Phys 103
Chapter 5
The Laws of Motion

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LECTURE 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

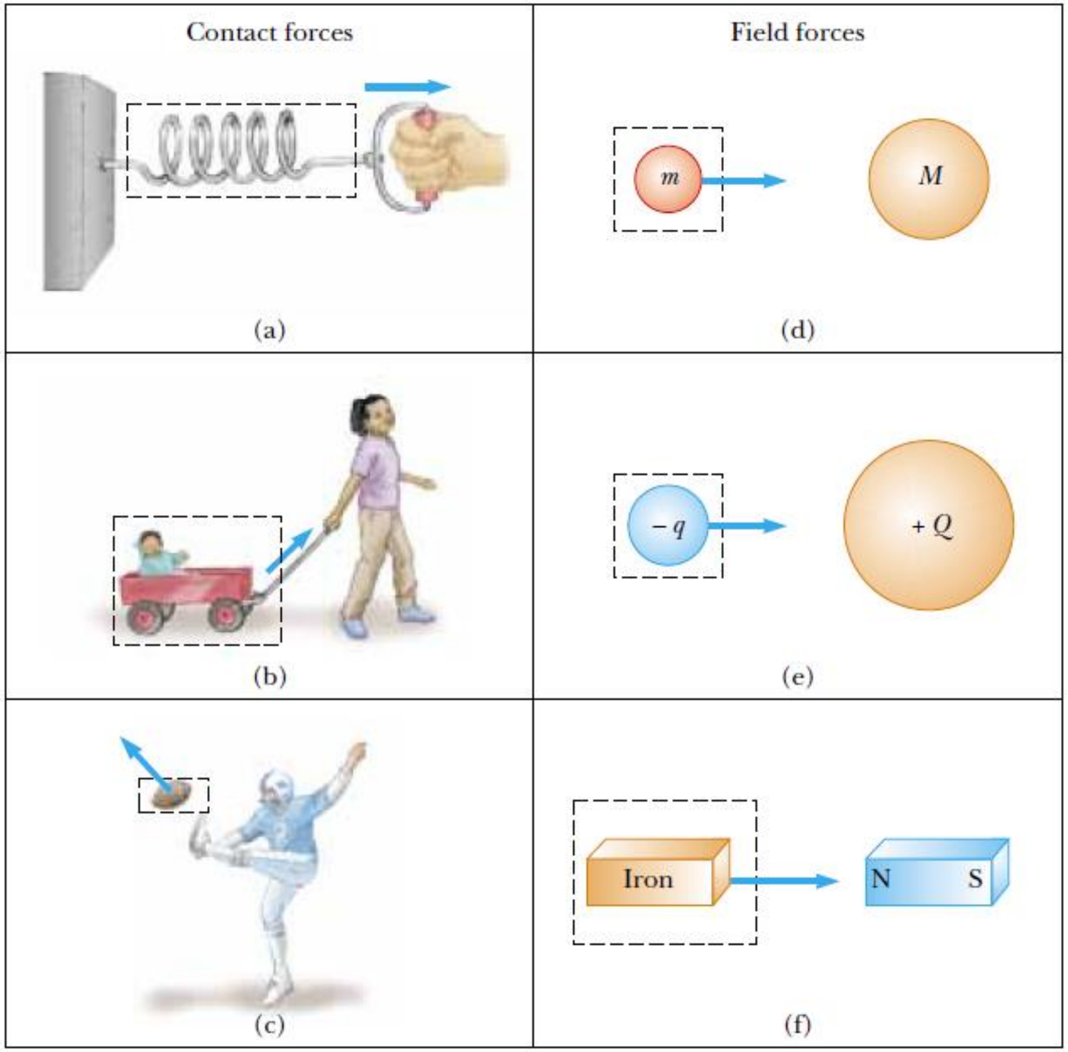
5.8 Forces of Friction

5.1 The Concept of Force

- An object accelerates due to an external force.
- If the net force exerted on an object is zero, the acceleration of the object is zero and its velocity remains constant.
- When the velocity of an object is constant (*including when the object is at rest*), the object is said to be in equilibrium.
- There are 2 types of forces:
  - Contact forces (e.g. when you pull a spring or press it)
  - Field forces (e.g. the force between earth and the moon)
- The only known *fundamental* forces in nature are all field forces: (1) *gravitational forces* between objects, (2) *electromagnetic forces* between electric charges, (3) *nuclear forces* between subatomic particles, and (4) *weak forces* that arise in certain radioactive decay processes.

5.1 The Concept of Force

Examples of Contact and Field forces



Newton’s Laws

Newton's Laws of Motion

1. An object in motion tends to stay in motion and an object at rest tends to stay at rest unless acted upon by an unbalanced force $\sum F = 0$

2. Force equals mass times acceleration $\sum F = ma$

3. For every action there is an equal and opposite reaction

$$F_{12} = -F_{21}$$

Newton's First Law

•*In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity.*

•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.

•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.

» The tendency of an object to resist any attempt to change its velocity is called *inertia*.

5.3 Mass

- **Mass:** is that property of an object that specifies how much resistance an object exhibits to changes in its velocity, the SI unit of mass is the kilogram.
- 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.

5.3 Mass

- Mass should not be confused with **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.

- On the other hand, the mass of an object is the same everywhere: an object having a mass of 2 kg on the Earth also has a mass of 2 kg on the Moon.

Newton's Second Law

Newton's Second Law

- *Acceleration of an object is directly proportional to the force acting on it.*
- In mathematical form: we can write this law as:

$$\sum \boldsymbol{F} = m\boldsymbol{a}$$

$$\sum F_x = ma_x \qquad \sum F_y = ma_y \qquad \sum F_z = ma_z$$

Units of Mass, Acceleration, and Force[a]			
System of Units	**Mass**	**Acceleration**	**Force**
SI	kg	m/s^2	$N = kg \cdot m/s^2$
U.S. customary	slug	ft/s^2	$lb = slug \cdot ft/s^2$

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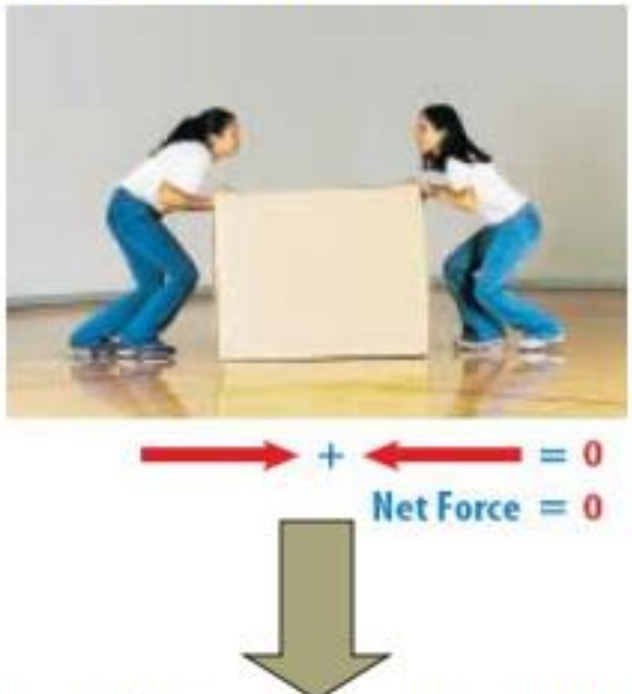
In the U.S. customary system, the unit of force is the **pound**, which is defined as the force that, when acting on a 1-slug mass,[2] produces an acceleration of 1 ft/s^2:

$$1\,\text{lb} \equiv 1\,\text{slug} \cdot \text{ft/s}^2 \tag{5.5}$$

A convenient approximation is that $1\,\text{N} \approx \frac{1}{4}\,\text{lb}$.

The units of mass, acceleration, and force are summarized in Table 5.1.

Balanced Versus Unbalanced



Balanced forces cause no acceleration.

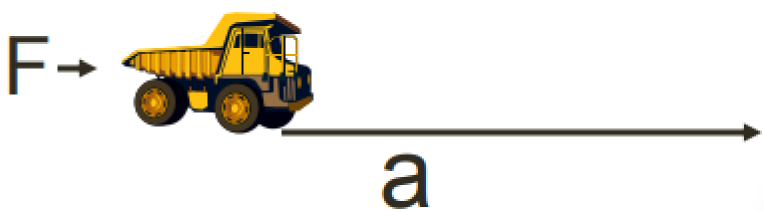
Balanced Versus Unbalanced

Unbalanced forces cause acceleration.

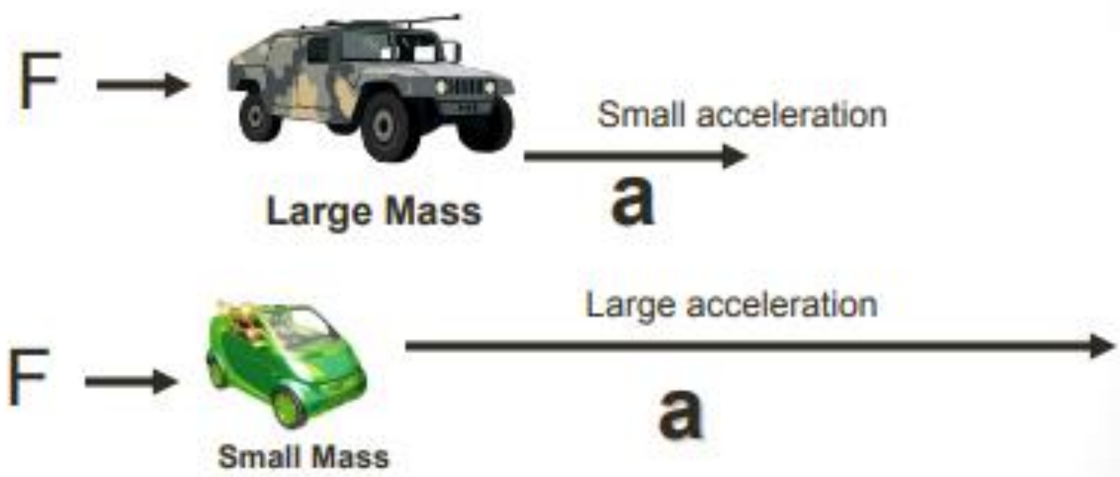
In Other Words…

Small Force ⟶ Small Acceleration

Large Force = Large Acceleration



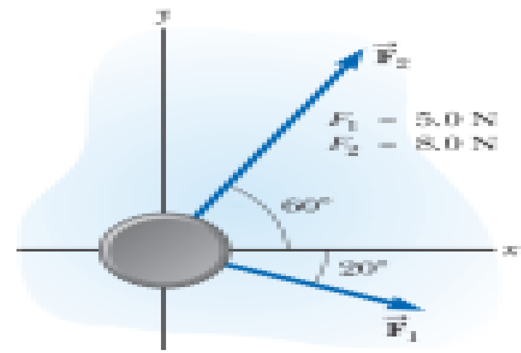
In other words…..using the same amount of force….



Example 5.1 An Accelerating Hockey Puck

AM

A hockey puck having a mass of 0.30 kg slides on the frictionless, horizontal surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting the forces on the puck shown in Figure 5.4. The force $\vec{\mathbf{F}}_1$ has a magnitude of 5.0 N, and is directed at $\theta = 20°$ below the x axis. The force $\vec{\mathbf{F}}_2$ has a magnitude of 8.0 N and its direction is $\phi = 60°$ above the x axis. Determine both the magnitude and the direction of the puck's acceleration.



$$\sum F_x = F_{1x} + F_{2x} = F_1 \cos\theta + F_2 \cos\phi$$

$$\sum F_y = F_{1y} + F_{2y} = F_1 \sin\theta + F_2 \sin\phi$$

$$a_x = \frac{\sum F_x}{m} = \frac{F_1 \cos\theta + F_2 \cos\phi}{m}$$

$$a_y = \frac{\sum F_y}{m} = \frac{F_1 \sin\theta + F_2 \sin\phi}{m}$$

$$a_x = \frac{(5.0\text{ N})\cos(-20°) + (8.0\text{ N})\cos(60°)}{0.30\text{ kg}} = 29\text{ m/s}^2$$

$$a_y = \frac{(5.0\text{ N})\sin(-20°) + (8.0\text{ N})\sin(60°)}{0.30\text{ kg}} = 17\text{ m/s}^2$$

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

$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right) = \tan^{-1}\left(\frac{17}{29}\right) = 31°$$

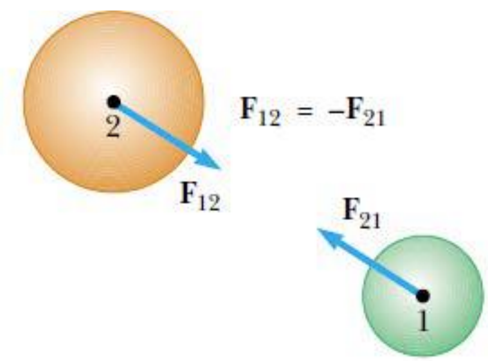
5.5 The Gravitational Force and Weight

- 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,3 and its magnitude is called the weight of the object.
- Using equation (5.2) with ***a***= ***g*** we have:
- Thus: the weight of an object = mg
- Kilogram is Not a Unit of Weight: You may have seen the "conversion" 1 kg = 2.2 lb. Despite popular statements of weights expressed in kilograms, the kilogram *is not a unit of weight*, it is a unit of mass. The conversion statement is not an equality; it is an equivalence that is only valid on the surface of the Earth.

Newton's Third Law

- *If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force F21exerted by object 2 on object 1:*

$$\boldsymbol{F_{12} = -F_{21}}$$



- The action force is equal in magnitude to the reaction force and opposite in direction.

What does this mean?

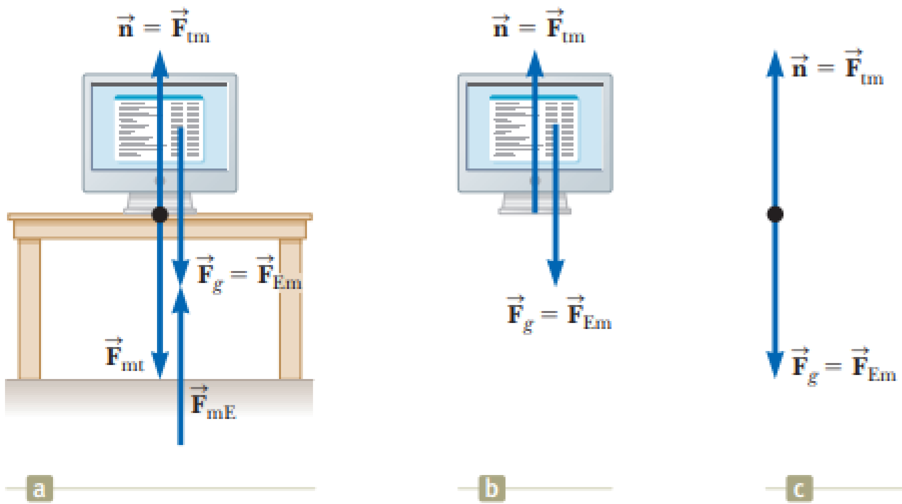
For every force acting on an object, there is an equal force acting in the opposite direction.

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.

Forces and Interactions

When you push on the wall, the wall pushes on you.

Normal force



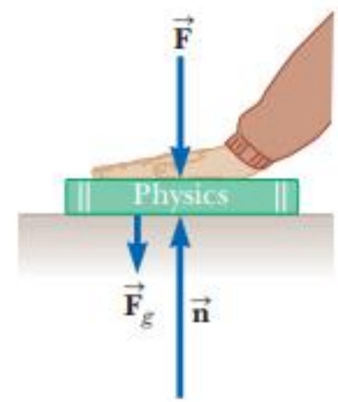


Figure 5.9 When a force $\vec{F}$ pushes vertically downward on another object, the normal force $\vec{n}$ on the object is greater than the gravitational force: $n = F_g + F$.

Newton’s Third Law

Newton’s third law describes the relationship between two forces in an interaction.

- One force is called the **action force.**
- The other force is called the **reaction force.**
- Neither force exists without the other.
- They are equal in strength and opposite in direction.
- They occur at the same time (simultaneously).

5.7 Some Applications of Newton's Laws

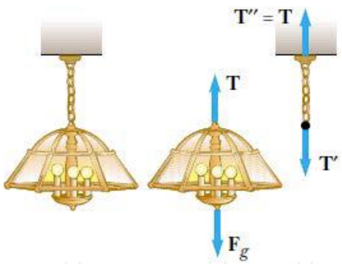
- ***when we apply Newton's laws to an object, we are interested only in external forces that act on the object***
- **Objects in Equilibrium:**
- If the acceleration of an object is zero, the particle is in **equilibrium**

$\sum F_x = 0 \qquad \sum F_y = 0 \qquad \sum F_z = 0$

- For example: a lamp hang by a robe from the ceiling, is in equilibrium because:

$$\sum F_y = T - mg = 0$$

$$ma = 0 \text{ so } a = 0$$



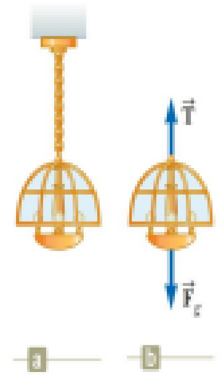
A lamp suspended from a ceiling by a chain of negligible mass balanced Under the effect of two forces **T** and **F**g.

Solving Newton Second Law Problems

- 1.Draw a free body diagram
- 2.Break vectors into components if needed
- 3.Find the NET force by adding and subtracting forces that are on the same axis as the acceleration.
- 4.Set net force equal to “ma” this is called writing an EQUATION OF MOTION.

Examples on free body diagram

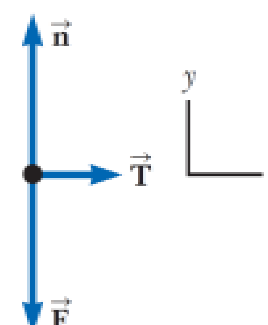
$$\sum F_y = T - F_g = 0 \text{ or } T = F_g$$



$$\sum F_x = T = ma_x$$

$$\sum F_y = n - F_g = 0$$

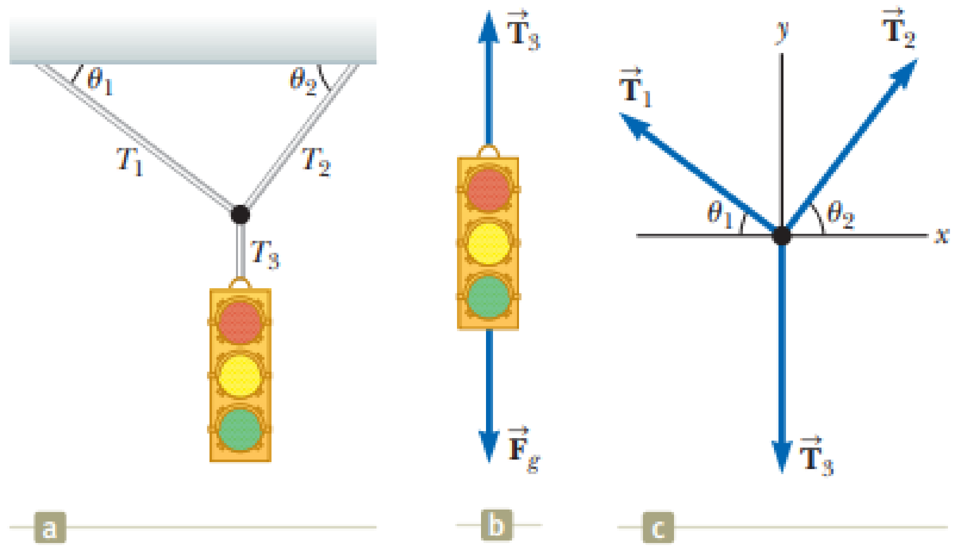
$$n = F_g$$



n is the *normal force*

Example 5.4 A Traffic Light at Rest **AM**

A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support as in Figure 5.10a. The upper cables make angles of $\theta_1 = 37.0°$ and $\theta_2 = 53.0°$ with the horizontal. These upper cables are not as strong as the vertical cable and will break if the tension in them exceeds 100 N. Does the traffic light remain hanging in this situation, or will one of the cables break?



$$\sum F_y = 0 \;\rightarrow\; T_3 - F_g = 0$$
$$T_3 = F_g$$

Force	*x* Component	*y* Component
$\vec{\mathbf{T}}_1$	$-T_1 \cos\theta_1$	$T_1 \sin\theta_1$
$\vec{\mathbf{T}}_2$	$T_2 \cos\theta_2$	$T_2 \sin\theta_2$
$\vec{\mathbf{T}}_3$	0	$-F_g$

$$(1) \quad \sum F_x = -T_1 \cos\theta_1 + T_2 \cos\theta_2 = 0$$
$$(2) \quad \sum F_y = T_1 \sin\theta_1 + T_2 \sin\theta_2 + (-F_g) = 0$$

Solve Equation (1) for T_2 in terms of T_1:
$$(3) \quad T_2 = T_1\left(\frac{\cos\theta_1}{\cos\theta_2}\right)$$

Substitute this value for T_2 into Equation (2):
$$T_1 \sin\theta_1 + T_1\left(\frac{\cos\theta_1}{\cos\theta_2}\right)(\sin\theta_2) - F_g = 0$$

Solve for T_1:
$$T_1 = \frac{F_g}{\sin\theta_1 + \cos\theta_1 \tan\theta_2}$$

Substitute numerical values:
$$T_1 = \frac{122\ \text{N}}{\sin 37.0^\circ + \cos 37.0^\circ \tan 53.0^\circ} = 73.4\ \text{N}$$

Using Equation (3), solve for T_2:
$$T_2 = (73.4\ \text{N})\left(\frac{\cos 37.0^\circ}{\cos 53.0^\circ}\right) = 97.4\ \text{N}$$

Example 5.6 The Runaway Car AM

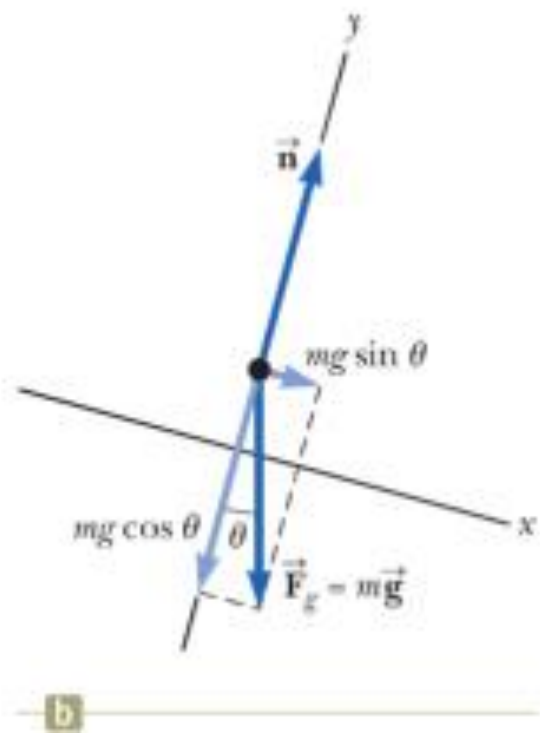
A car of mass m is on an icy driveway inclined at an angle θ as in Figure 5.11a.

(A) Find the acceleration of the car, assuming the driveway is frictionless.

(1) $\sum F_x = mg\sin\theta = ma_x$

(2) $\sum F_y = n - mg\cos\theta = 0$

(3) $a_x = g\sin\theta$



(B) Suppose the car is released from rest at the top of the incline and the distance from the car's front bumper to the bottom of the incline is d. How long does it take the front bumper to reach the bottom of the hill, and what is the car's speed as it arrives there?

$$d = \frac{1}{2}a_x t^2$$

$$(4) \quad t = \sqrt{\frac{2d}{a_x}} = \sqrt{\frac{2d}{g\sin\theta}}$$

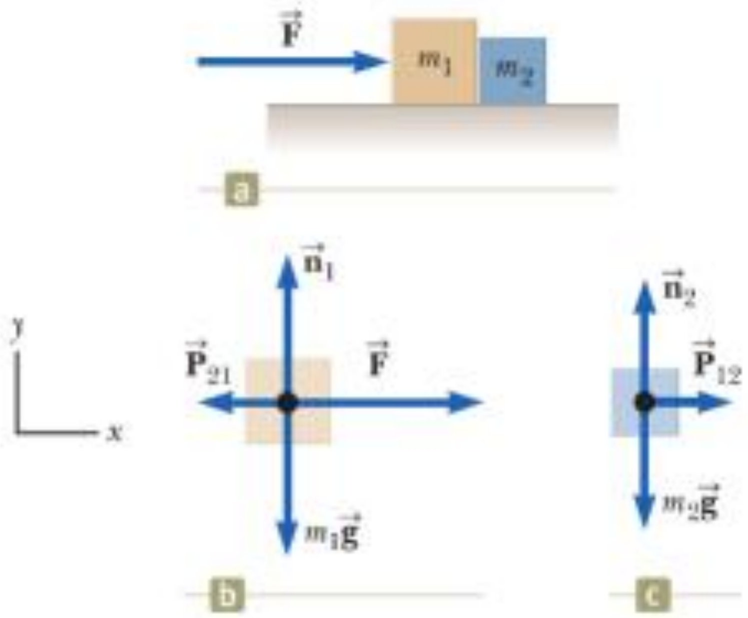
$$v_{xf}^{\,2} = 2a_x d$$

$$(5) \quad v_{xf} = \sqrt{2a_x d} = \sqrt{2gd\sin\theta}$$

Example 5.7 One Block Pushes Another AM

Two blocks of masses m_1 and m_2, with $m_1 > m_2$, are placed in contact with each other on a frictionless, horizontal surface as in Figure 5.12a. A constant horizontal force $\vec{\mathbf{F}}$ is applied to m_1 as shown.

(A) Find the magnitude of the acceleration of the system.



$$\sum F_x = F = (m_1 + m_2)a_x$$

$$(1) \quad a_x = \frac{F}{m_1 + m_2}$$

(B) Determine the magnitude of the contact force between the two blocks.

$$(2) \quad \sum F_x = P_{12} = m_2 a_x$$

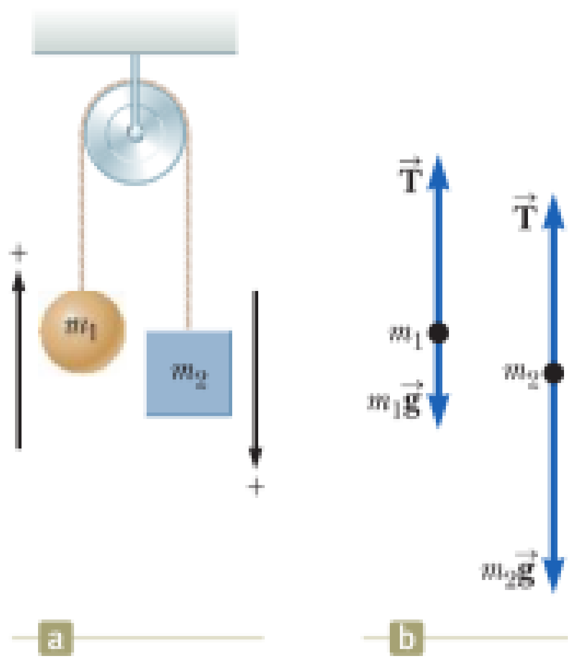
$$(3) \quad P_{12} = m_2 a_x = \left(\frac{m_2}{m_1 + m_2}\right)F$$

$$(4) \quad \sum F_x = F - P_{21} = F - P_{12} = m_1 a_x$$

$$P_{12} = F - m_1 a_x = F - m_1\left(\frac{F}{m_1 + m_2}\right) = \left(\frac{m_2}{m_1 + m_2}\right)F$$

Example 5.9 The Atwood Machine AM

When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass as in Figure 5.14a, the arrangement is called an *Atwood machine*. The device is sometimes used in the laboratory to determine the value of *g*. Determine the magnitude of the acceleration of the two objects and the tension in the lightweight string.



$$(1)\quad \sum F_y = T - m_1 g = m_1 a_y$$

$$(2)\quad \sum F_y = m_2 g - T = m_2 a_y$$

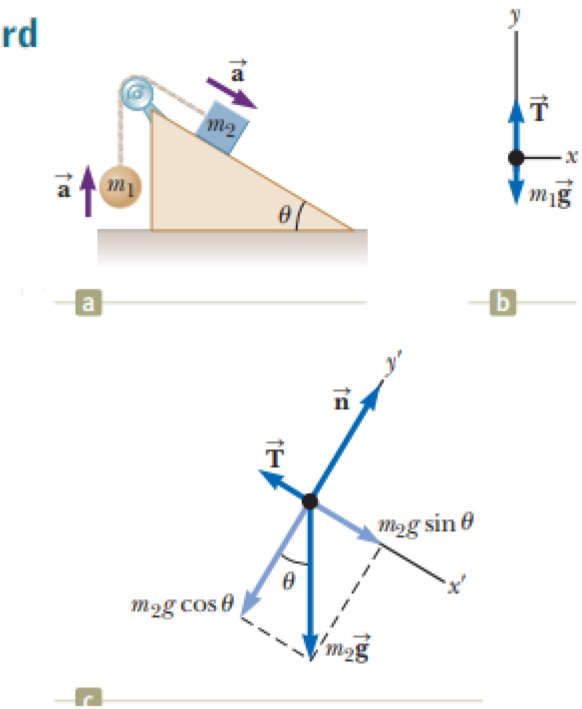
$$-m_1 g + m_2 g = m_1 a_y + m_2 a_y$$

$$(3)\quad a_y = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g$$

$$(4)\quad T = m_1(g + a_y) = \left(\frac{2 m_1 m_2}{m_1 + m_2}\right) g$$

Example 5.10 Acceleration of Two Objects Connected by a Cord

A ball of mass m_1 and a block of mass m_2 are attached by a lightweight cord that passes over a frictionless pulley of negligible mass as in Figure 5.15a. The block lies on a frictionless incline of angle θ. Find the magnitude of the acceleration of the two objects and the tension in the cord.



$$(1)\quad \sum F_y = T - m_1 g = m_1 a_y = m_1 a$$

$$(2)\quad \sum F_{x'} = m_2 g\sin\theta - T = m_2 a_{x'} = m_2 a$$

$$(3)\quad \sum F_{y'} = n - m_2 g\cos\theta = 0$$

In Equation (2), we replaced $a_{x'}$ with a because the two objects have accelerations of equal magnitude a.

Solve Equation (1) for T:

$$(4)\quad T = m_1(g + a)$$

Substitute this expression for T into Equation (2):

$$m_2 g\sin\theta - m_1(g + a) = m_2 a$$

Solve for a:

$$(5)\quad a = \left(\frac{m_2\sin\theta - m_1}{m_1 + m_2}\right)g$$

Substitute this expression for a into Equation (4) to find T:

$$(6)\quad T = \left(\frac{m_1 m_2(\sin\theta + 1)}{m_1 + m_2}\right)g$$

Example 5.8 Weighing a Fish in an Elevator AM

A person weighs a fish of mass m on a spring scale attached to the ceiling of an elevator as illustrated in Figure 5.13.

(A) Show that if the elevator accelerates either upward or downward, the spring scale gives a reading that is different from the weight of the fish.

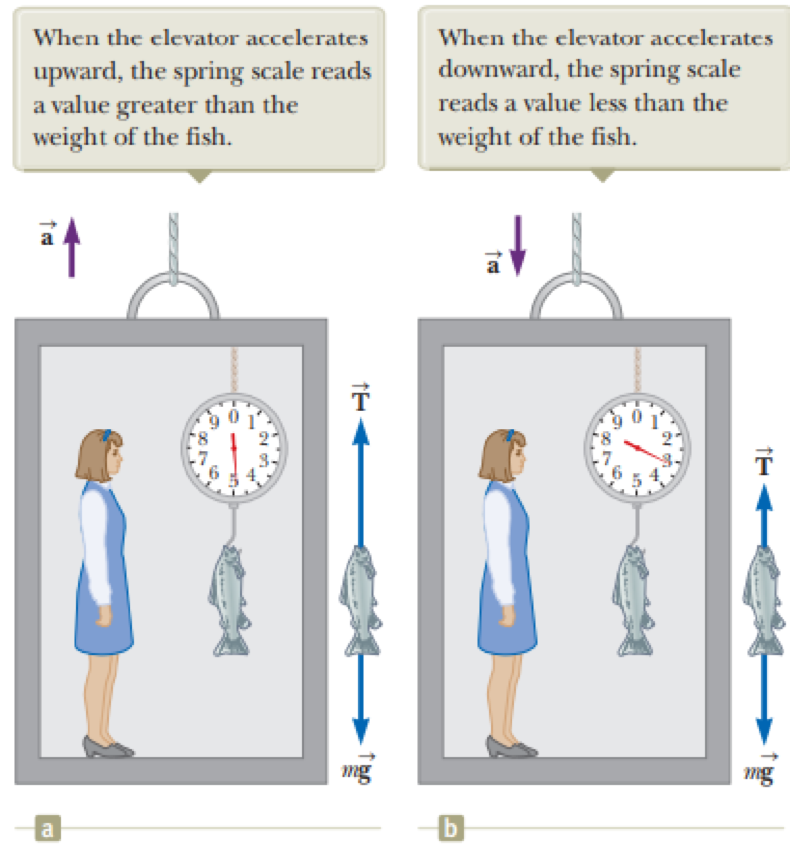
$$\sum F_y = T - mg = ma_y$$

$$(1)\quad T = ma_y + mg = mg\left(\frac{a_y}{g} + 1\right) = F_g\left(\frac{a_y}{g} + 1\right)$$

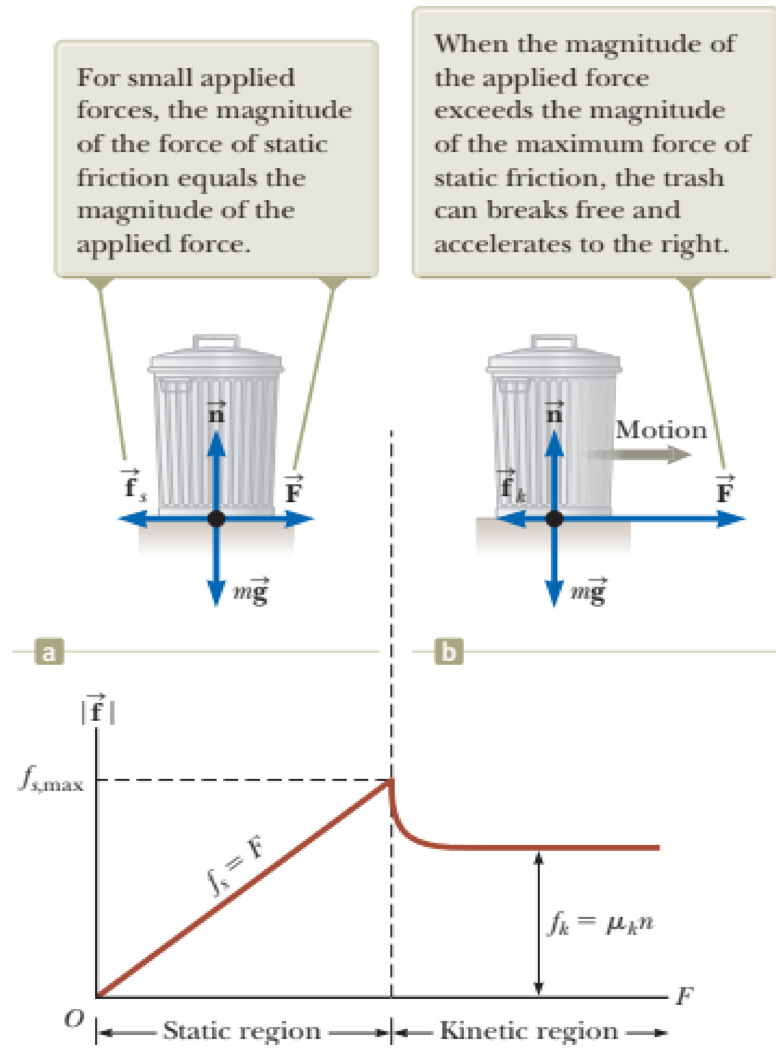
(B) Evaluate the scale readings for a 40.0-N fish if the elevator moves with an acceleration $a_y = \pm 2.00\ \mathrm{m/s^2}$.

$$T = (40.0\ \mathrm{N})\left(\frac{2.00\ \mathrm{m/s^2}}{9.80\ \mathrm{m/s^2}} + 1\right) = 48.2\ \mathrm{N}$$

$$T = (40.0\ \mathrm{N})\left(\frac{-2.00\ \mathrm{m/s^2}}{9.80\ \mathrm{m/s^2}} + 1\right) = 31.8\ \mathrm{N}$$



Forces of Friction



5.8 Forces of Friction

- When an object is in motion either on a surface or in a viscous medium such as air or water, there is resistance to the motion because the object interacts with its surroundings. We call such resistance a ***force of friction***
- There are two types of frictional forces:Static: $\boldsymbol{f_s}$ and kinetic: $\boldsymbol{f_k}$

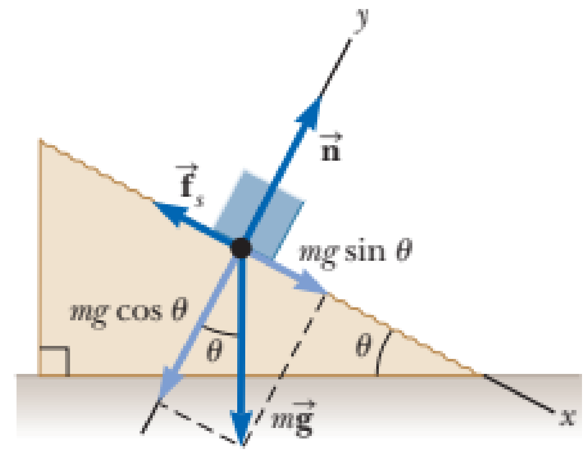
$$\boldsymbol{f_s = \mu_s n}$$

$$\boldsymbol{f_k = \mu_k n}$$

- We define these two types as:
- μ_s is called coefficient of static friction, and $\mu_k$is called coefficient of kentic friction. $\mu_s > \mu_k$, $(0 \leq \mu \leq 1)$
- The direction of the friction force on an object is parallel to the surface with which the object is in contact and ***opposite*** to the actual motion.

Example 5.11 Experimental Determination of μ_s and μ_k AM

The following is a simple method of measuring coefficients of friction. Suppose a block is placed on a rough surface inclined relative to the horizontal as shown in Figure 5.18. The incline angle is increased until the block starts to move. Show that you can obtain μ_s by measuring the critical angle θ_c at which this slipping just occurs.



$$(1)\quad \sum F_x = mg\sin\theta - f_s = 0$$

$$(2)\quad \sum F_y = n - mg\cos\theta = 0$$

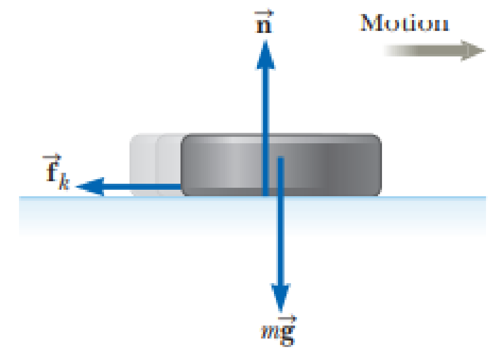
$$(3)\quad f_s = mg\sin\theta = \left(\frac{n}{\cos\theta}\right)\sin\theta = n\tan\theta$$

$$\mu_s n = n\tan\theta_c$$

$$\mu_s = \tan\theta_c$$

Example 5.12 The Sliding Hockey Puck AM

A hockey puck on a frozen pond is given an initial speed of 20.0 m/s. If the puck always remains on the ice and slides 115 m before coming to rest, determine the coefficient of kinetic friction between the puck and ice.



$$(1)\quad \sum F_x = -f_k = ma_x$$

$$(2)\quad \sum F_y = n - mg = 0$$

$$-\mu_k n = -\mu_k mg = ma_x$$

$$a_x = -\mu_k g$$

$$0 = v_{xi}^2 + 2a_x x_f = v_{xi}^2 - 2\mu_k g x_f$$

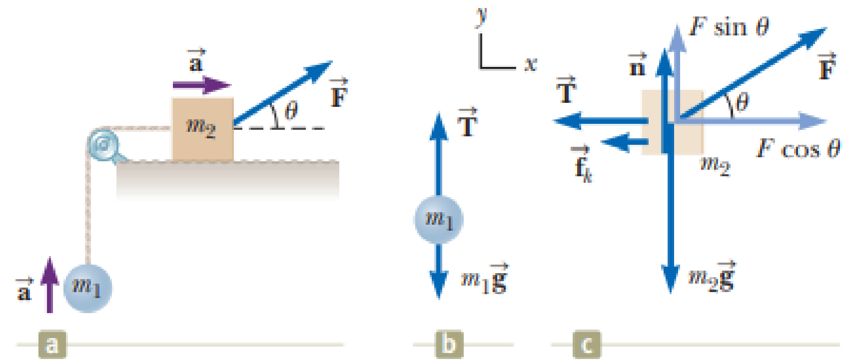
$$\mu_k = \frac{v_{xi}^2}{2gx_f}$$

$$\mu_k = \frac{(20.0\ \mathrm{m/s})^2}{2(9.80\ \mathrm{m/s^2})(115\ \mathrm{m})} = 0.177$$

Example 5.13 Acceleration of Two Connected Objects When Friction Is Present

AM

A block of mass m_2 on a rough, horizontal surface is connected to a ball of mass m_1 by a lightweight cord over a lightweight, frictionless pulley as shown in Figure 5.20a. A force of magnitude F at an angle θ with the horizontal is applied to the block as shown, and the block slides to the right. The coefficient of kinetic friction between the block and surface is μ_k. Determine the magnitude of the acceleration of the two objects.



$$(1) \quad \sum F_x = F\cos\theta - f_k - T = m_2 a_x = m_2 a$$

$$(2) \quad \sum F_y = n + F\sin\theta - m_2 g = 0$$

$$(3) \quad \sum F_y = T - m_1 g = m_1 a_y = m_1 a$$

$$n = m_2 g - F\sin\theta$$

$$(4) \quad f_k = \mu_k(m_2 g - F\sin\theta)$$

$$F\cos\theta - \mu_k(m_2 g - F\sin\theta) - m_1(a + g) = m_2 a$$

$$(5) \quad a = \frac{F(\cos\theta + \mu_k \sin\theta) - (m_1 + \mu_k m_2)g}{m_1 + m_2}$$

PROBLEMS

Sections 5.1 through 5.6

3. A 3.00-kg object undergoes an acceleration given by

a =(2.00ˆi + 5.00ˆj) m/s2.

Find the resultant force acting on it and the magnitude of the resultant force.

SOLUTIONS TO PROBLEM:

$$\sum \boldsymbol{F} = \boldsymbol{ma}$$

$$\left|\sum \boldsymbol{F}\right| = \sqrt{\boldsymbol{F_x}^2 + \boldsymbol{F_y}^2}$$

PROBLEMS

Sections 5.1 through 5.6

7. An electron of mass 9.11 1 10#31 kg has an initial speed of 3.00 1 105 m/s. It travels in a straight line, and its speed increases to 7.00 1 105 m/s in a distance of 5.00 cm. Assuming its acceleration is constant, (a) determine the force exerted on the electron and (b) compare this force with the weight of the electron, which we neglected.

SOLUTIONS TO PROBLEM:

$$\sum \boldsymbol{F} = \boldsymbol{ma}\,, v_f{}^2 = v_i{}^2 + 2ax_f$$

$$F_f = mg$$

PROBLEMS

Sections 5.1 through 5.6

11. Two forces **F**1 and **F**2 act on a 5.00-kg object. If *F*1 = 20.0 N and *F*2 =15.0 N, find the accelerations in (a) and (b) of Figure P5.11.

SOLUTIONS TO PROBLEM:

$\sum \boldsymbol{F} = F_1 + F_2 \,, \quad \sum \boldsymbol{F} = \boldsymbol{ma}$

$\left| \boldsymbol{a} \right| = \sqrt{\boldsymbol{a_x}^2 + \boldsymbol{a_y}^2}.$

$\theta = tan^{-1} \frac{a_y}{a_x}.$

$F_{2x} = 15 \cos 60$

$F_{2y} = 15\, sin\, 60$

$\boldsymbol{F_2} = F_{2x} i + F_{2y} j$

$\sum \boldsymbol{F} = F_1 + F_2 = m\boldsymbol{a}$

$\left| \boldsymbol{a} \right|$ and θ

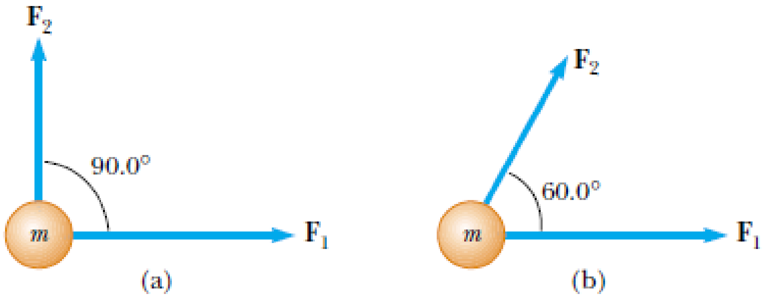


Figure P5.11

PROBLEMS

Section 5.7 Some Applications of Newton's Laws

16. A 3.00-kg object is moving in a plane, with its *x* and *y* coordinates given by $x = 5t^2 - 1$ and $y = 3t^3 + 2$, where *x* and *y* are in meters and *t* is in seconds. Find the magnitude of the net force acting on this object at t = 2.00 s.

SOLUTIONS TO PROBLEM:

$$v_x = \frac{dx}{dt}, v_y = \frac{dy}{dt}$$

$$a_x = \frac{dv_x}{dt}, a_y = \frac{dv_y}{dt}$$

$$\sum F_x = m a_x, \sum F_y = m a_y$$

$$\left| \sum \boldsymbol{F} \right| = \sqrt{\boldsymbol{F_x}^2 + \boldsymbol{F_y}^2}$$

PROBLEMS

Section 5.7 Some Applications of Newton's Laws

18. *A* bag of cement of weight 325 N hangs from three wires as suggested in Figure P5.18. Two of the wires make angles $\theta_1 = 60.0°$ and $\theta_2 = 25.0°$ with the horizontal. If the system is in equilibrium, find the tensions T_1, T_2, and T_3 in the wires.

SOLUTIONS TO PROBLEM:

$T_3 = F_g$

$T_1 \sin\theta_1 + T_2 \sin\theta_2 = F_g$

$T_1 \cos\theta_1 = T_2 \cos\theta_2$

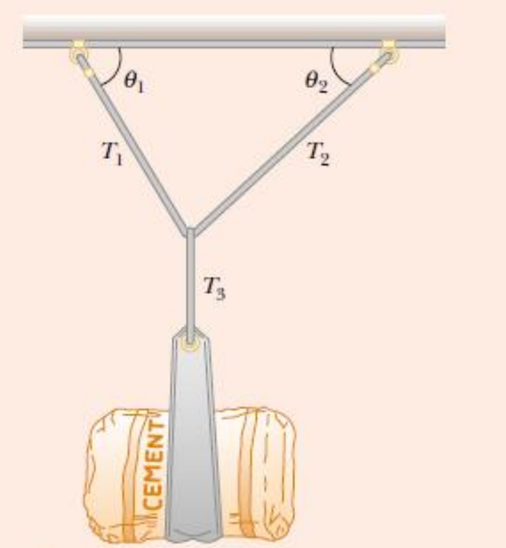


Figure P5.18 Problems 18 and 19.

PROBLEMS

Section 5.7 Some Applications of Newton's Laws

24. A 5.00-kg object placed on a frictionless, horizontal table is connected to a string that passes over a pulley and then is fastened to a hanging 9.00-kg object, as in Figure P5.24. Draw free-body diagrams of both objects. Find the acceleration of the two objects and the tension in the string.

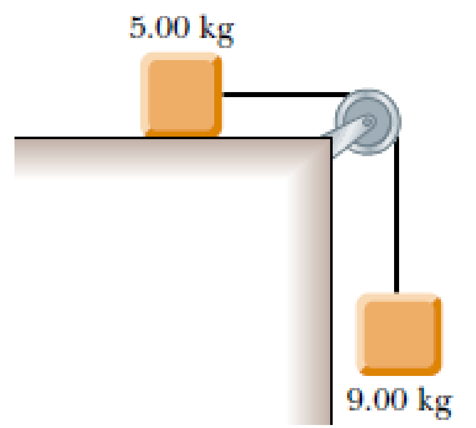


Figure P5.24 Problems 24 and 43.

SOLUTIONS TO PROBLEM:

$$\sum F_x = m a_x, \sum F_y = m a_y$$

88.2N-T=9a

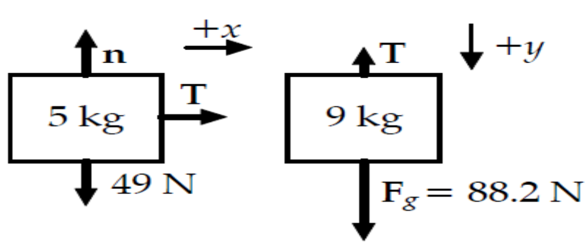


FIG. P5.24

PROBLEMS

Section 5.7 Some Applications of Newton’s Laws

25. A block is given an initial velocity of 5.00 m/s up a frictionless 20.0° incline (Fig. P5.22). How far up the incline does the block slide before coming to rest?

SOLUTIONS TO PROBLEM:

After it leaves your hand, the block’s speed changes onlybecause of one component of its weight:

$$\sum F_x = \boldsymbol{m}a_x - mgsin20 = ma$$

$$v_f{}^2 = v_i{}^2 + 2a(x_f - x_i) taking\ v_f = 0$$

$$x_{f=?}$$

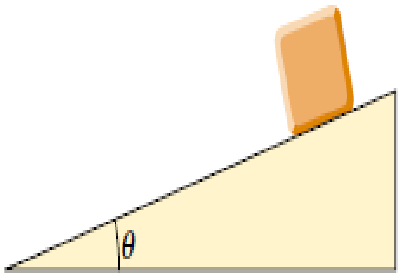


Figure P5.22 Problems 22 and 25.

PROBLEMS

Section 5.7 Some Applications of Newton's Laws

26. Two objects are connected by a light string that passes over a frictionless pulley, as in Figure P5.26. Draw free-body diagrams of both objects. If the incline is frictionless and if m_1 = 2.00 kg, m_2 = 6.00 kg, and θ = 55.0°, find (a) the accelerations of the objects, (b) the tension in the string, and (c) the speed of each object 2.00 s after being released from rest.

SOLUTIONS TO PROBLEM:

$$\sum F_x = m_2 g sin\boldsymbol{\theta} - T = m_2\, a$$

And $T - m_1 g = m_1\, a$

$v_i = 0,\ v_f = at$

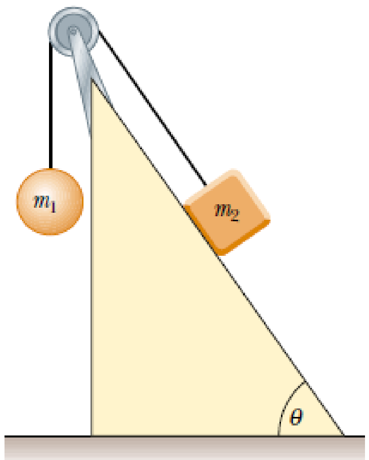
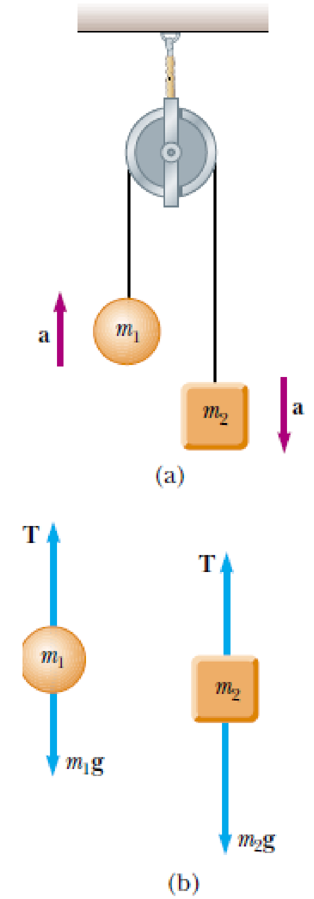


Figure P5.26

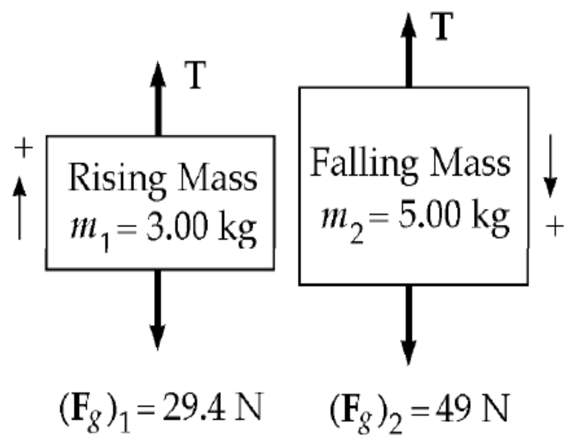
PROBLEMS

Section 5.7 Some Applications of Newton's Laws

28. Two objects with masses of 3.00 kg and 5.00 kg are connected by a light string that passes over a light frictionless pulley to form an Atwood machine, as in Figure 5.14a. Determine (a) the tension in the string, (b) the acceleration of each object, and (c) the distance each object will move in the first second of motion if they start from rest.



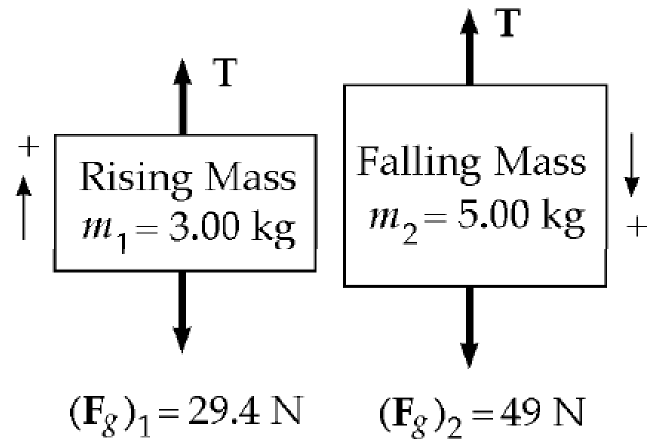
SOLUTIONS TO PROBLEM:



PROBLEMS

Section 5.7 Some Applications of Newton's Laws

28.



SOLUTIONS TO PROBLEM:

First, consider the 3.00 kg rising mass. The forces on it are the tension, *T*, and its weight, 29.4 N. With the upward direction as positive, the second law becomes

$$\sum F_y = ma_y : T - 29 = 3a$$

The forces on the falling 5.00 kg mass are its weight and *T*, and its acceleration is the same as that of the rising mass. Calling the positive direction down for this mass, we have

$$\sum F_y = ma_y : 49 - T = 5a$$

$$y_f = y_i + v_{yi}t + \frac{1}{2}a_y t^2 = \frac{1}{2}a_y t^2$$

PROBLEMS

Section 5.7 Some Applications of Newton's Laws

30. In the Atwood machine shown in Figure 5.14a, m_1 = 2.00 kg and m_2 = 7.00 kg. The masses of the pulley and string are negligible by comparison. The pulley turns without friction and the string does not stretch. The lighter object is released with a sharp push that sets it into motion at v_i = 2.40 m/s downward. (a) How far will m_1 descend below its initial level? (b) Find the velocity of m_1 after 1.80 seconds.

SOLUTIONS TO PROBLEM:

PROBLEMS

Section 5.7 Some Applications of Newton's Laws

31. In the system shown in Figure P5.31, a horizontal force $\mathbf{F}_x$ acts on the 8.00-kg object. The horizontal surface is frictionless.

(a) For what values of F_x does the 2.00-kg object accelerate upward? (b) For what values of F_x is the tension in the cord zero? (c) Plot the acceleration of the 8.00-kg object versus F_x. Include values of F_x from -100 N to +100 N.

SOLUTIONS TO PROBLEM:

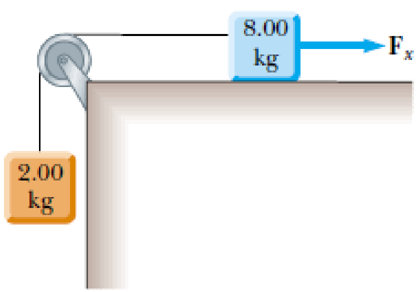


Figure P5.31

PROBLEMS

Section 5.8 Forces of Friction

37. A car is traveling at 50.0 mi/h on a horizontal highway. (a) If the coefficient of static friction between road and tires on a rainy day is 0.100, what is the minimum distance in which the car will stop? (b) What is the stopping distance when the surface is dry and $\mu_s = 0.600$?

SOLUTIONS TO PROBLEM:

PROBLEMS

Section 5.8 Forces of Friction

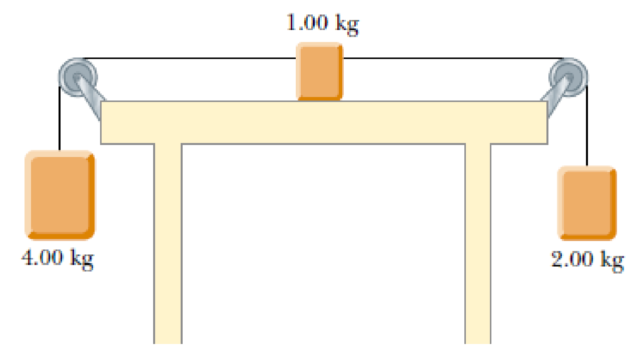
41. A 3.00-kg block starts from rest at the top of a 30.0° incline and slides a distance of 2.00 m down the incline in 1.50 s. Find (a) the magnitude of the acceleration of the block, (b) the coefficient of kinetic friction between block and plane, (c) the friction force acting on the block, and (d) the speed of the block after it has slid 2.00 m.

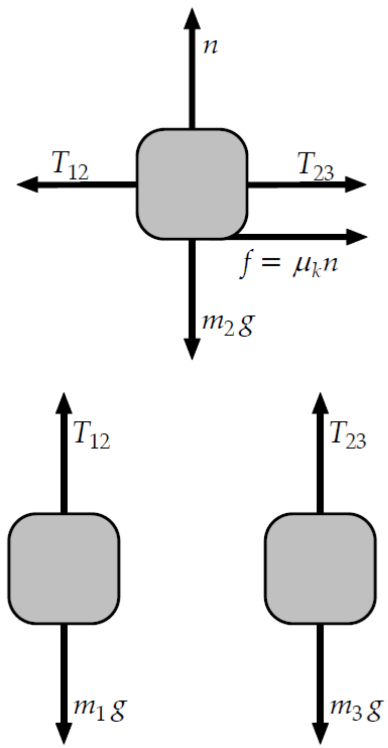
SOLUTIONS TO PROBLEM:

PROBLEMS

Section 5.8 Forces of Friction

44. Three objects are connected on the table as shown in Figure P5.44. The table is rough and has a coefficient of kinetic friction of 0.350. The objects have masses of 4.00 kg, 1.00 kg, and 2.00 kg, as shown, and the pulleys are frictionless. Draw free-body diagrams of each of the objects. (a) Determine the acceleration of each object and their directions. (b) Determine the tensions in the two cords.





SOLUTIONS TO PROBLEM:

PROBLEMS

Section 5.8 Forces of Friction

44.

SOLUTIONS TO PROBLEM:

Let a represent the positive magnitude of the acceleration $-a\hat{\mathbf{j}}$ of m_1, of the acceleration $-a\hat{\mathbf{i}}$ of m_2, and of the acceleration $+a\hat{\mathbf{j}}$ of m_3. Call T_{12} the tension in the left rope and T_{23} the tension in the cord on the right.

For m_1, $\quad \sum F_y = ma_y \quad +T_{12} - m_1 g = -m_1 a$

For m_2, $\quad \sum F_x = ma_x \quad -T_{12} + \mu_k n + T_{23} = -m_2 a$

and $\quad \sum F_y = ma_y \quad n - m_2 g = 0$

for m_3, $\quad \sum F_y = ma_y \quad T_{23} - m_3 g = +m_3 a$

we have three simultaneous equations

$$-T_{12} + 39.2\text{ N} = (4.00\text{ kg})a$$
$$+T_{12} - 0.350(9.80\text{ N}) - T_{23} = (1.00\text{ kg})a$$
$$+T_{23} - 19.6\text{ N} = (2.00\text{ kg})a.$$

PROBLEMS

Section 5.8 Forces of Friction

45. Two blocks connected by a rope of negligible mass are being dragged by a horizontal force **F** (Fig. P5.45). Suppose that F = 68.0 N, $m1$ = 12.0 kg, $m2$ = 18.0 kg, and the coefficient of kinetic friction between each block and the surface is 0.100. (a) Draw a free-body diagram for each block. (b) Determine the tension T and the magnitude of the acceleration of the system.

SOLUTIONS TO PROBLEM:

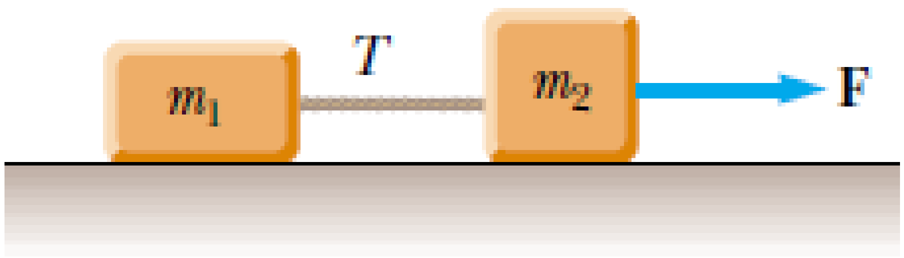


Figure P5.45

PROBLEMS

Section 5.8 Forces of Friction

46. A block of mass 3.00 kg is pushed up against a wall by a force **P** that makes a 50.0° angle with the horizontal as shown in Figure P5.46. The coefficient of static friction between the block and the wall is 0.250. Determine the possible values for the magnitude of **P** that allow the block to remain stationary.

SOLUTIONS TO PROBLEM:

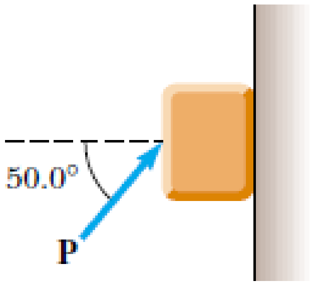


Figure P5.46

PROBLEMS

Additional Problems

58. Review problem. A block of mass m = 2.00 kg is released from rest at h = 0.500 m above the surface of a table, at the top of a θ= 30.0° incline as shown in Figure P5.58. The frictionless incline is fixed on a table of height H = 2.00 m. (a) Determine the acceleration of the block as it slides down the incline. (b) What is the velocity of the block as it leaves the incline? (c) How far from the table will the block hit the floor? (d) How much time has elapsed between when the block is released and when it hits the floor? (e) Does the mass of the block affect any of the above calculations?

SOLUTIONS TO PROBLEM:

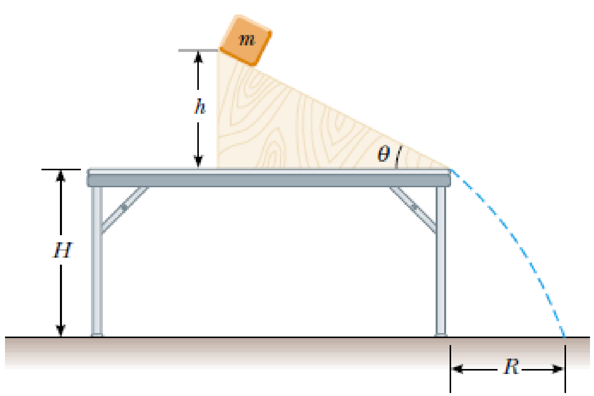


Figure P5.58 Problems 58 and 70.