قوانین حرکت

تا اینجا به مطالعه سینماتیک یعنی بررسی و تشریح حرکات ممکن اجسام مادی بدون توجه به عامل پدید آورنده آنها پرداخته ایم

$x = x(t)$ $v = v(t)$

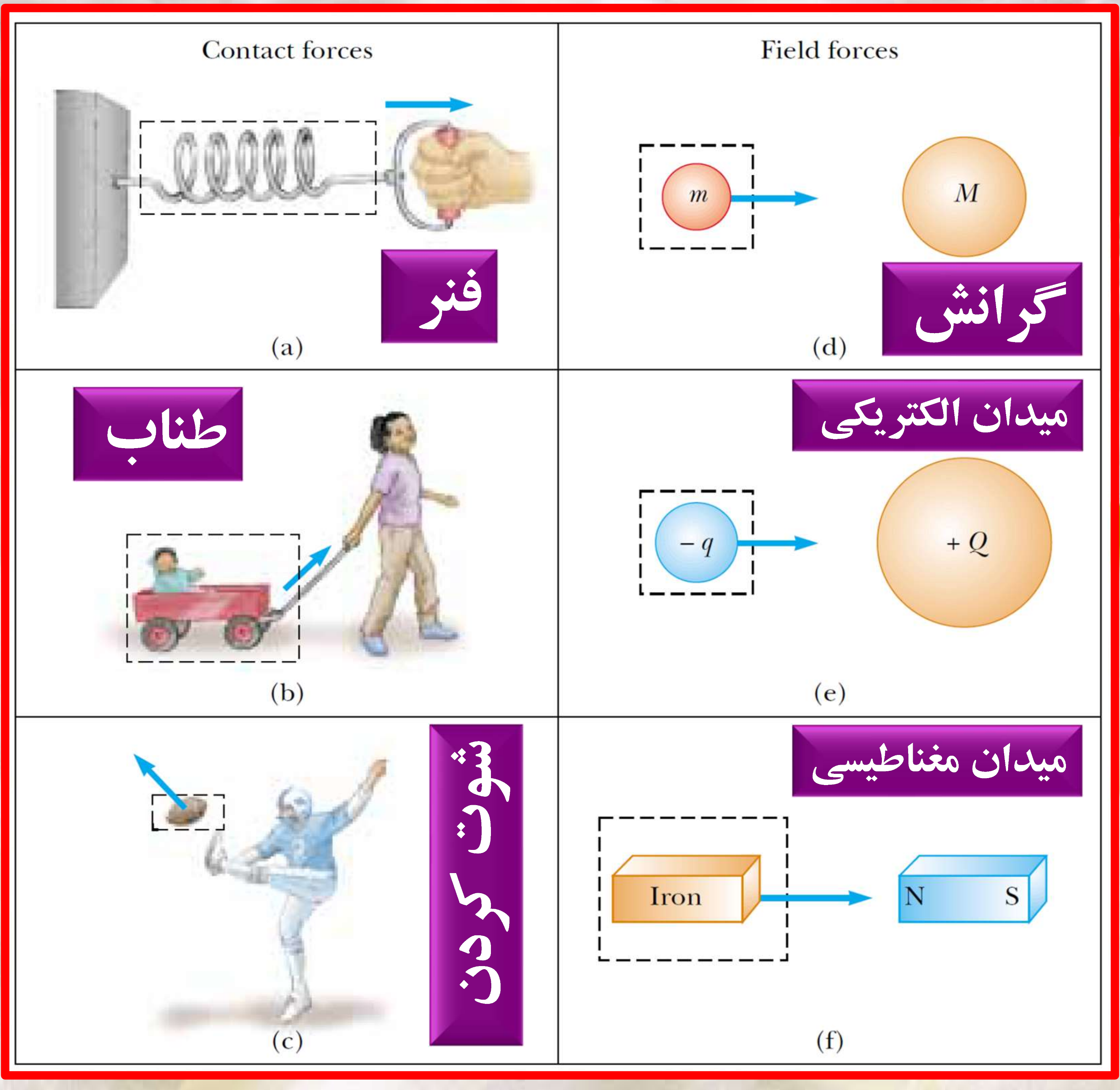
در اینجا به مطالعه دینامیک یعنی بررسی و تشریح حرکات ممکن اجسام مادی با توجه به عامل پدید آورنده آنها (نیروهای وارده) می پردازیم

$F = ma \Rightarrow x = x(t)$ $v = v(t)$

انواع نیروها:

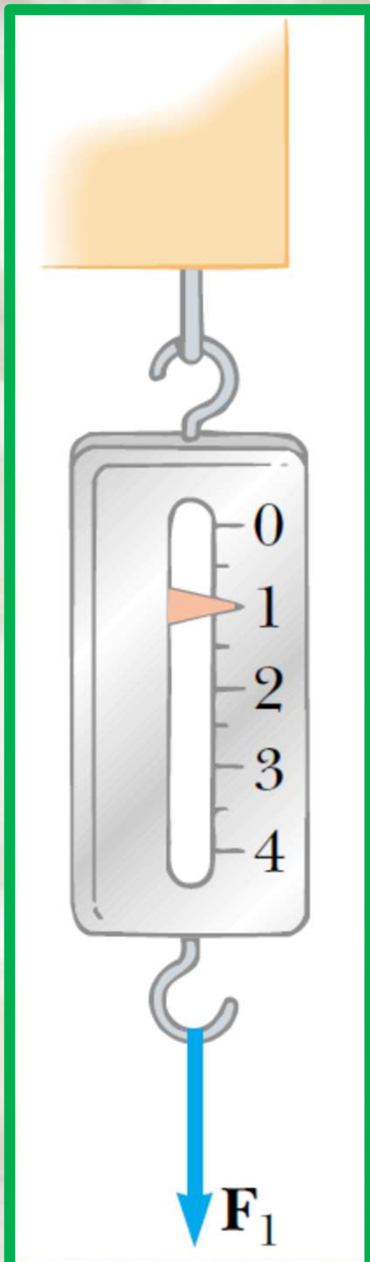
2) نیروهای میدانی:

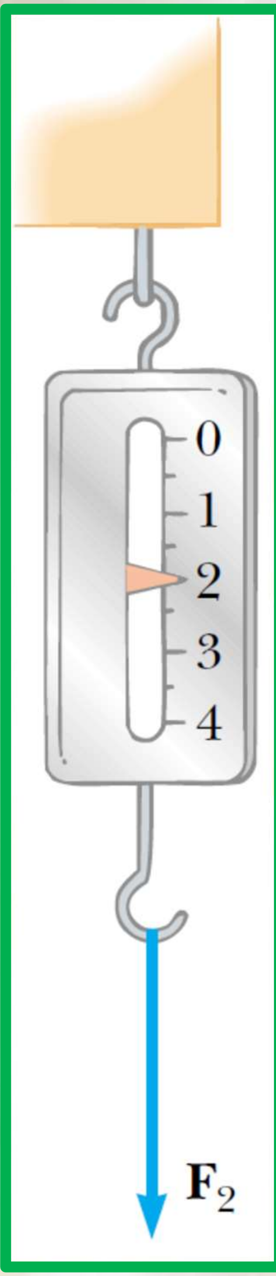
1) نیروهای تماسی:

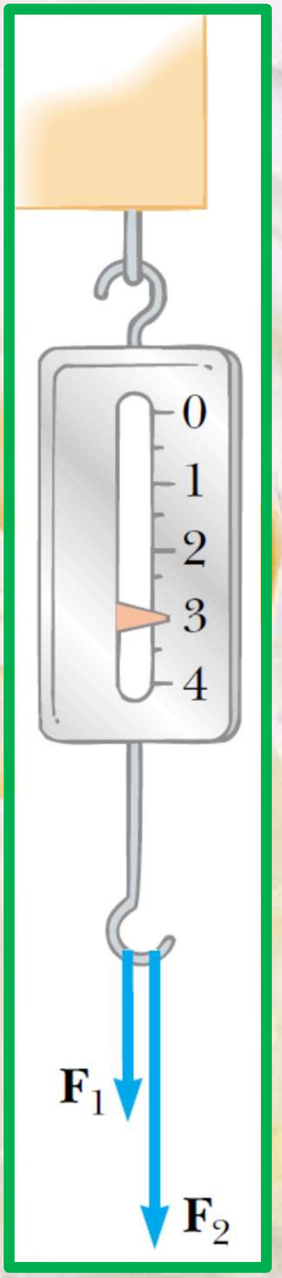


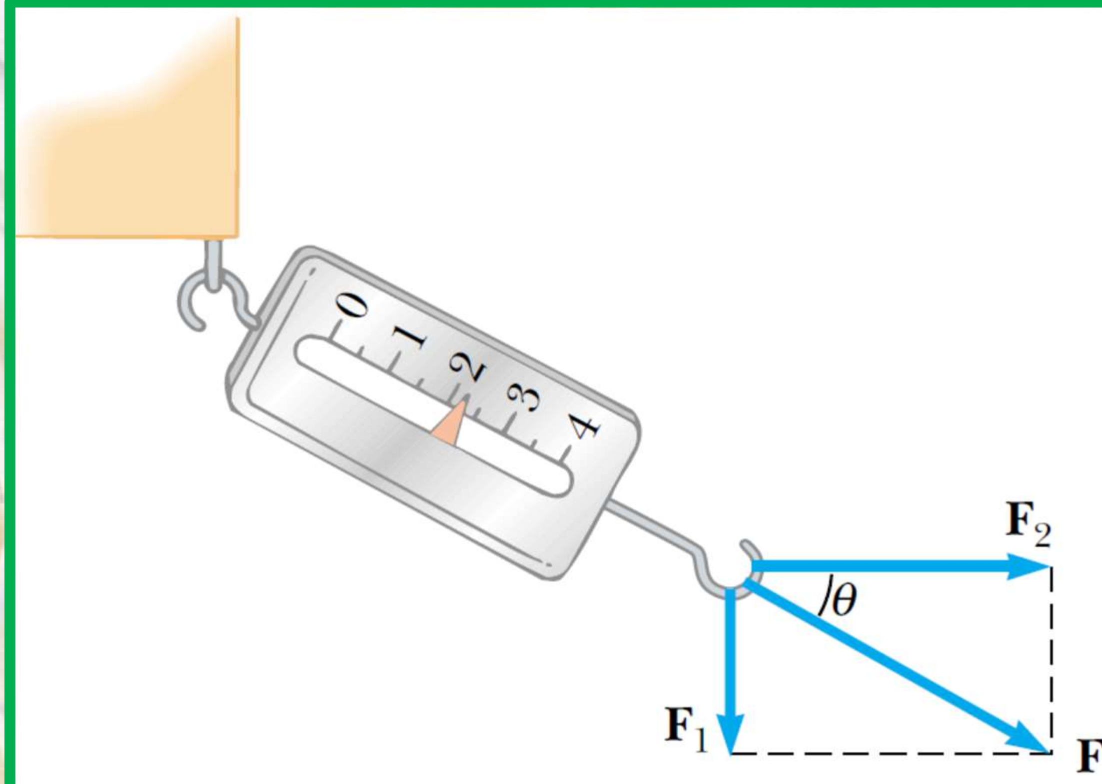
نیروها را چگونه اندازه گیری کنیم؟ به وسیله فنر چرا؟

چون فنرها می توانند به طور خطی با نیرو طبق قانون هوک افزایش یابند









آیا نیرو یک کمیت برداری است؟ بله

چرا؟ چون از قاعده جمع بردارها مطابق شکل پیروی می کنند

قوانین حرکت نیوتن

1) هر جسم حالت سکون یا حرکت یکنواخت خود را بر روی یک خط راست حفظ می کند مگر آن که تحت تاثیر نیروهای خارجی وارد بر آن مجبور به تغییر حالت خود گردد

2) میزان تغییر اندازه حرکت یک جسم بر حسب زمان با نیروی وارد بر آن متناسب و با آن همجهت است

$$\vec{p} = p_x\hat{\imath} + p_y\hat{\jmath} + p_z\hat{k}$$

$$\frac{d\vec{p}}{dt} = \vec{F}$$

$$p_x = mv_x \qquad p_y = mv_y \qquad p_z = mv_z$$

3) هر عملی همواره با عکس العملی مساوی و در جهت مخالف روبه رو است

جرم گرانشی و جرم اینرسی

$$F = m_G g$$

جرم گرانشی

جرم اینرسی

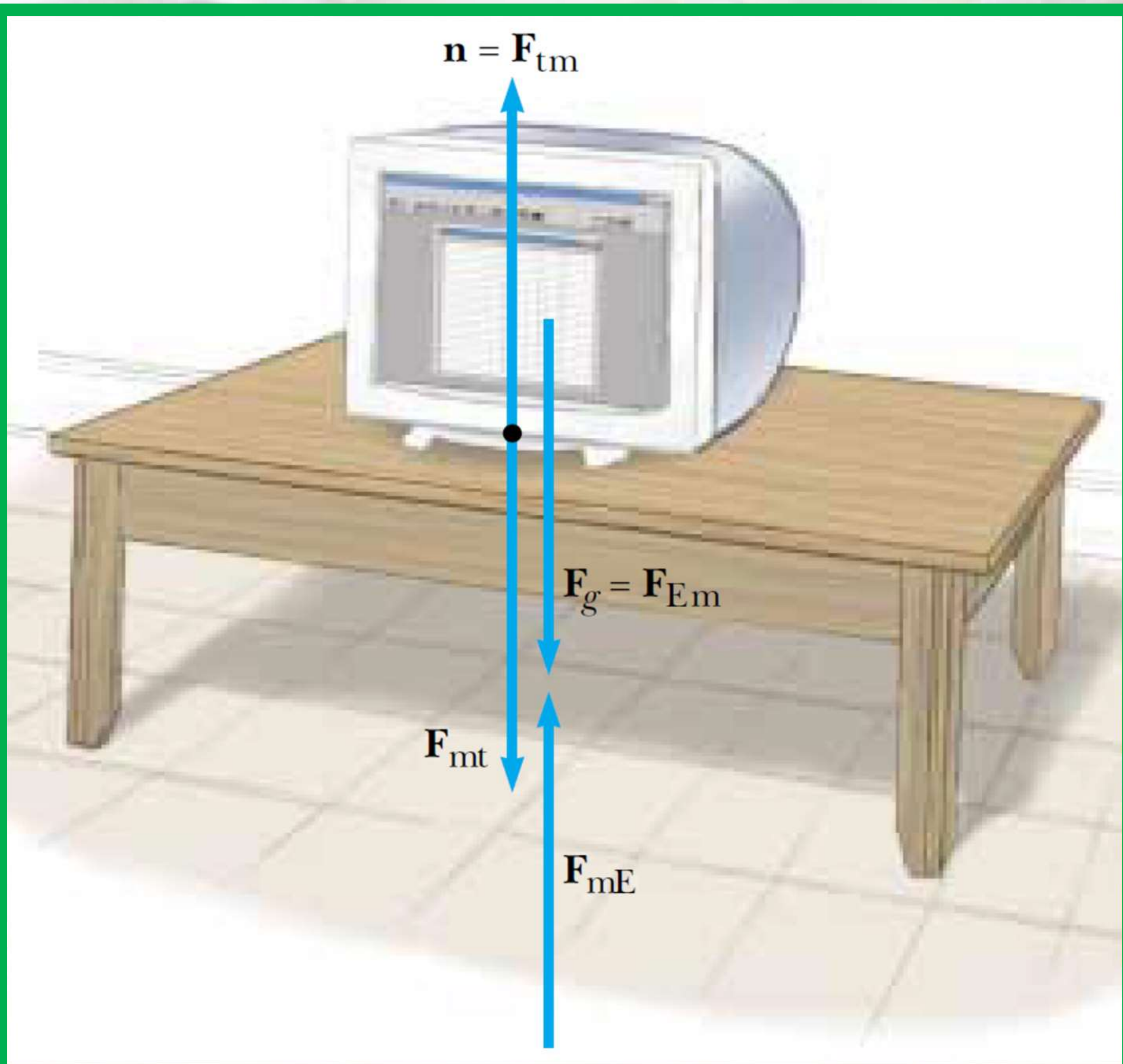
$$F = m_I a$$

$$m_I = m_G$$

قوانین حرکت نیوتن در یک نگاه

1) Inertial frames exist
2) $\mathbf{F} = m\mathbf{a}$
3) $\mathbf{F}_{12} = -\mathbf{F}_{21}$

نیروی عمود بر سطح



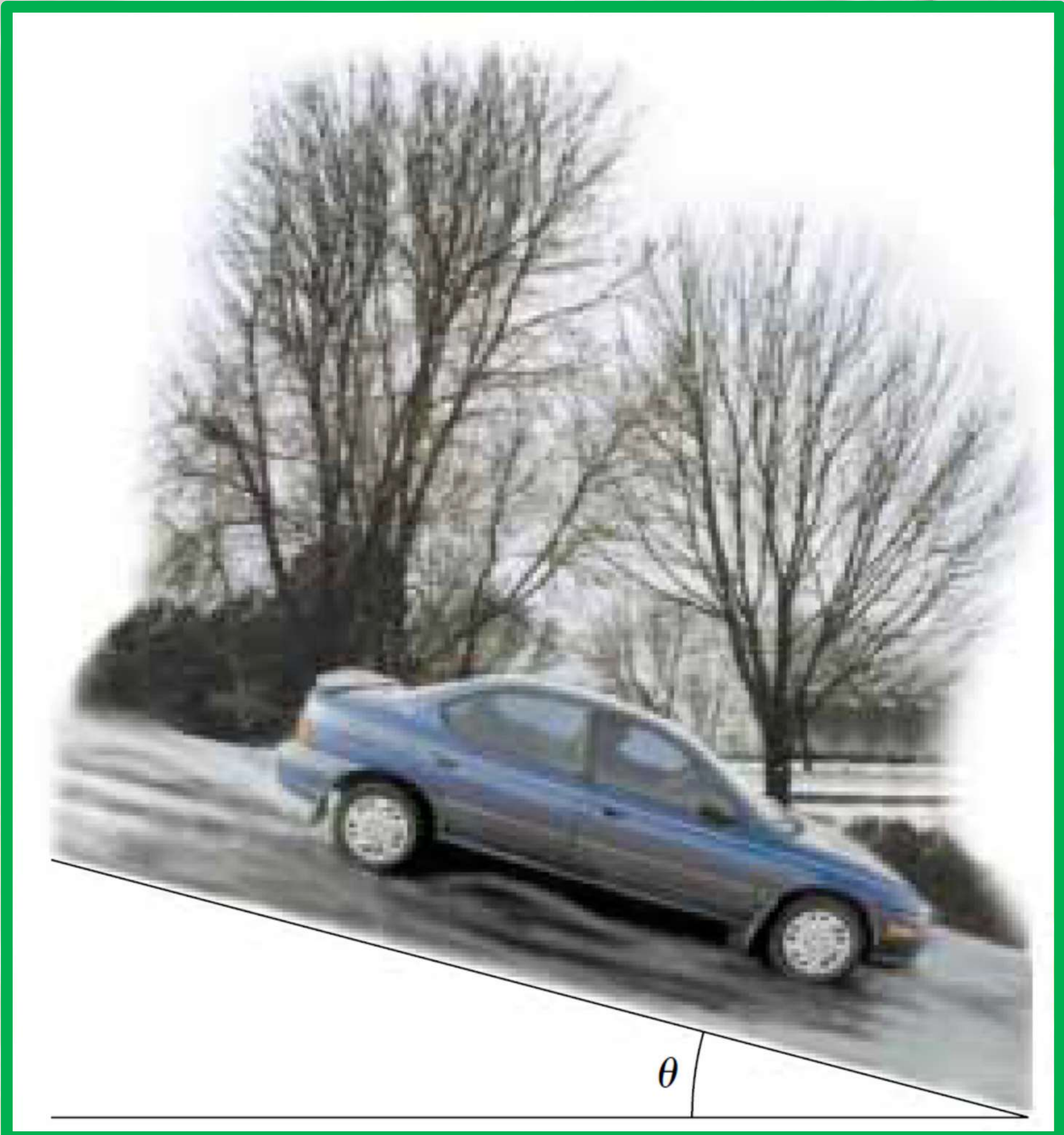
$$n + F_g = 0$$

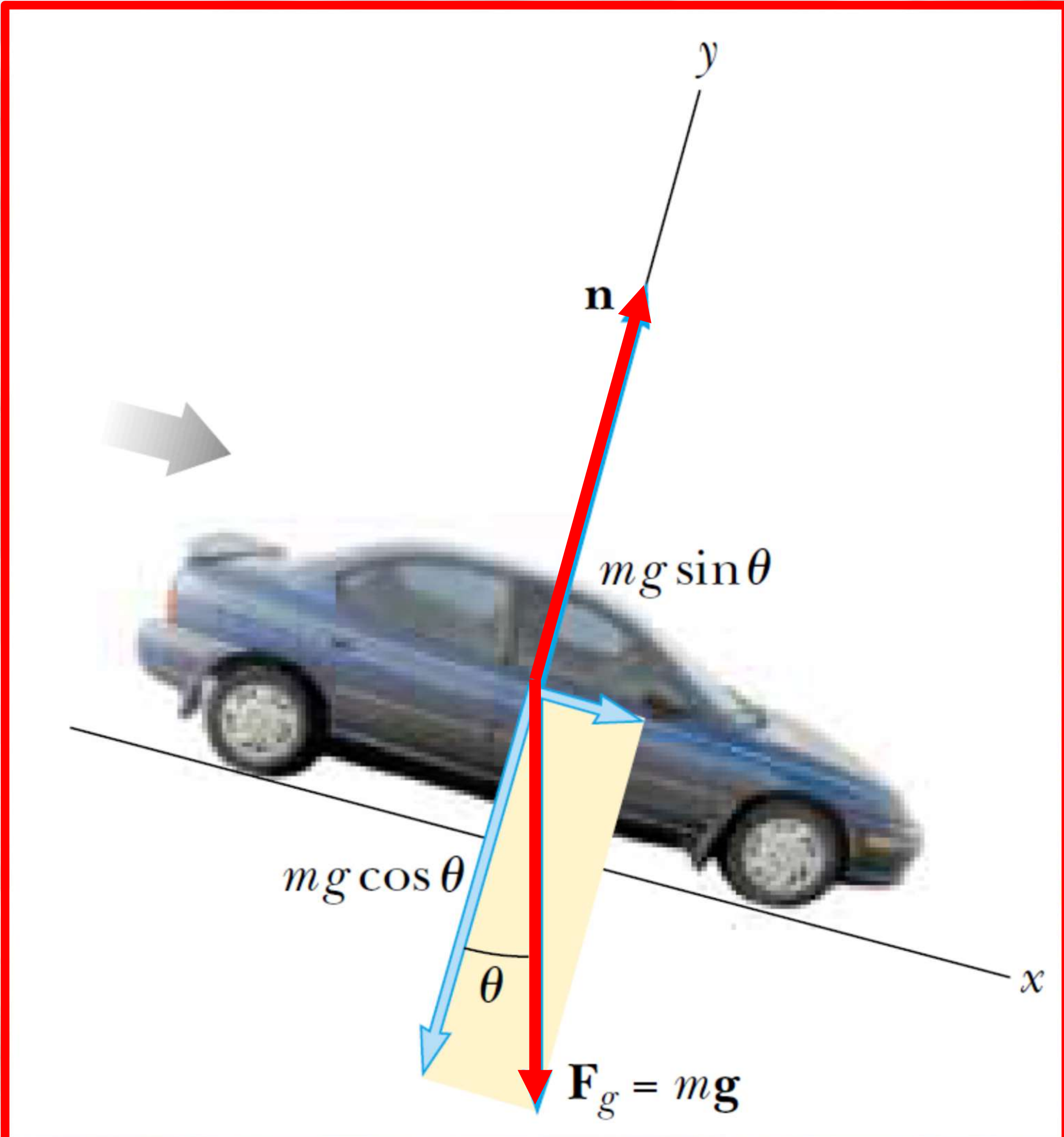
$$n - mg = 0$$

$$n = mg$$

$$F_g = -mg$$

لغزیدن بدون اصطکاک روی یک سطح شیب دار



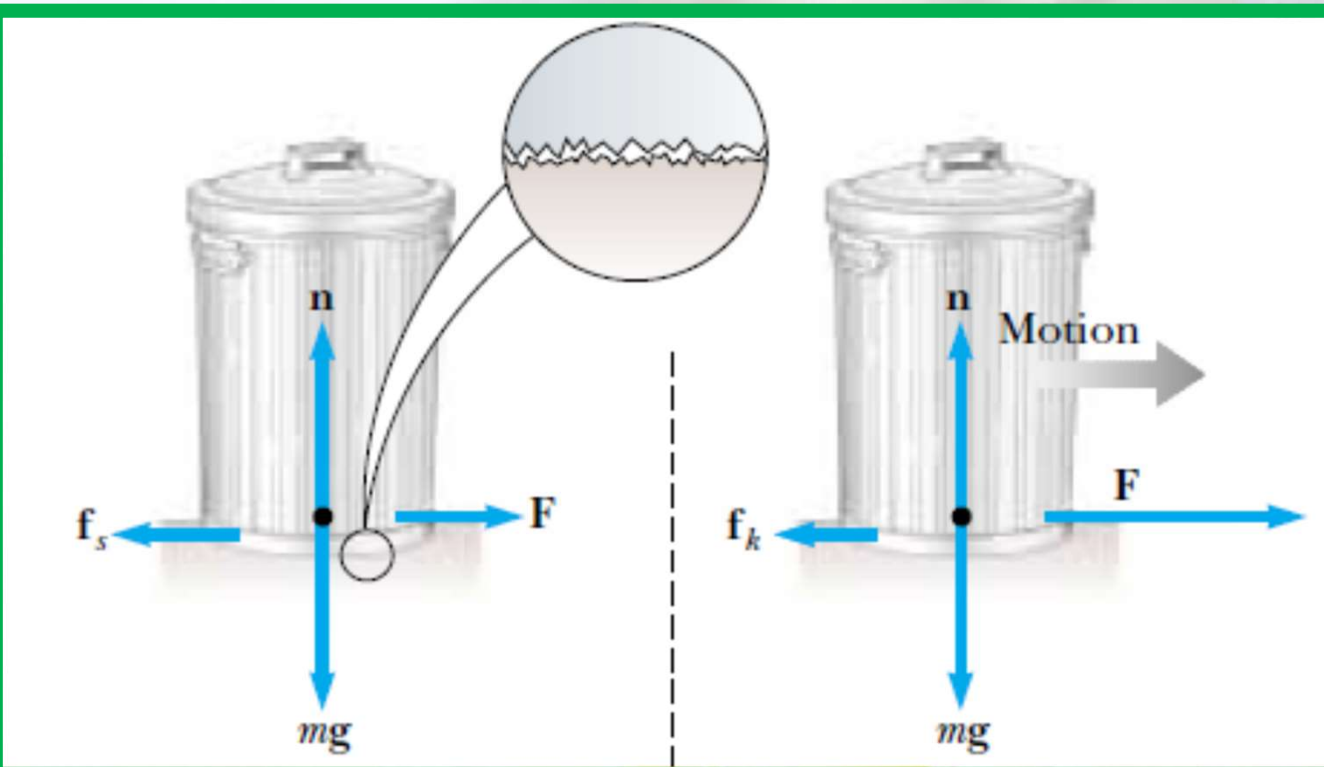


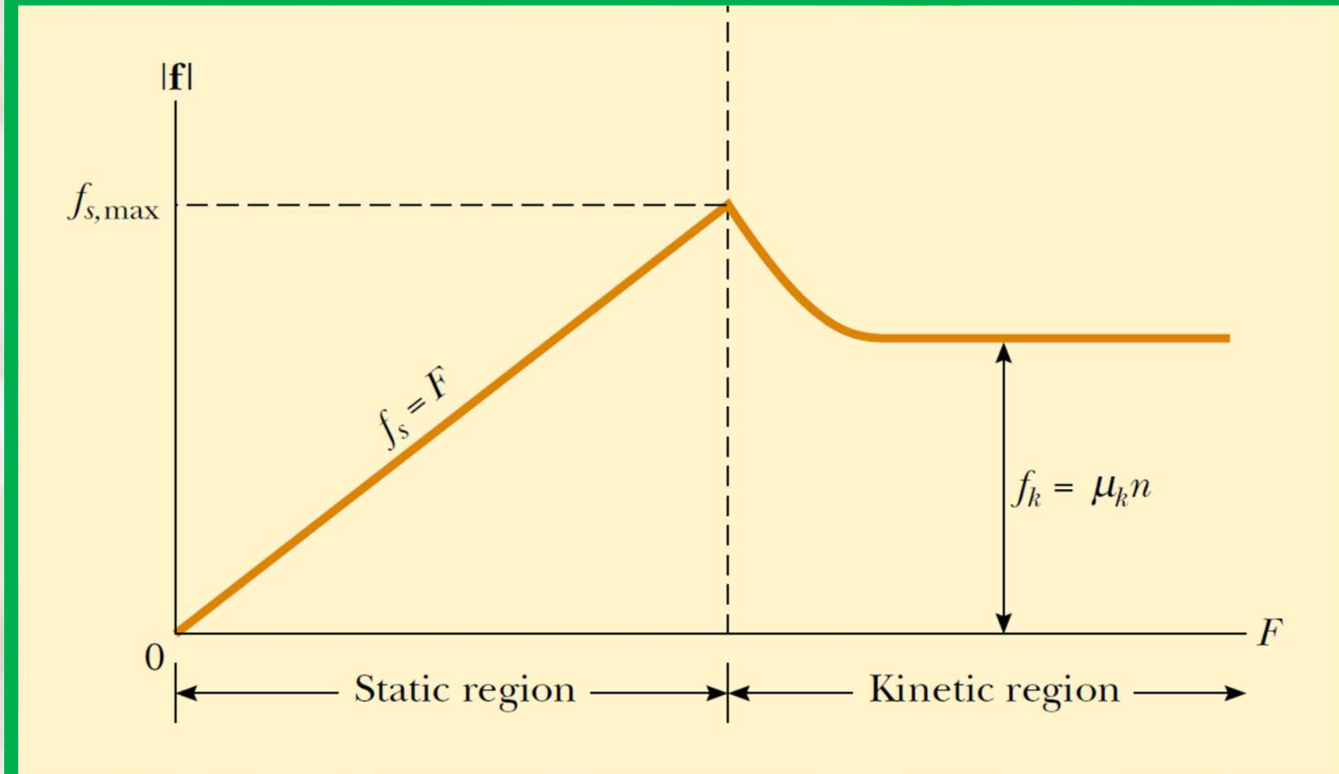
$$mgcos\theta = n$$

$$mgsin\theta = ma$$

$$gsin\theta = a$$

منشا نیروی اصطکاک





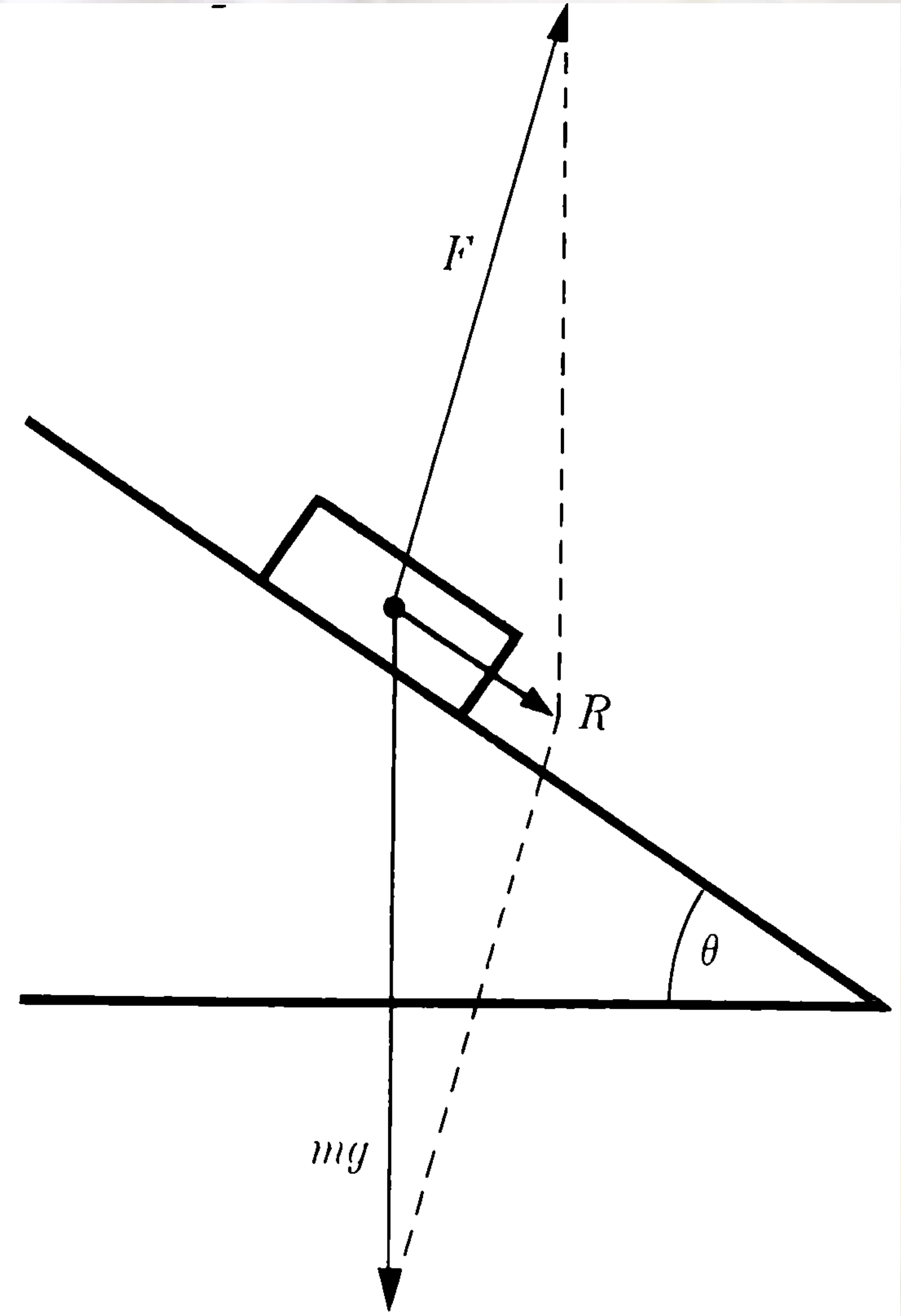
Coefficients of Friction[a]

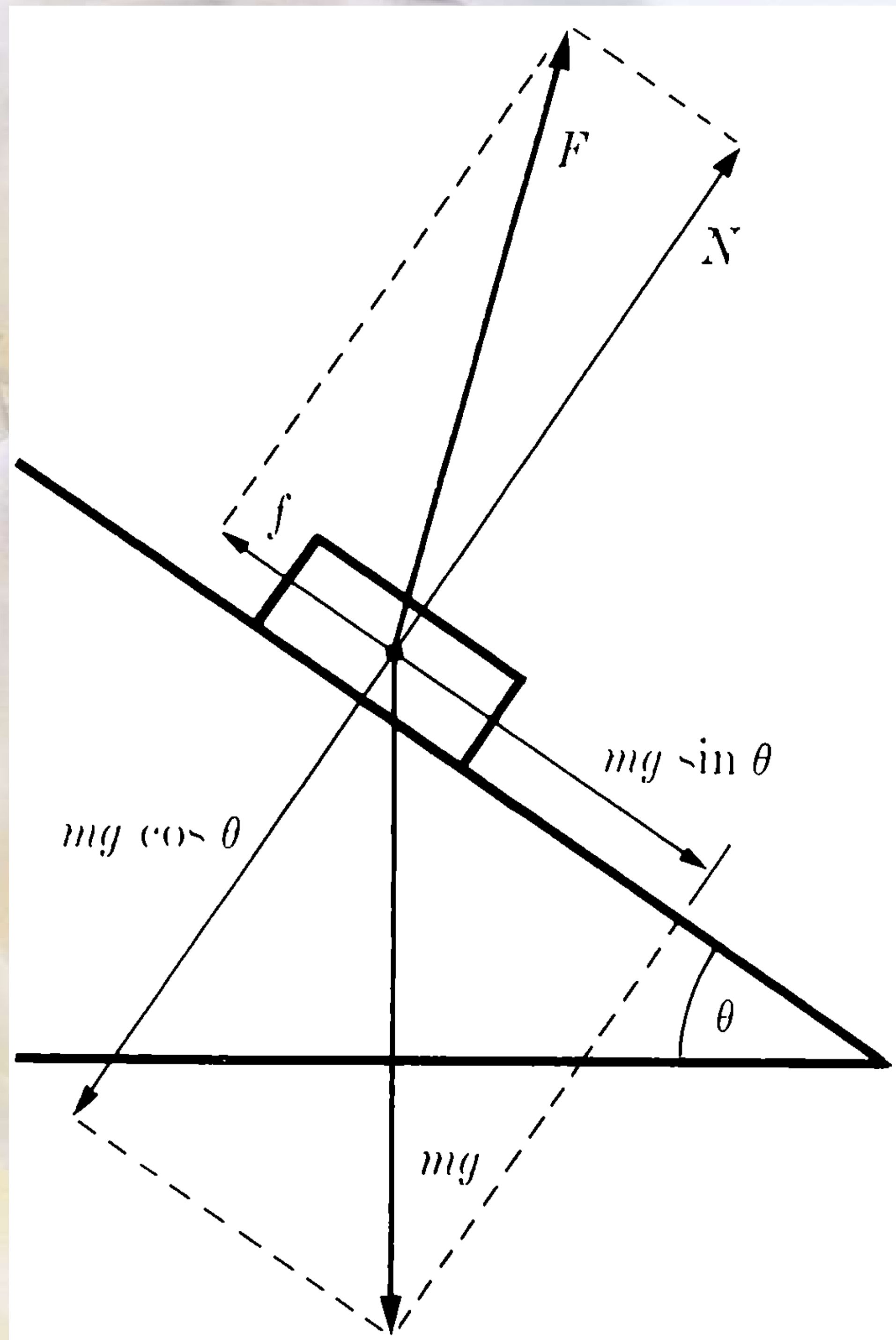
	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

Coefficients of Friction[a]

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

4) سطح شیب دار





$$R = ma$$

$$R = mgsin\theta - f$$

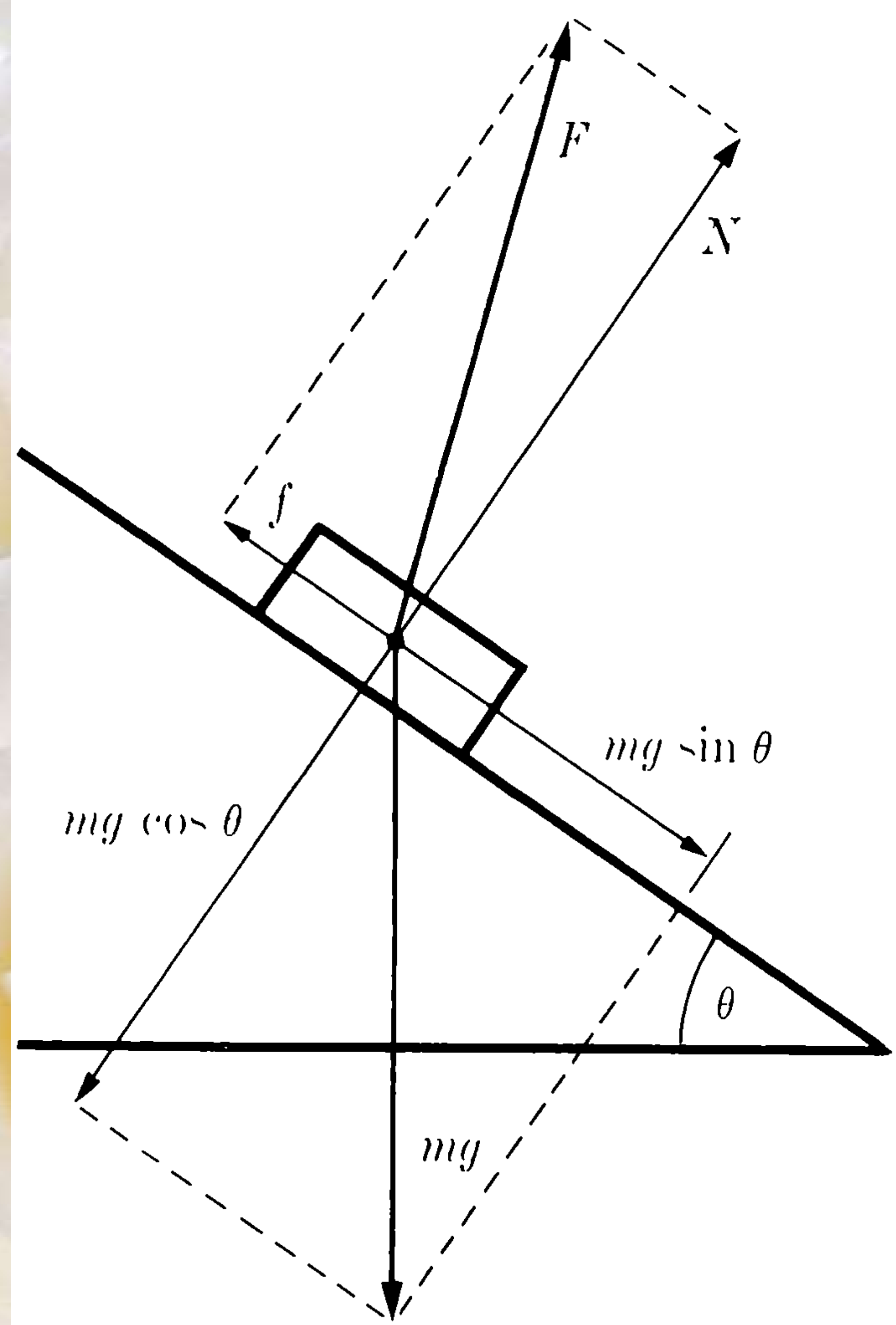
$$0 = N - mgcos\theta$$

نیروی اصطکاک متناسب با نیروی قـــایم است

$$f = \mu N = \mu mgcos\theta$$

$$R = ma = mgsin\theta - \mu mgcos\theta$$

$$a = g(sin\theta - \mu cos\theta)$$



شتاب سر خوردن به پایین

شتاب لغزیدن به بالا (در صورت داشتن سرعت اولیه به بالا)

$$a = g(sin\theta + \mu cos\theta)$$

چون در این صورت جهت نیروی اصطکاک f و در نتیجه علامت آن عوض می شود

اکنون می توان مکان و سرعت جسم را در هر لحظه از زمان با جایگزینی شتابهای فوق در معادلات حرکت به دست آمده در مساله حرکت ذره تحت نیروی ثابت به دست آورد:

$$v = v_0 + g(sin\theta - \mu cos\theta)t$$

$$x = x_0 + v_0 t + \frac{1}{2} g(sin\theta - \mu cos\theta)t^2$$

اگر جسم ساکن باشد نیروی اصطکاک f می تواند هر مقداری که در شرط زیر صدق کند را داشته باشد

$$f \leq f_s = \mu_s N$$

$$N = mgcos\theta$$

$$\mu_s = tan\theta_0$$

که در آن ضریب اصطکاک استاتیک معمولا از ضریب اصطکاک دینامیک بزرگتر است

در حالت استاتیک داریم که:

$$R = 0 = mgsin\theta - f$$

$$mgsin\theta = f$$

$$mgsin\theta = f \leq \mu_s N = \mu_s mgcos\theta$$

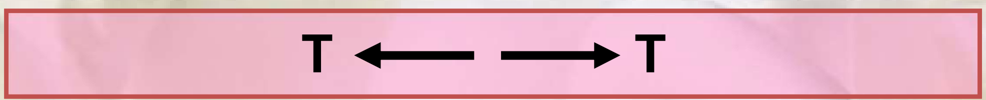
$$sin\theta \leq \mu_s cos\theta$$

$$\mu_s \geq tan\theta$$

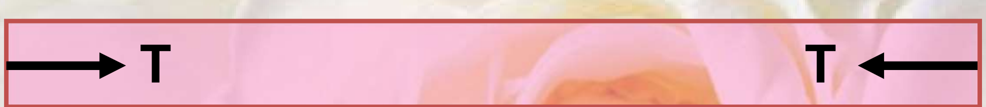
$$tan\theta_0 \geq tan\theta$$

طنابها و قرقره ها

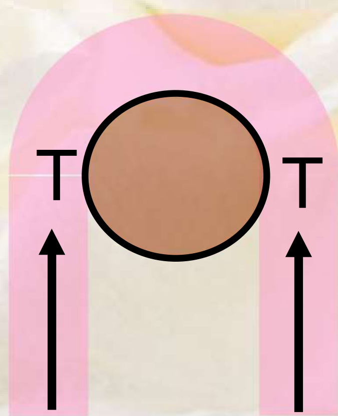
درون طنابها نیروی خالص در هر نقطه از آنها برابر صفر است



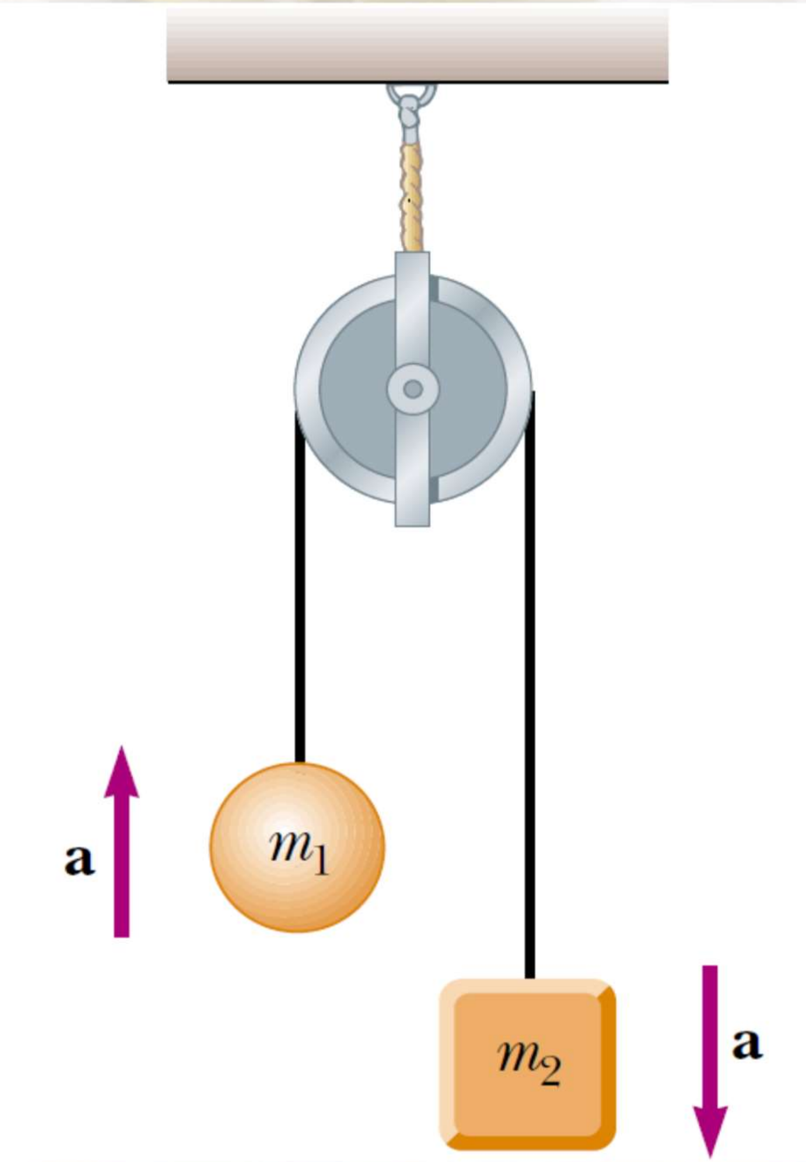
در دو انتها، طنابها نیروی کشش وارد می کنند

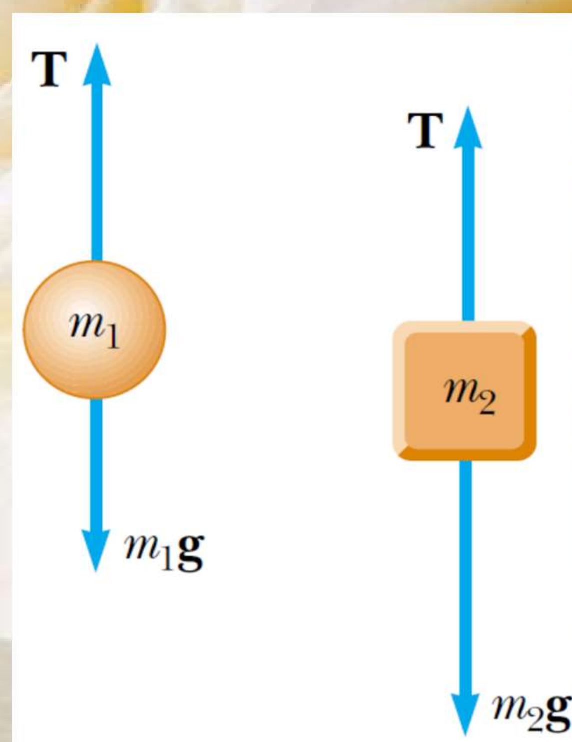


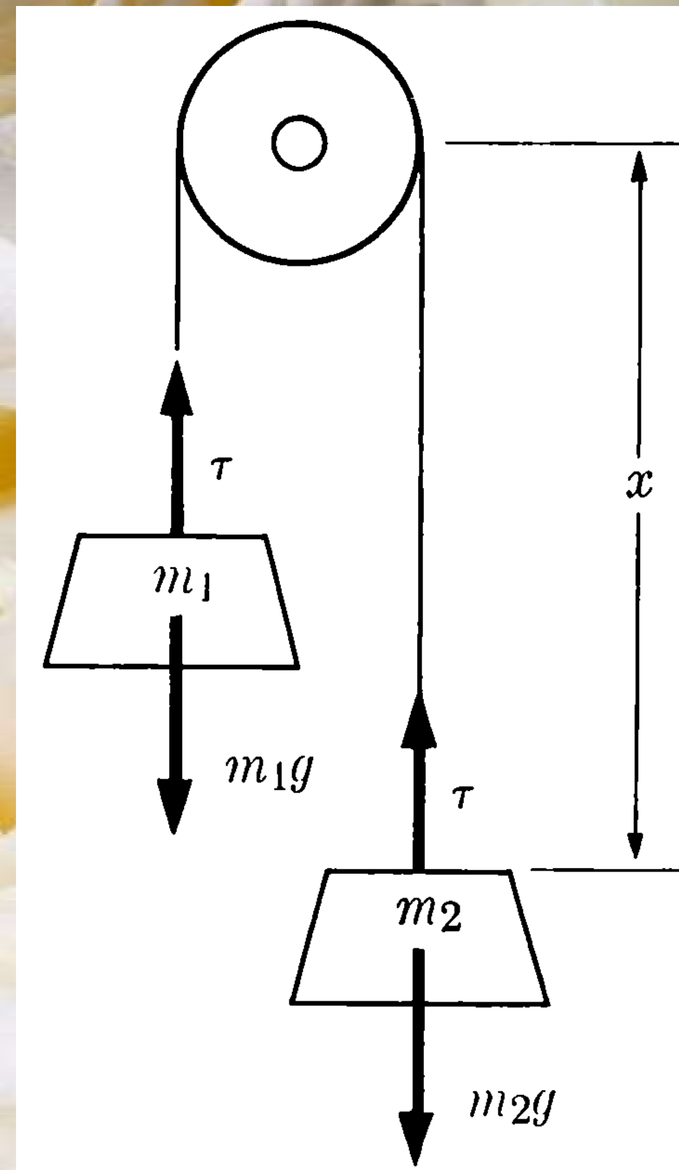
جهت نیروی کشش توسط قرقره ها تغییر می یابد



3) قرقره آتوود







$$v = \frac{dx}{dt}$$

$$a = \frac{dv}{dt}$$

$$F_1 = -m_1 g + \tau$$

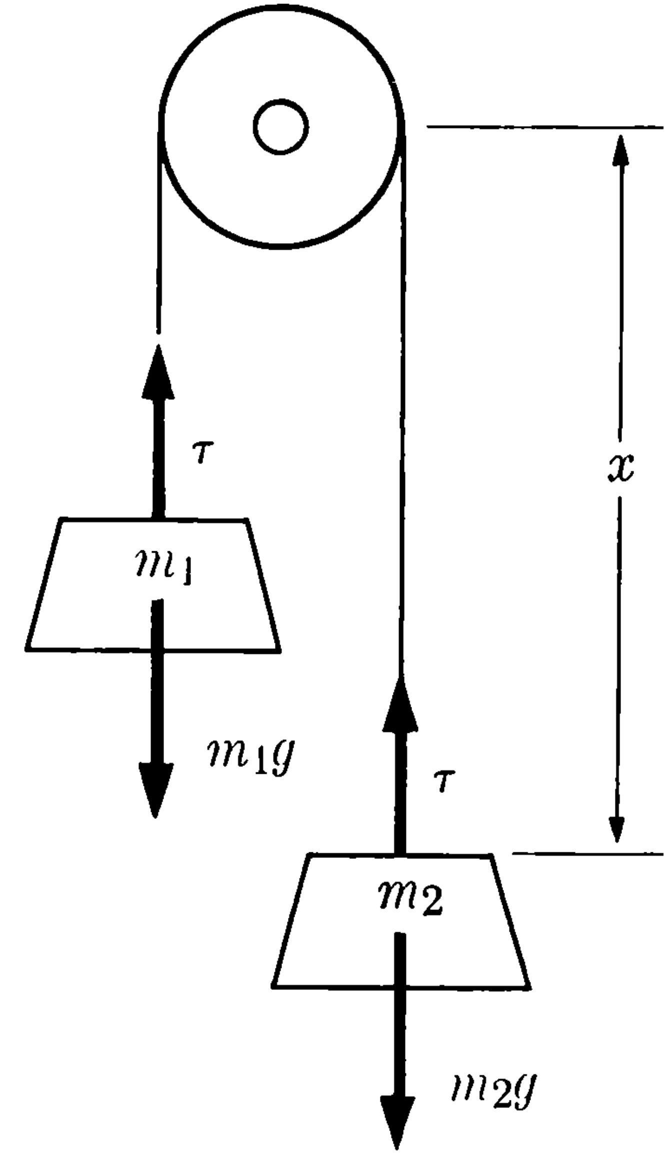
$$F_2 = m_2 g - \tau$$

$$m_1 a = -m_1 g + \tau$$

$$m_2 a = m_2 g - \tau$$

$+$

$$(m_1 + m_2)a = (m_2 - m_1)g$$



$$a = \frac{d^2x}{dt^2} = \frac{m_2 - m_1}{m_1 + m_2} g$$

$$m_1 a = -m_1 g + \tau$$

$$m_1(a + g) = \tau$$

$$m_1 \left(\frac{m_2 - m_1}{m_1 + m_2} + 1 \right) g = \tau$$

$$\tau = \frac{2m_1 m_2}{m_1 + m_2} g$$

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

$$\tau = \frac{2m_1 m_2}{m_1 + m_2} g$$

اگر

$$m_1 = m_2$$

$$a = 0$$

$$\tau = m_1 g = m_2 g$$

اگر

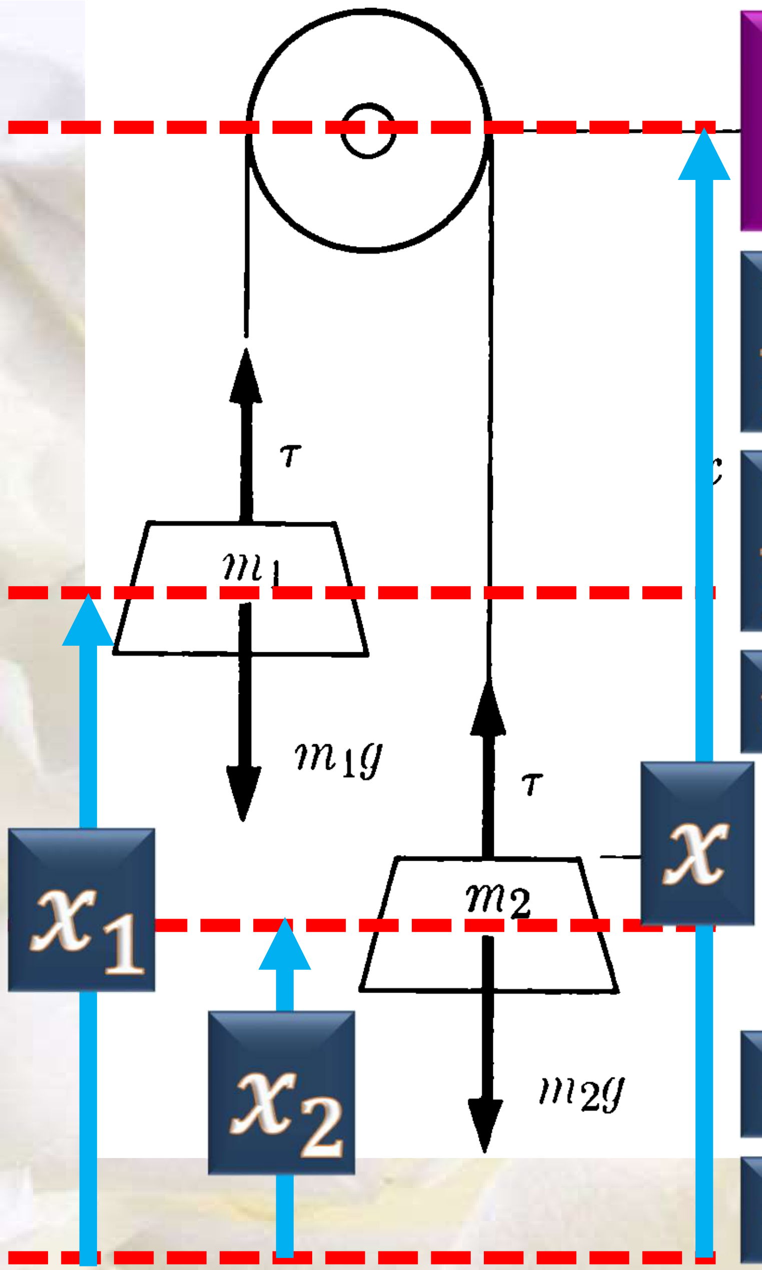
$$m_2 \gg m_1$$

$$a = g$$

$$\tau = 0$$

تمرین: قرقره آتوود را هنگامی که با نیروی ثابت F به بالا کشیده می شود مورد بررسی قرار دهید

شتاب را بدون در نظر گرفتن نیروی کشش نخ به دست آورید



$$\frac{1}{2}m_1v_1^2+\frac{1}{2}m_2v_2^2+m_1gx_1+m_2gx_2=E$$

$$\frac{1}{2}m_1\dot{x}_1^2+\frac{1}{2}m_2\dot{x}_2^2+m_1gx_1+m_2gx_2=E$$

$$m_1\dot{x}_1\ddot{x}_1+m_2\dot{x}_2\ddot{x}_2+m_1g\dot{x}_1+m_2g\dot{x}_2=0$$

$x_1+x_2=cte.$ قید $\dot{x}_1+\dot{x}_2=0$

$\dot{x}_1=-\dot{x}_2$ $\ddot{x}_1=-\ddot{x}_2$

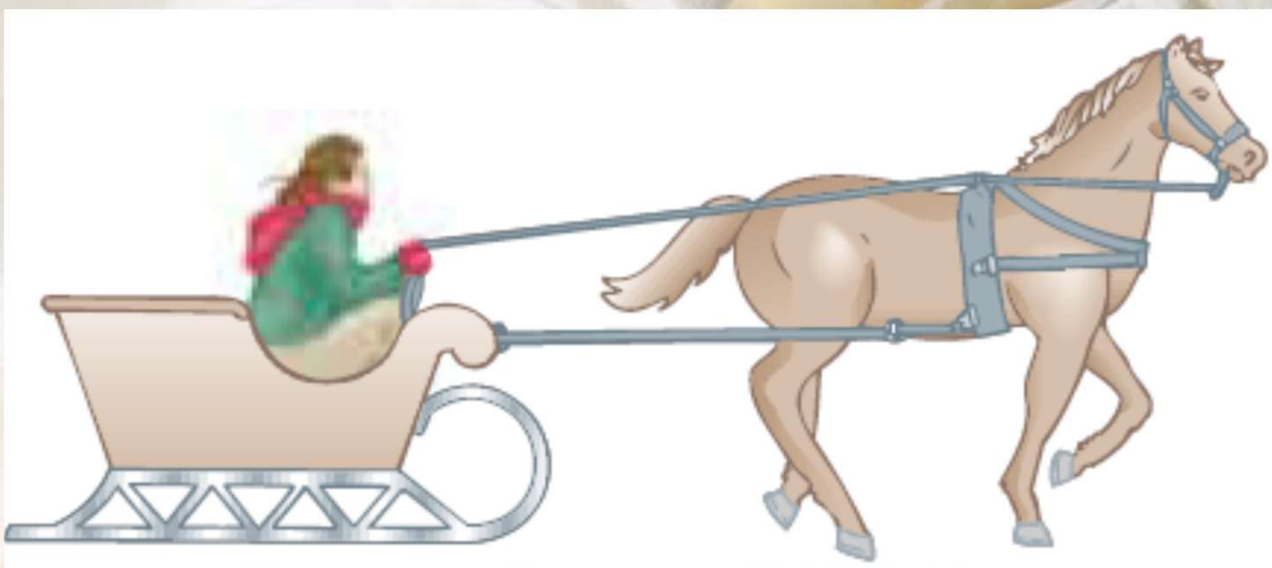
$$(m_1+m_2)\dot{x}_1\ddot{x}_1+(m_1-m_2)g\dot{x}_1=0$$

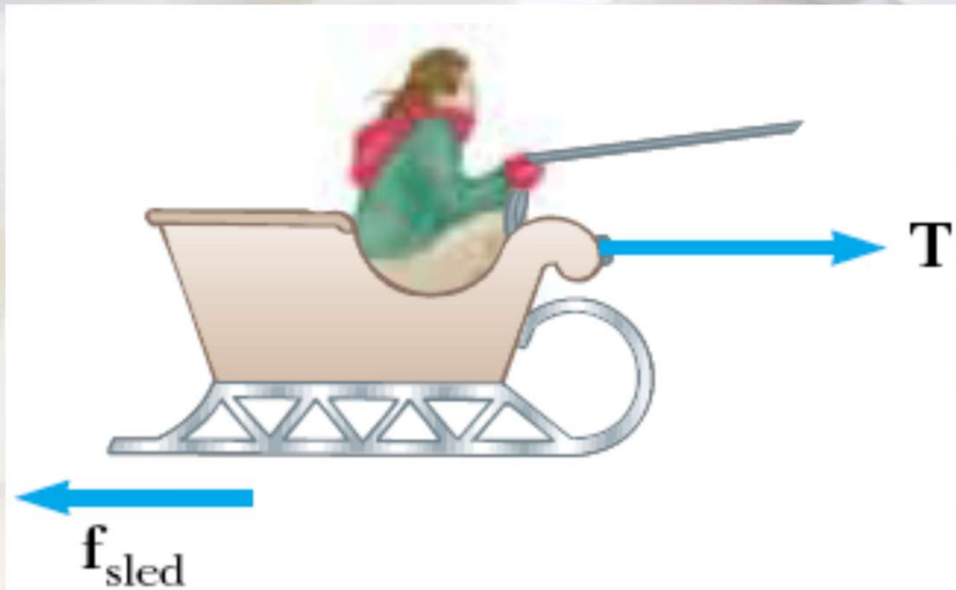
$$(m_1+m_2)\ddot{x}_1=(m_2-m_1)g$$

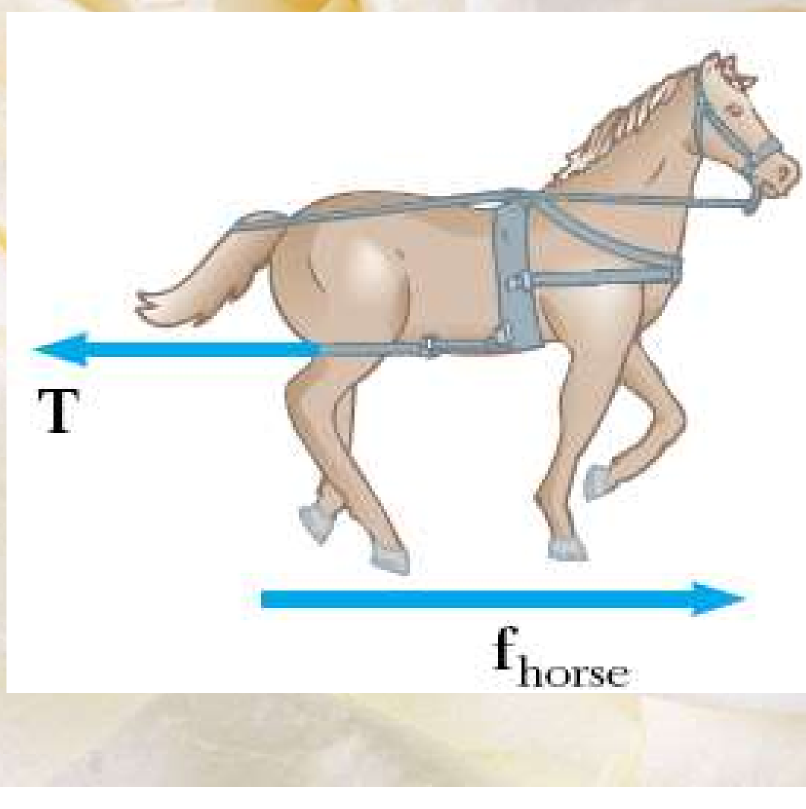
$$\ddot{x}_1=\frac{(m_2-m_1)}{(m_1+m_2)}g$$

Conceptual Example 5.11 Why Does the Sled Accelerate?

A horse pulls a sled along a level, snow-covered road, causing the sled to accelerate, as shown in Figure 5.18a. Newton's third law states that the sled exerts a force of equal magnitude and opposite direction on the horse. In view of this, how can the sled accelerate—don't the forces cancel? Under what condition does the system (horse plus sled) move with constant velocity?




T
f_sled


T
f_horse

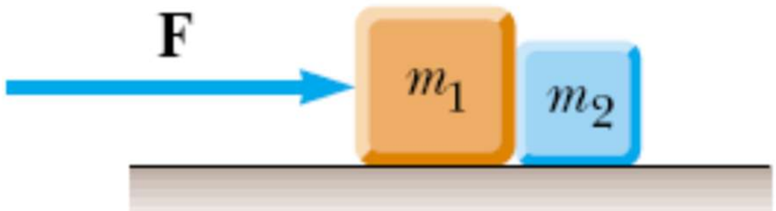
Solution Remember that the forces described in Newton's third law act on *different* objects—the horse exerts a force on the sled, and the sled exerts an equal-magnitude and oppositely directed force on the horse. Because we are interested only in the motion of the sled, we do not consider the forces it exerts on the horse. When determining the motion of an object, you must add only the forces on that object. (This is the principle behind drawing a free-body diagram.) The horizontal forces exerted on the sled are the forward force $\mathbf{T}$ exerted by the horse and the backward force of friction $\mathbf{f}_{sled}$ between sled and snow (see Fig. 5.18b). When the forward force on the sled exceeds the backward force, the sled accelerates to the right.

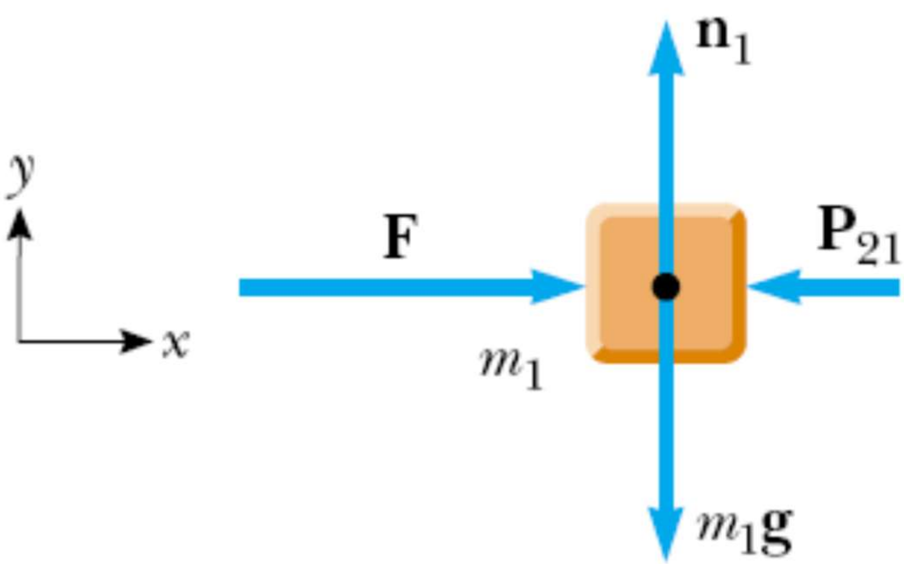
The horizontal forces exerted on the horse are the forward force $\mathbf{f}_{\text{horse}}$ exerted by the Earth and the backward tension force $\mathbf{T}$ exerted by the sled (Fig. 5.18c). The resultant of these two forces causes the horse to accelerate.

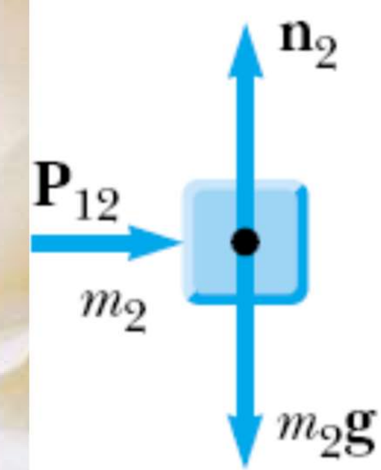
The force that accelerates the system (horse plus sled) is the net force $\mathbf{f}_{\text{horse}} - \mathbf{f}_{\text{sled}}$. When $\mathbf{f}_{\text{horse}}$ balances $\mathbf{f}_{\text{sled}}$, the system moves with constant velocity.

Example 5.7 One Block Pushes Another

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 $\mathbf{F}$ is applied to m_1 as shown. **(A)** Find the magnitude of the acceleration of the system.







Solution *Conceptualize* the situation using Figure 5.12a and realizing that both blocks must experience the *same* acceleration because they are in contact with each other and remain in contact throughout the motion. We *categorize* this as a Newton's second law problem because we have a force applied to a system and we are looking for an acceleration. To *analyze* the problem, we first address the combination of two blocks as a system. Because **F** is the only external horizontal force acting on the system, we have

$$\sum F_x(\text{system}) = F = (m_1 + m_2)\, a_x$$

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

To *finalize* this part, note that this would be the same acceleration as that of a single object of mass equal to the combined masses of the two blocks in Figure 5.12a and subject to the same force.

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

Solution *Conceptualize* by noting that the contact force is internal to the system of two blocks. Thus, we cannot find this force by modeling the whole system (the two blocks) as a single particle. We must now treat each of the two blocks individually by *categorizing* each as a particle subject to a net force. To *analyze* the situation, we first construct a free-body diagram for each block, as shown in Figures 5.12b and 5.12c, where the contact force is denoted by **P**. From Figure 5.12c we see that the only horizontal force acting on m_2 is the contact force $\mathbf{P}_{12}$ (the force exerted by m_1 on m_2), which is directed to the right. Applying Newton's second law to m_2 gives

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

Substituting the value of the acceleration a_x given by (1) into (2) gives

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

To *finalize* the problem, we see from this result that the contact force P_{12} is *less* than the applied force F. This is consistent with the fact that the force required to accelerate block 2 alone must be less than the force required to produce the same acceleration for the two-block system.

To *finalize* further, it is instructive to check this expression for P_{12} by considering the forces acting on m_1, shown in Figure 5.12b. The horizontal forces acting on m_1 are the applied force $\mathbf{F}$ to the right and the contact force $\mathbf{P}_{21}$ to the left (the force exerted by m_2 on m_1). From Newton's third law, $\mathbf{P}_{21}$ is the reaction to $\mathbf{P}_{12}$, so $P_{21} = P_{12}$. Applying Newton's second law to m_1 gives

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

Substituting into (4) the value of a_x from (1), we obtain

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

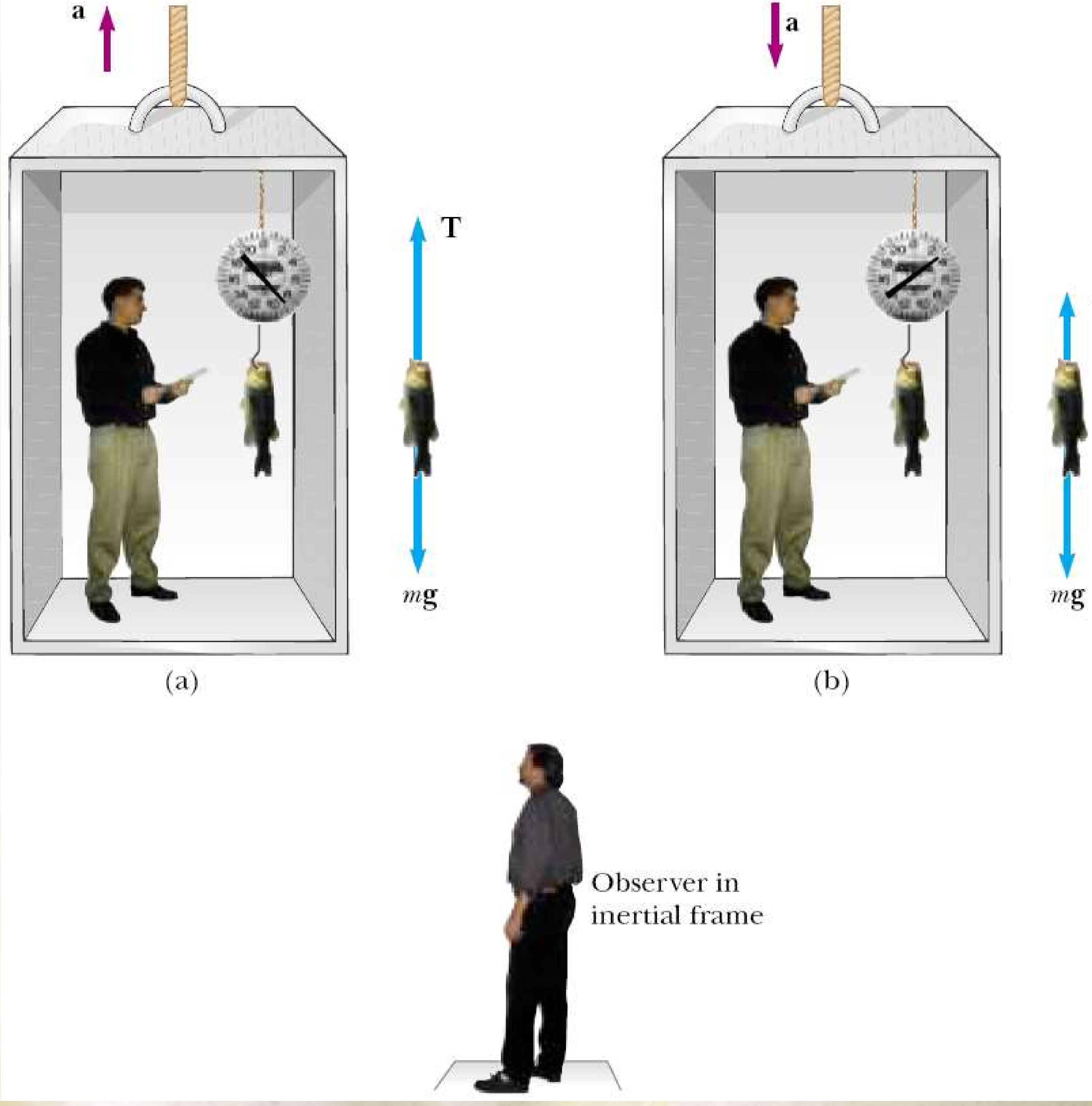
This agrees with (3), as it must.

What If? Imagine that the force F in Figure 5.12 is applied toward the left on the right-hand block of mass m_2. Is the magnitude of the force P_{12} the same as it was when the force was applied toward the right on m_1?

Answer With the force applied toward the left on m_2, the contact force must accelerate m_1. In the original situation, the contact force accelerates m_2. Because $m_1 > m_2$, this will require more force, so the magnitude of $\mathbf{P}_{12}$ is greater than in the original situation.

Example 5.8 Weighing a Fish in an Elevator

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. 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.


a
T
mg
(a)
a
mg
(b)
Observer in
inertial frame

Solution *Conceptualize* by noting that the reading on the scale is related to the extension of the spring in the scale, which is related to the force on the end of the spring as in Figure 5.2. Imagine that a string is hanging from the end of the spring, so that the magnitude of the force exerted on the spring is equal to the tension T in the string. Thus, we are looking for T. The force $\mathbf{T}$ pulls down on the string and pulls up on the fish. Thus, we can *categorize* this problem as one of analyzing the forces and acceleration associated with the fish by means of Newton's second law. To *analyze* the problem, we inspect the free-body diagrams for the fish in Figure 5.13 and note that the external forces acting on the fish are the downward gravitational force

$\mathbf{F}_g = m\mathbf{g}$ and the force $\mathbf{T}$ exerted by the scale. If the elevator is either at rest or moving at constant velocity, the fish does not accelerate, and so $\Sigma F_y = T - F_g = 0$ or $T = F_g = mg$. (Remember that the scalar mg is the weight of the fish.)

If the elevator moves with an acceleration $\mathbf{a}$ relative to an observer standing outside the elevator in an inertial frame (see Fig. 5.13), Newton's second law applied to the fish gives the net force on the fish:

$$\sum F_y = T - mg = ma_y \quad (1)$$

where we have chosen upward as the positive y direction. Thus, we conclude from (1) that the scale reading T is greater than the fish's weight mg if $\mathbf{a}$ is upward, so that a_y is positive, and that the reading is less than mg if $\mathbf{a}$ is downward, so that a_y is negative.

For example, if the weight of the fish is 40.0 N and **a** is upward, so that $a_y = +2.00\ \mathrm{m/s^2}$, the scale reading from (1) is

$$(2) \quad T = ma_y + mg = mg\left(\frac{a_y}{g} + 1\right)$$

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

$$= \boxed{48.2\ \mathrm{N}}$$

If **a** is downward so that $a_y = -2.00\ \mathrm{m/s^2}$, then (2) gives us

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

$$= \boxed{31.8\ \mathrm{N}}$$

To *finalize* this problem, take this advice—if you buy a fish in an elevator, make sure the fish is weighed while the elevator is either at rest or accelerating downward! Furthermore, note that from the information given here, one cannot determine the direction of motion of the elevator.

What If? **Suppose the elevator cable breaks, so that the elevator and its contents are in free-fall. What happens to the reading on the scale?**

Answer If the elevator falls freely, its acceleration is $a_y = -g$. We see from (2) that the scale reading T is zero in this case; that is, the fish *appears* to be weightless.

Quick Quiz 5.1 Which of the following statements is most correct? (a) It is possible for an object to have motion in the absence of forces on the object. (b) It is possible to have forces on an object in the absence of motion of the object. (c) Neither (a) nor (b) is correct. (d) Both (a) and (b) are correct.

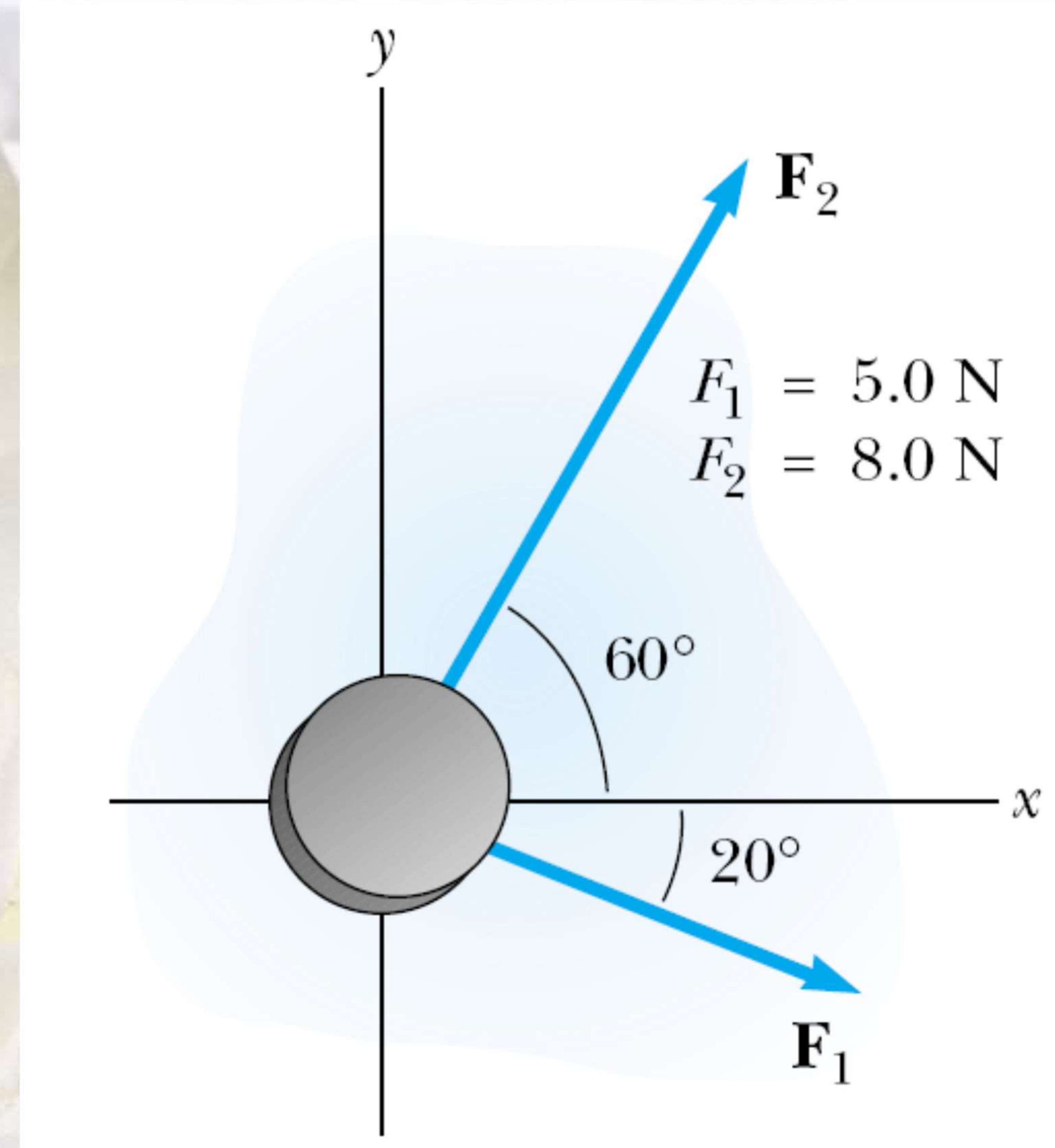
Quick Quiz 5.2 An object experiences no acceleration. Which of the following *cannot* be true for the object? (a) A single force acts on the object. (b) No forces act on the object. (c) Forces act on the object, but the forces cancel.

Quick Quiz 5.3 An object experiences a net force and exhibits an acceleration in response. Which of the following statements is *always* true? (a) The object moves in the direction of the force. (b) The acceleration is in the same direction as the velocity. (c) The acceleration is in the same direction as the force. (d) The velocity of the object increases.

Quick Quiz 5.4 You push an object, initially at rest, across a frictionless floor with a constant force for a time interval Δt, resulting in a final speed of v for the object. You repeat the experiment, but with a force that is twice as large. What time interval is now required to reach the same final speed v? (a) $4\Delta t$ (b) $2\Delta t$ (c) Δt (d) $\Delta t/2$ (e) $\Delta t/4$.

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 5.4. 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.


y
$\mathbf{F}_2$
$F_1 = 5.0$ N
$F_2 = 8.0$ N
60°
x
20°
$\mathbf{F}_1$

Solution *Conceptualize* this problem by studying Figure 5.4. Because we can determine a net force and we want an acceleration, we *categorize* this problem as one that may be solved using Newton's second law. To *analyze* the problem, we resolve the force vectors into components. The net force acting on the puck in the x direction is

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

The net force acting on the puck in the y direction is

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

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

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

and its direction relative to the positive x axis is

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

To *finalize* the problem, we can graphically add the vectors in Figure 5.4 to check the reasonableness of our answer. Because the acceleration vector is along the direction of the resultant force, a drawing showing the resultant force helps us check the validity of the answer. (Try it!)

What If? Suppose three hockey sticks strike the puck simultaneously, with two of them exerting the forces shown in Figure 5.4. The result of the three forces is that the hockey puck shows *no* acceleration. What must be the components of the third force?

Answer If there is zero acceleration, the net force acting on the puck must be zero. Thus, the three forces must cancel. We have found the components of the combination of the first two forces. The components of the third force must be of equal magnitude and opposite sign in order that all of the components add to zero. Thus, $F_{3x} = -8.7$ N, $F_{3y} = -5.2$ N.

Quick Quiz 5.5 A baseball of mass m is thrown upward with some initial speed. A gravitational force is exerted on the ball (a) at all points in its motion (b) at all points in its motion except at the highest point (c) at no points in its motion.

Quick Quiz 5.6 Suppose you are talking by interplanetary telephone to your friend, who lives on the Moon. He tells you that he has just won a newton of gold in a contest. Excitedly, you tell him that you entered the Earth version of the same contest and also won a newton of gold! Who is richer? (a) You (b) Your friend (c) You are equally rich.

Conceptual Example 5.2 How Much Do You Weigh in an Elevator?

You have most likely had the experience of standing in an elevator that accelerates upward as it moves toward a higher floor. In this case, you feel heavier. In fact, if you are standing on a bathroom scale at the time, the scale measures a force having a magnitude that is greater than your weight. Thus, you have tactile and measured evidence that leads you to believe you are heavier in this situation. *Are* you heavier?

Solution No, your weight is unchanged. To provide the acceleration upward, the floor or scale must exert on your feet an upward force that is greater in magnitude than your weight. It is this greater force that you feel, which you interpret as feeling heavier. The scale reads this upward force, not your weight, and so its reading increases.

Quick Quiz 5.7 If a fly collides with the windshield of a fast-moving bus, which object experiences an impact force with a larger magnitude? (a) the fly (b) the bus (c) the same force is experienced by both.

Quick Quiz 5.8 If a fly collides with the windshield of a fast-moving bus, which object experiences the greater acceleration: (a) the fly (b) the bus (c) the same acceleration is experienced by both.

Quick Quiz 5.9 Which of the following is the reaction force to the gravitational force acting on your body as you sit in your desk chair? (a) The normal force exerted by the chair (b) The force you exert downward on the seat of the chair (c) Neither of these forces.

Quick Quiz 5.10 In a free-body diagram for a single object, you draw (a) the forces acting on the object and the forces the object exerts on other objects, or (b) only the forces acting on the object.

Conceptual Example 5.3 You Push Me and I'll Push You

A large man and a small boy stand facing each other on frictionless ice. They put their hands together and push against each other so that they move apart.

(A) Who moves away with the higher speed?

Solution This situation is similar to what we saw in Quick Quizzes 5.7 and 5.8. According to Newton's third law, the force exerted by the man on the boy and the force exerted by the boy on the man are an action–reaction pair, and so they must be equal in magnitude. (A bathroom scale placed between their hands would read the same, regardless of which way it faced.) Therefore, the boy, having the smaller mass, experiences the greater acceleration. Both individuals accelerate for the same amount of time, but the greater acceleration of the boy over this time interval results in his moving away from the interaction with the higher speed.

(B) Who moves farther while their hands are in contact?

Solution Because the boy has the greater acceleration and, therefore, the greater average velocity, he moves farther during the time interval in which the hands are in contact.

PROBLEM-SOLVING HINTS

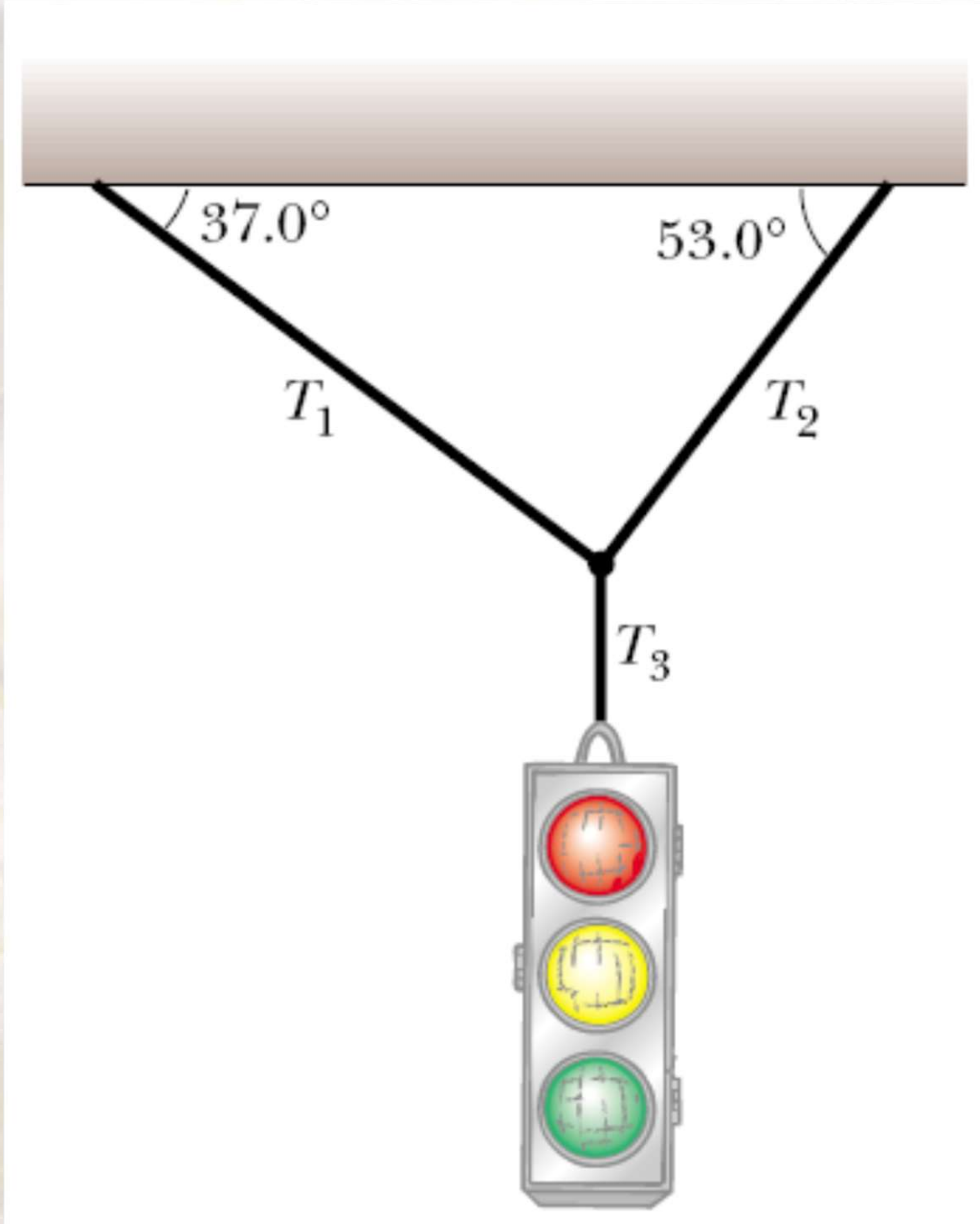
Applying Newton's Laws

The following procedure is recommended when dealing with problems involving Newton's laws:

- Draw a simple, neat diagram of the system to help *conceptualize* the problem.
- *Categorize* the problem: if any acceleration component is zero, the particle is in equilibrium in this direction and $\Sigma F = 0$. If not, the particle is undergoing an acceleration, the problem is one of nonequilibrium in this direction, and $\Sigma F = ma$.
- *Analyze* the problem by isolating the object whose motion is being analyzed. Draw a free-body diagram for this object. For systems containing more than one object, draw *separate* free-body diagrams for each object. *Do not* include in the free-body diagram forces exerted by the object on its surroundings.
- Establish convenient coordinate axes for each object and find the components of the forces along these axes. Apply Newton's second law, $\Sigma \mathbf{F} = m\mathbf{a}$, in component form. Check your dimensions to make sure that all terms have units of force.
- Solve the component equations for the unknowns. Remember that you must have as many independent equations as you have unknowns to obtain a complete solution.
- *Finalize* by making sure your results are consistent with the free-body diagram. Also check the predictions of your solutions for extreme values of the variables. By doing so, you can often detect errors in your results.

Example 5.4 A Traffic Light at Rest

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 37.0° and 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. Will the traffic light remain hanging in this situation, or will one of the cables break?


37.0°
53.0°
T_1
T_2
T_3