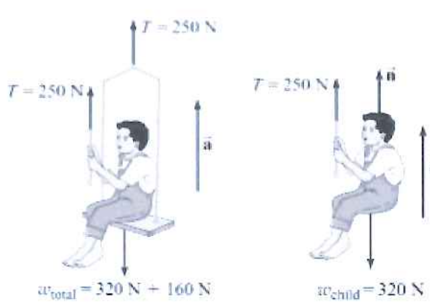
Figure P4.88

a. Show that the acceleration of the system is *upward*, and find its magnitude.

b. Find the force the child exerts on the chair.

4.88 **(a)** Consider the first free-body diagram in which the child and the chair are treated as a combined system. The weight of this system is w_{total} = 480 N, and its mass is

$$m_{total} = \frac{w_{total}}{g} = 49.0\text{ kg}$$



Taking upward as positive, the acceleration of this system is found from Newton's second law as

$$\Sigma F_y = 2T - w_{total} = m_{total} a_y$$

Thus $a_y = \dfrac{2(250\text{ N}) - 480\text{ N}}{49.0\text{ kg}} = +0.408\text{ m/s}^2$ or $\boxed{0.408\text{ m/s}^2\text{ upward}}$.

(b) The downward force that the child exerts on the chair has the same magnitude as the upward normal force exerted on the child by the chair. This is found from the free-body diagram of the child alone as

$$\Sigma F_y = T + n - w_{\text{child}} = m_{\text{child}} a_y \quad \text{so} \quad n = m_{\text{child}} a_y + w_{\text{child}} - T$$

Hence, $$n = \left(\frac{320 \text{ N}}{9.80 \text{ m/s}^2} \right)(0.408 \text{ m/s}^2) + 320 \text{ N} - 250 \text{ N} = \boxed{83.3 \text{ N}}$$

Two-Body Problems: The System Approach

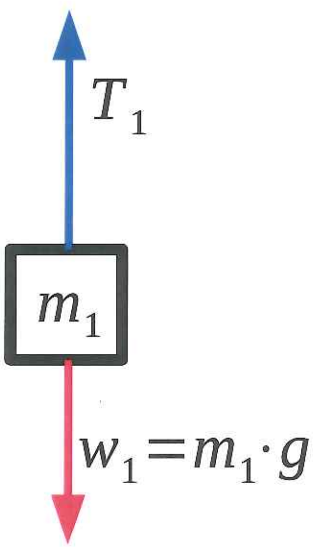
$$\Sigma F_{\text{ext}} = \left(\Sigma m_i\right) a_{\text{sys}}$$

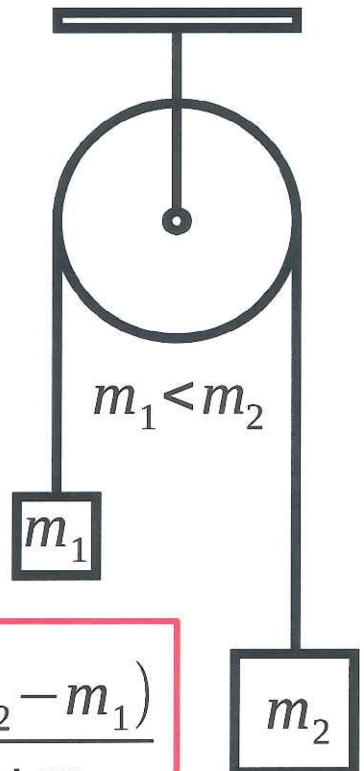
$$F_{\text{ext}} = \text{external forces}$$

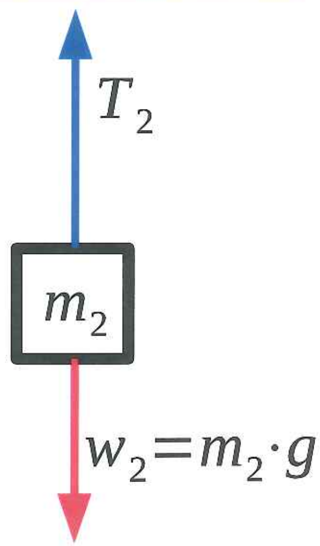
Chapter 4:Force and Newton's Laws

Newton's Second Law – Atwood's Machine

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



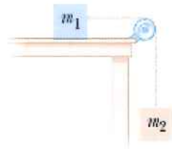




$$F_{net,1} = T - w_1$$
$$F_{net,1} = m_1 \cdot a$$
$$T = m_1 \cdot a + m_1 \cdot g$$

$$a = \frac{g(m_2 - m_1)}{m_1 + m_2}$$

$$F_{net,2} = T - w_2$$
$$F_{net,2} = m_2 \cdot a$$
$$T = m_2 \cdot g - m_2 \cdot a$$



a. the acceleration of each object and

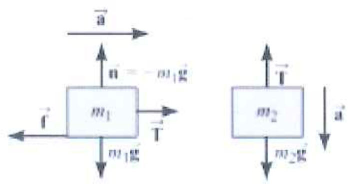
b. the tension in the cable.

65. Objects with masses $m_1 = 10.0$ kg and $m_2 = 5.00$ kg are connected by a light string that passes over a frictionless pulley as in Figure P4.64. If, when the system starts from rest, m_2 falls 1.00 m in 1.20 s, determine the coefficient of kinetic friction between m_1 and the table.

4.65 The acceleration of the system is found from

$$\Delta y = v_{0y}t + \frac{1}{2}at^2, \text{ or } 1.00\text{ m} = 0 + \frac{1}{2}a(1.20\text{ s})^2$$

which gives $a = 1.39\text{ m/s}^2$.



Using the force diagram of m_2, the second law gives

$(5.00\text{ kg})(9.80\text{ m/s}^2) - T(5.00\text{ kg})(1.39\text{ m/s}^2)$ or $T = 42.1$ N.

Then applying the second law to the horizontal motion of m_1,

$42.1\text{ N} - f = (10.0\text{ kg})(1.39\text{ m/s}^2)$ or $f = 28.2$ N.

Because $n = m_1 g = 98.0$ N, we have $\mu_k = \frac{f}{n} = \frac{28.2\text{ N}}{98.0\text{ N}} = \boxed{0.288}$.

84. T On an airplane's takeoff, the combined action of the air around the engines and wings of an airplane exerts an 8 000-N force on the plane, directed upward at an angle of 65.0° above the horizontal. The plane rises with constant velocity in the vertical direction while continuing to accelerate in the horizontal direction.

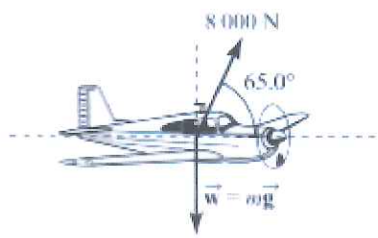
a. What is the weight of the plane?

b. What is its horizontal acceleration?

4.84 **(a)** In the vertical direction, we have

$$\Sigma F_y = (8\,000 \text{ N}) \sin 65.0° - w = ma_y = 0$$

so $$w = (8\,000 \text{ N}) \sin 65.0° = \boxed{7.25 \times 10^3 \text{ N}}$$



(b) Along the horizontal, Newton's second law yields

$$\Sigma F_x = (8\,000 \text{ N})\cos 65.0° = ma_x = \left(\frac{w}{g}a_x\right)$$

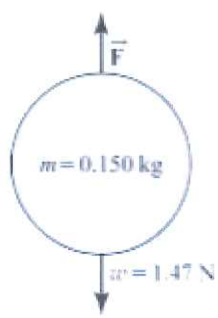
or

$$a_x = \frac{g[(8\,000 \text{ N})\cos 65.0°]}{w} = \frac{(9.80 \text{ m/s}^2)(8\,000 \text{ N})\cos 65.0°}{7.25 \times 10^3 \text{ N}} = \boxed{4.57 \text{ m/s}^2}$$

72. As a protest against the umpire's calls, a baseball pitcher throws a ball straight up into the air at a speed of 20.0 m/s. In the process, he moves his hand through a distance of 1.50 m. If the ball has a mass of 0.150 kg, find the force he exerts on the ball to give it this upward speed.

4.72 The acceleration of the ball is found from

$$a = \frac{v^2 - v_0^2}{2(\Delta y)} = \frac{(20.0\text{ m/s})^2 - 0}{2(1.50\text{ m})} = 133\text{ m/s}^2$$



From the second law, $\Sigma F_y = F - w = ma_y$, so

$$F = w + ma_y = 1.47\text{ N} + (0.150\text{ kg})(133\text{ m/s}^2) = \boxed{21.4\text{ N}}.$$

77. A boy coasts down a hill on a sled, reaching a level surface at the bottom with a speed of 7.00 m/s. If the coefficient of friction between the sled's runners and the snow is 0.050 0 and the boy and sled together weigh 600. N, how far does the sled travel on the level surface before coming to rest?

4.77 On the level surface, the normal force exerted on the sled by the ice equals the total weight, or $n = 600$ N. Thus, the friction force is

$f_k = \mu_k n = (0.050\ 0)(600\ \text{N}) = 30\ \text{N}.$

Hence, Newton's second law yields $\Sigma F_x = -f_k = ma_x$, or

$$a_x = \frac{-f_k}{m} = \frac{-f_k}{w/g} = \frac{-(30\ \text{N})(9.80\ \text{m/s}^2)}{600\ \text{N}} = -0.490\ \text{m/s}^2$$

The distance the sled travels on the level surface before coming to rest is

$$\Delta x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0-(7.00\ \text{m/s})^2}{2(-0.490\ \text{m/s}^2)} = \boxed{50.0\ \text{m}}$$