# Chapter 4
# Dynamics:
# Newton's Laws of Motion

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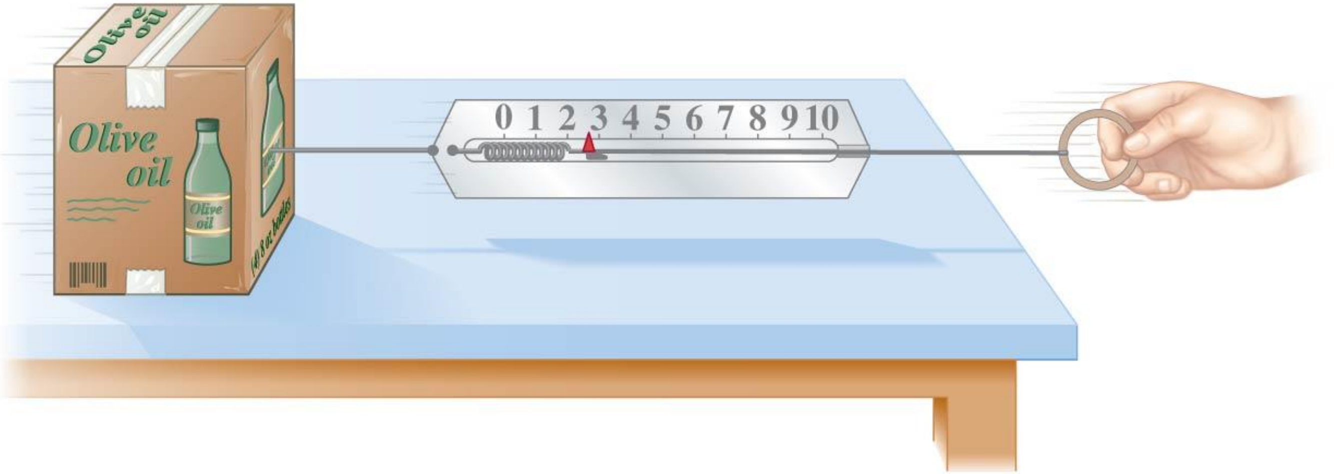
# 4-1 Force

A force is a push or pull. An object at rest needs a force to get it moving; a moving object needs a force to change its velocity.

The magnitude of a force can be measured using a spring scale.



# 4-2 Newton's First Law of Motion

Newton's first law is often called the law of inertia.

Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.

Question: A school bus comes to a sudden stop, and all of the backpacks on the floor start to slide forward. What causes them to do that?

# 4-2 Newton's First Law of Motion

Newton's first law does not hold in every reference frame!!!

It is only valid in certain reference frames

(inertial reference frames)

Inertial reference frames:

- An inertial reference frame is one in which Newton's first law is valid.
- This excludes rotating and accelerating frames.

# 4-3 Mass

Mass is the measure of inertia of an object.

*The more mass an object has, the greater the force needed to give it a particular acceleration.*

In the SI system, mass is measured in kilograms.

Mass is not weight:

- Mass is a property of an object. Weight is the force exerted on that object by gravity.
- If you go to the moon, whose gravitational acceleration is about 1/6 $g$, you will weigh much less. Your mass, however, will be the same.

# 4-4 Newton's Second Law of Motion

*a net force causes acceleration* *OR* $\Sigma F = ma$

$F_{net} = ma$

Force is a vector ( vector algebra must be used when add forces)

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

The unit of force in the SI system is the newton (N).

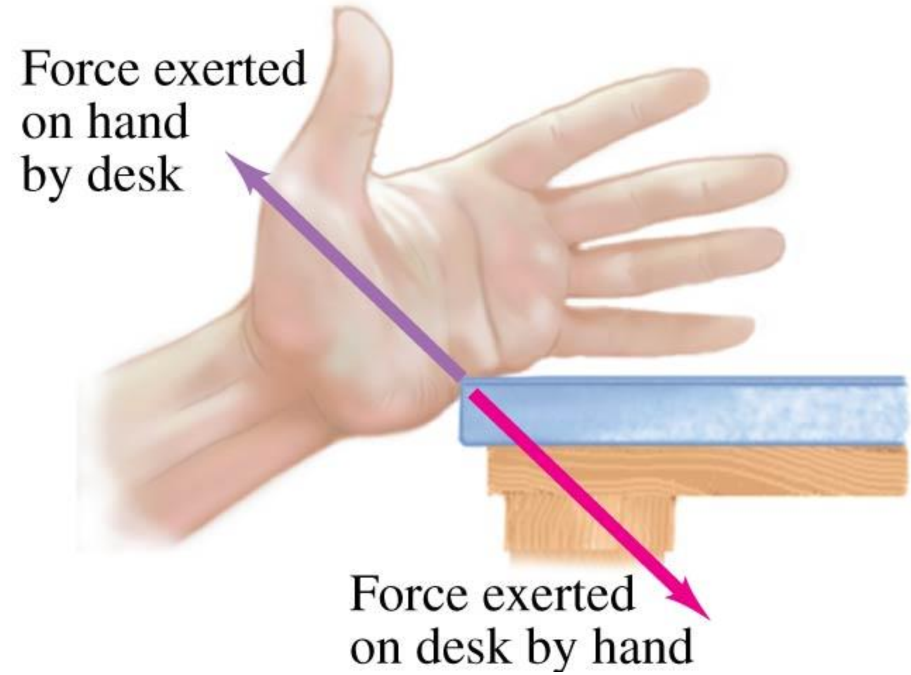
$kg \frac{m}{s^2}$

# 4-5 Newton's Third Law of Motion

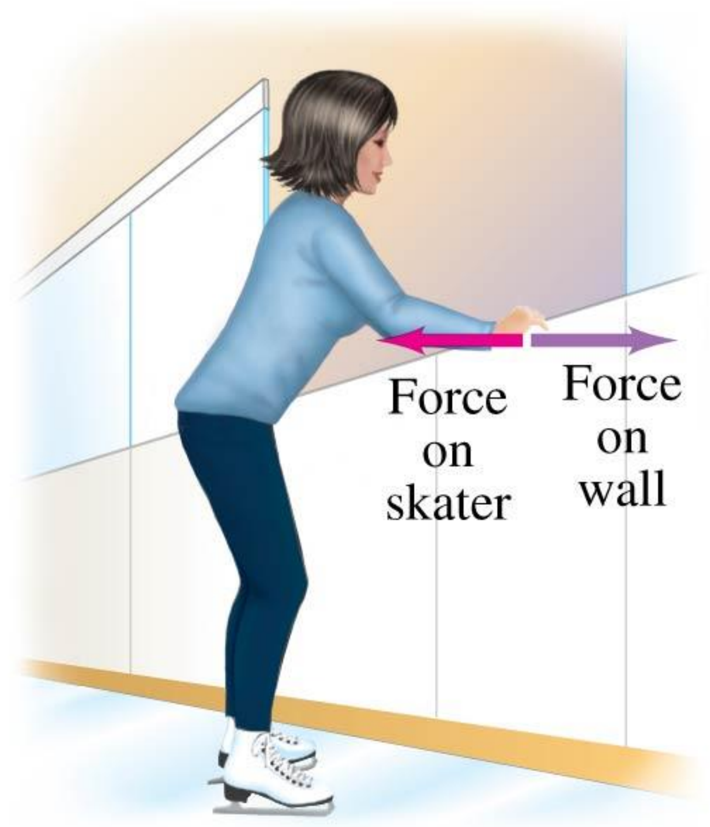
Any time a force is exerted on an object, that force is caused by another object.

Newton's third law:

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

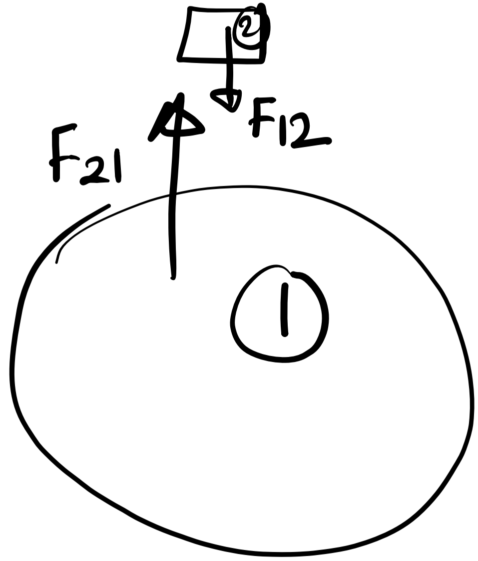


# 4-5 Newton's Third Law of Motion




A key to the correct application of the third law is that *the forces are exerted on different objects*. Make sure you don't use them as if they were acting on the *same* object.

Question: What are the action and reaction forces in case of freely falling object




$F_{12}$ : gravitional force exerted by earth on the object

$F_{21}$ : gravitional force exerted by the object on earth

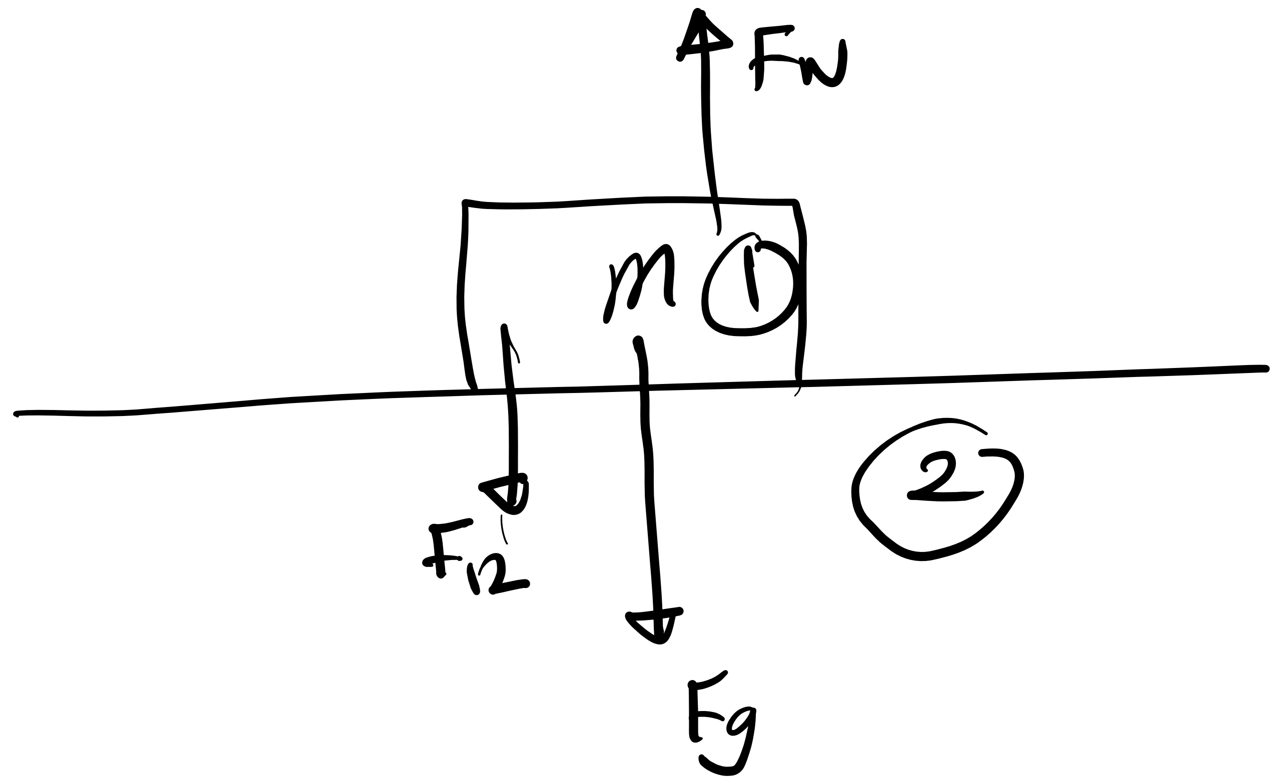
# 4-6 Weight—the Force of Gravity; and the Normal Force

Weight is the force exerted on an object by gravity. Close to the surface of the Earth, where the gravitational force is nearly constant, the weight is:

$$\vec{W} = \vec{\mathbf{F}}_{\mathrm{G}} = m\vec{\mathbf{g}} \qquad (4\text{-}3)$$

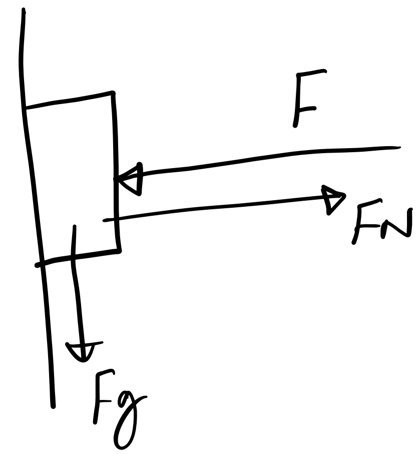
$$\vec{g} = 9.8 \ m/s^2 \ [\text{down}]$$

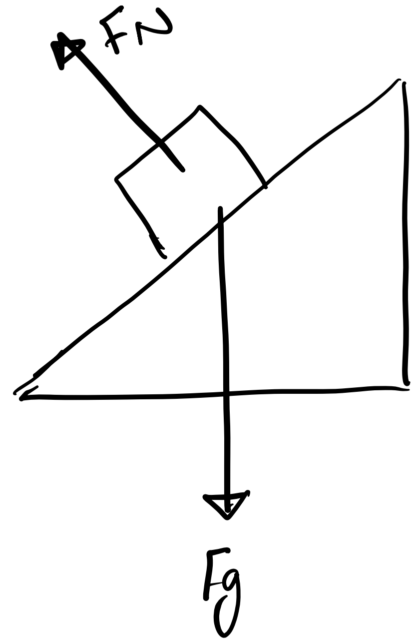
# Normal Force

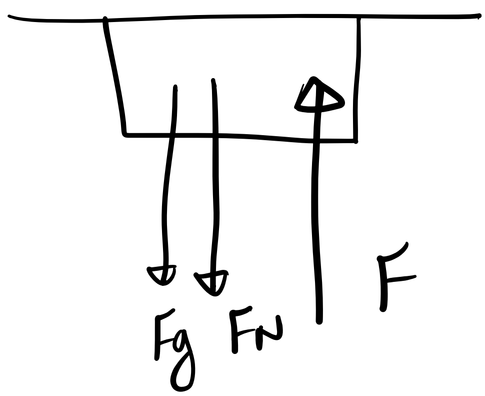



$F_{12}$ : force exerted by the object on the surface (pushing down on the surface by its weight)

$F_N \Rightarrow F_{21}$ : force exterted by the surface on the object (pushing up)

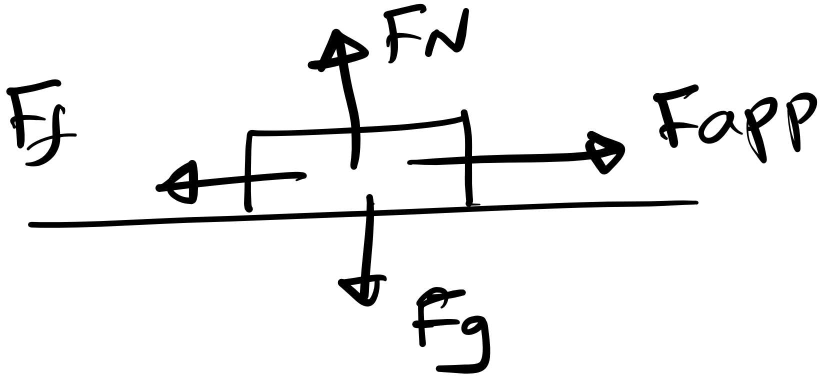

F
FN
Fg


FN
Fg


Fg
FN
F

# Free Body Diagrams FBD

a force pushing an object on a rough horizontal surface




$$\sum F_x = ma_x$$

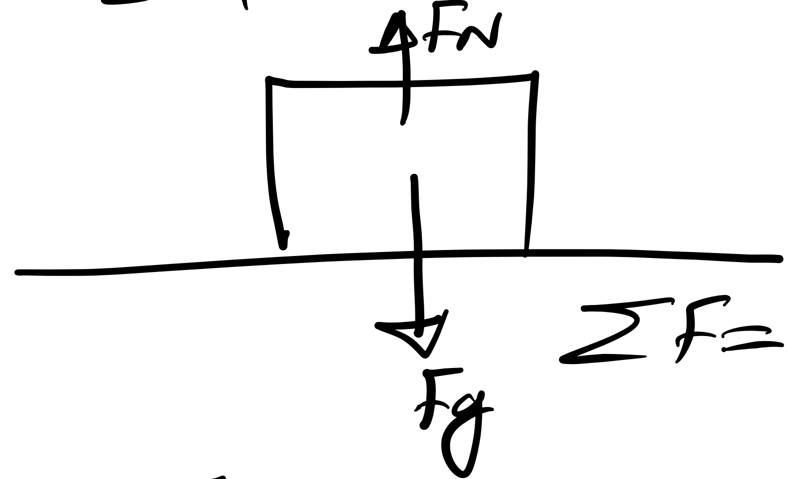
$$F_{app} - F_f = ma_x$$

$$\sum F_y = ma_y \quad (a_y = 0)$$

$$F_N - F_g = 0$$

$$F_N = F_g$$

object at rest on a horizontal surface

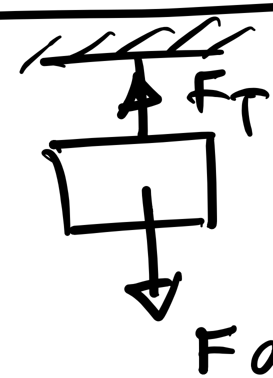



$$\sum F = ma$$

$$\Rightarrow F_{net} = \sum F = F_N - F_g = 0$$

$$F_N = F_g$$

object hanged by a string



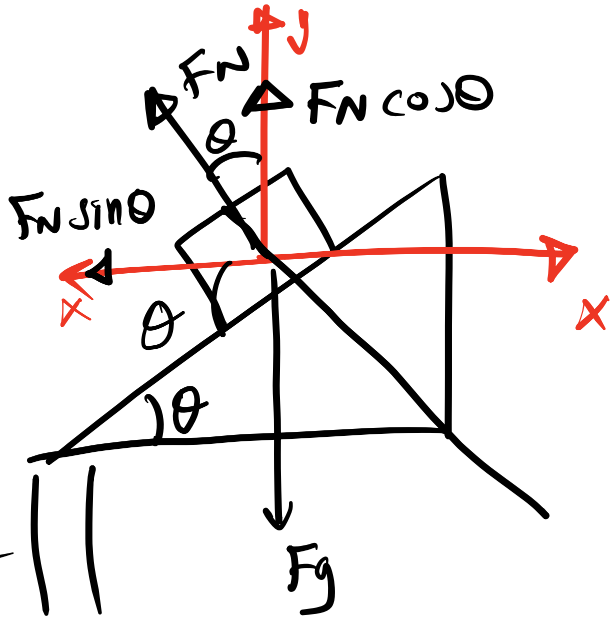

$$F_T - F_g = 0 \Rightarrow F_T = F_g$$

$\sum F_x = ma_x$

$F_N \sin\theta = ma_x$

$\sum F_y = ma_y$

$F_N \cos\theta - mg = ma_y$




# Dont Do that!!

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$\sum F_x = ma_x$

$F_g \sin\theta = ma_x$

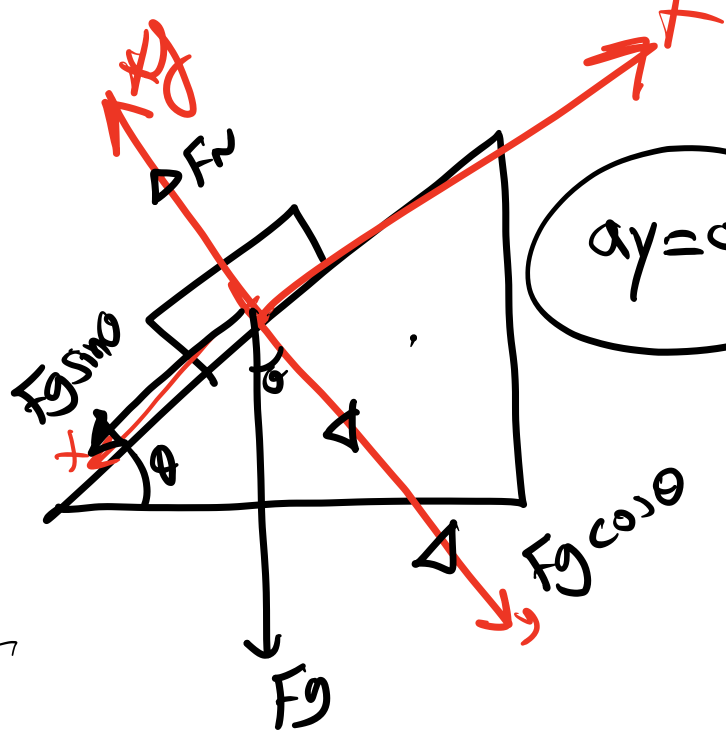
$\sum F_y = ma_y$

$F_N - F_g \cos\theta = 0$

$F_N = F_g \cos\theta$

$mg \sin\theta = ma_x$

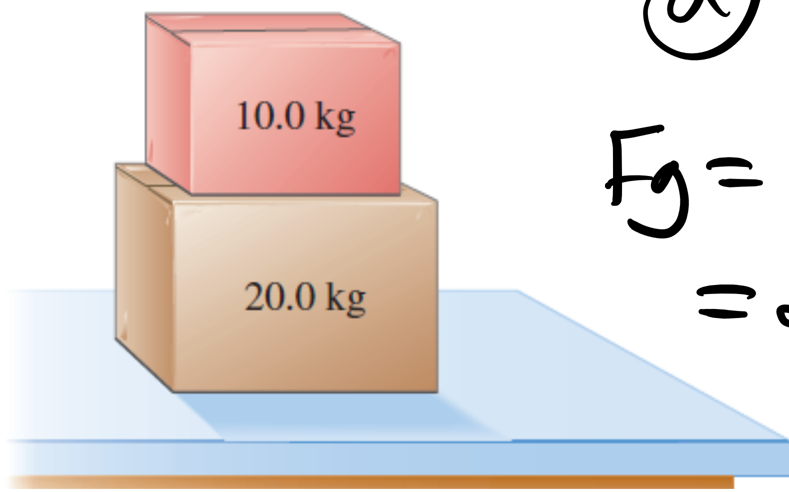
$a_x = g \sin\theta$



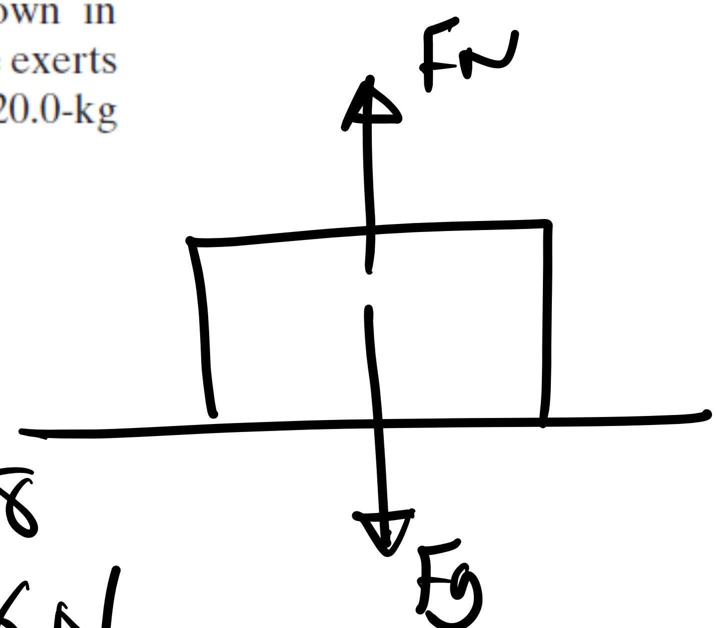

$a_y = 0$

object is sliding down a smooth inclined plane

**11.** (II) A 20.0-kg box rests on a table. (*a*) What is the weight of the box and the normal force acting on it? (*b*) A 10.0-kg box is placed on top of the 20.0-kg box, as shown in Fig. 4–43. Determine the normal force that the table exerts on the 20.0-kg box and the normal force that the 20.0-kg box exerts on the 10.0-kg box.




(a)



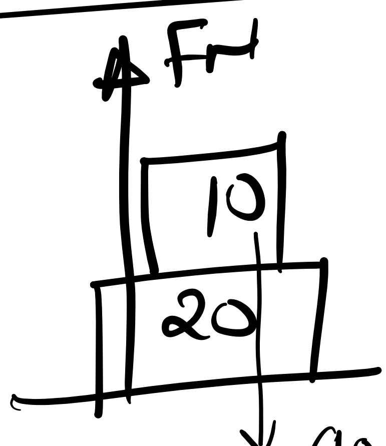

$F_g = mg$

$= 20 \times 9.8$

$= 196\ N$

$F_N = F_g = 196\ N$

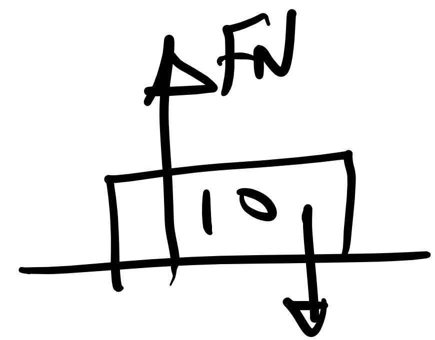
(b)




$(10+20) \times 9.8$

$F_N = 30 \times 9.8$

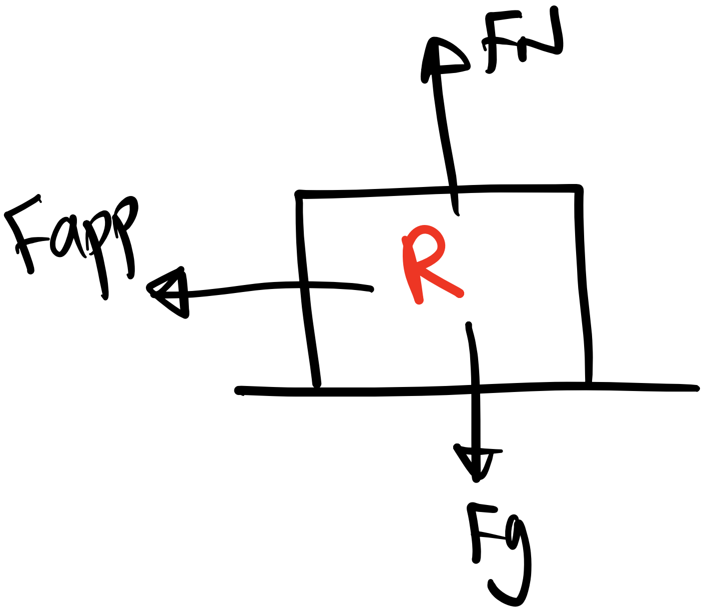
$= 294\ N$




$(10 \times 9.8)$

$F_N = 98\ N$

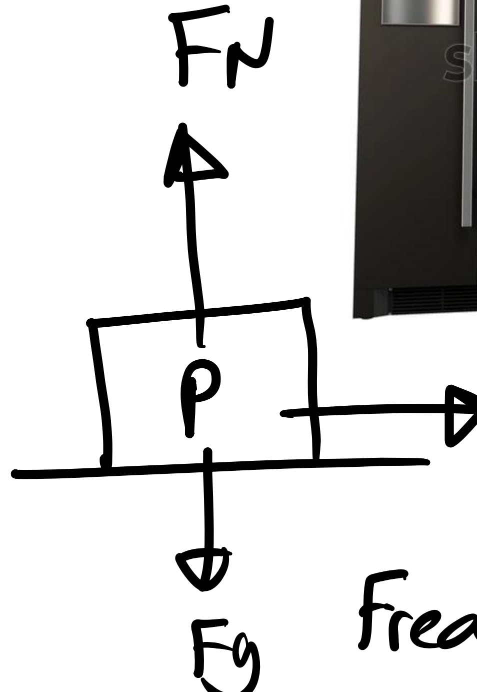
Assume no force of friction exists on either the person or the refrigerator. The person has a mass of 60.0 kg, and the refrigerator has a mass of 1200 kg. The force exerted by the person on the refrigerator is 180 N [forward]. Calculate the refrigerator's acceleration and the person's acceleration.


$F_{app} = ma$

$180 = 1200a$

$a = 0.15\ m/s^2$ [forward]

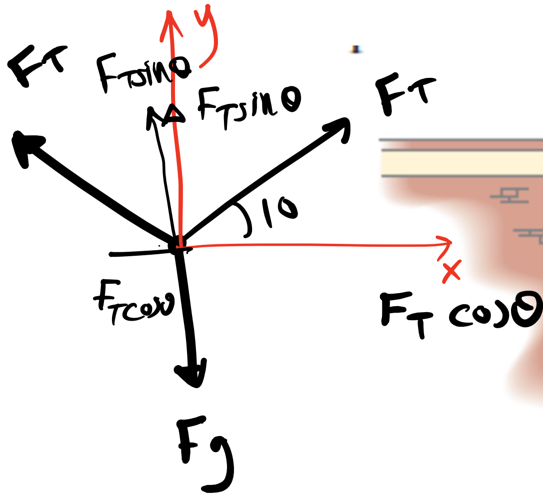


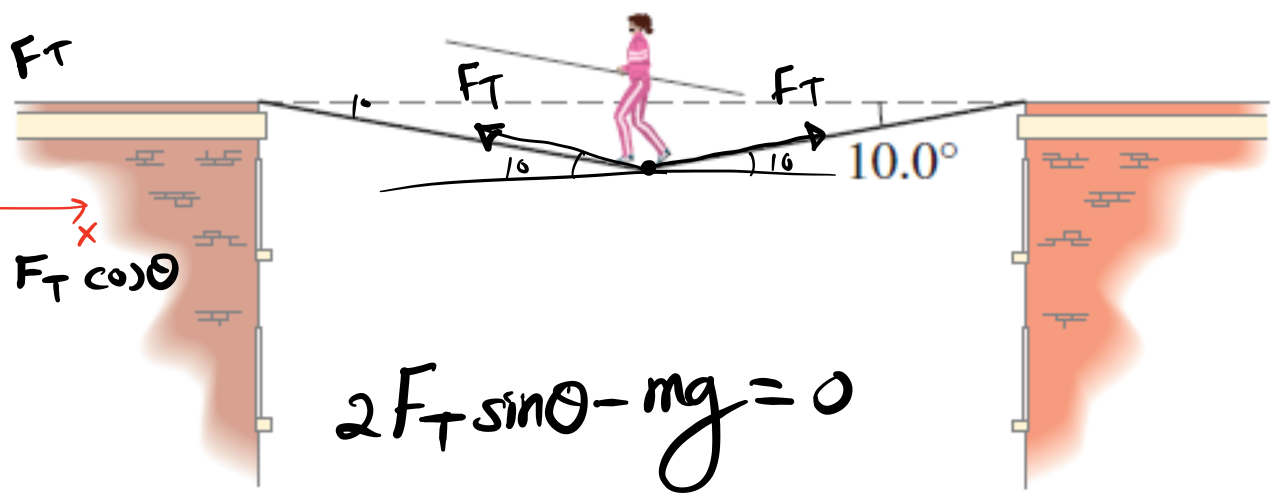

$F_{reaction} = ma$

$180 = 60a$

$a = 3\ m/s^2$ [backward]

Arlene is to walk across a "high wire" strung horizontally between two buildings 10.0 m apart. The sag in the rope when she is at the midpoint is 10.0°, as shown in If her mass is 50.0 kg, what is the tension in the rope at this point?




$$2F_T \sin\theta - mg = 0$$

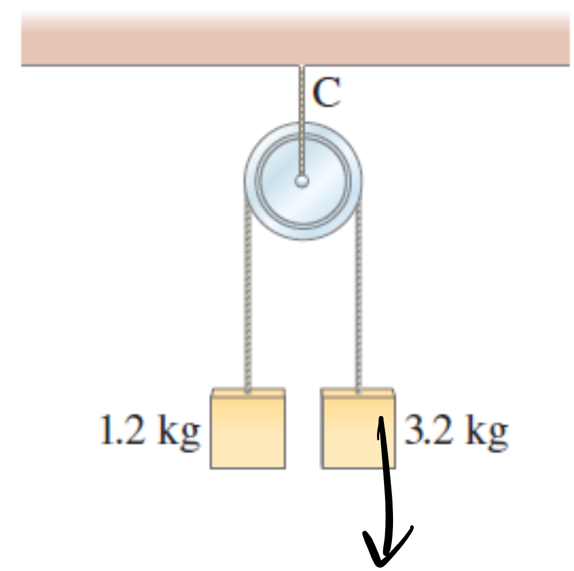
$$F_T = \frac{mg}{2\sin\theta}$$

$$= \frac{50 \times 9.8}{2 \times \sin 10^\circ}$$

$$= 1411\ N$$

# Atwood machine

Determine the tension and acceleration. Ignore the mass of the pulley and cords.




OR

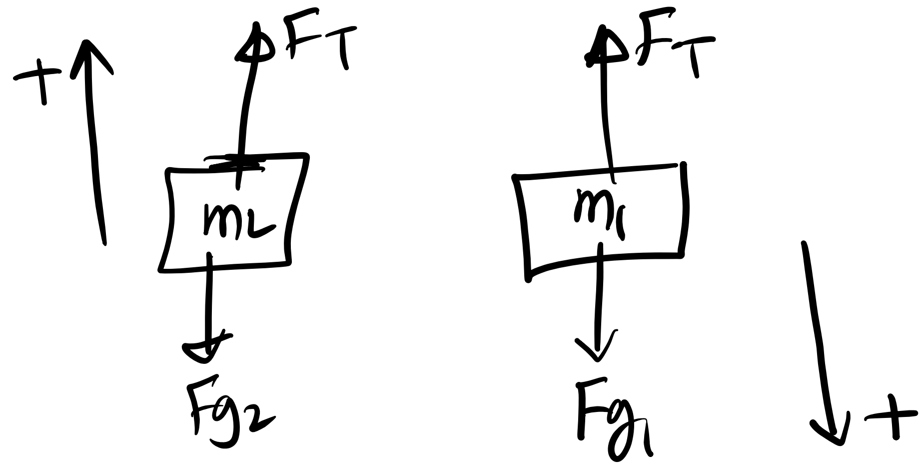
consider the pulley to be frictionless

⇓

ignore the rotation of the pulley

the tension will be the same in both sides of the pulley

Find a? Find T?




$F_T - F_{g2} = m_2 a$ $\quad$ $F_{g1} - F_T = m_1 a$

$$\begin{aligned} F_{g1} - \cancel{F_T} &= m_1 a \\ \cancel{F_T} - F_{g2} &= m_2 a \quad \oplus \end{aligned}$$

---

$$F_{g1} - F_{g2} = (m_1 + m_2)a$$

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

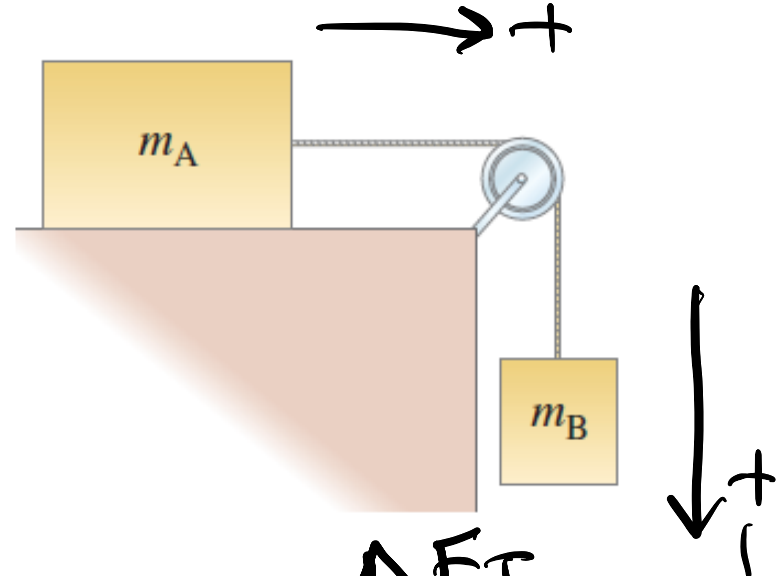
$$= \frac{19.6}{4.4} = 4.45\ m/s^2$$

$$F_T = \underline{F_{g2}} + m_2 a$$

$$= m(g + a)$$

$$\approx 17.1\ N$$ ✓

Two blocks are connected by a massless string that passes over a frictionless pulley. Calculate T and a if the surface is frictionless. $m_A = 3kg, m_B = 2kg$

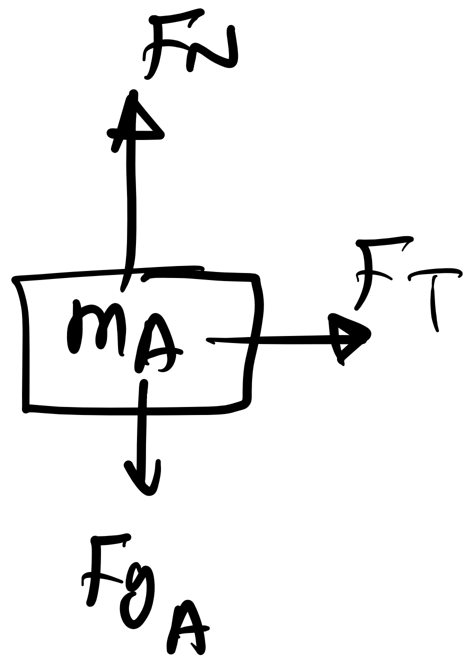


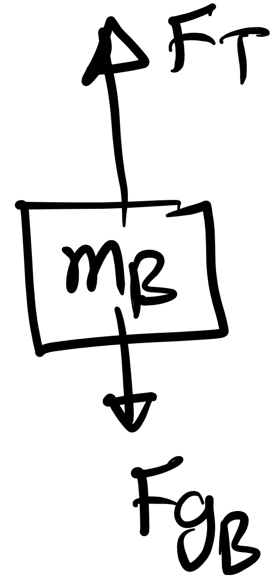

$$F_{Bg} - F_T = m_B a$$

$$F_T = m_A a$$

(+)

$$F_{Bg} = (m_B + m_A)a$$




$$a = \frac{m_B g}{m_B + m_A}$$

$$= \frac{2 \times 9.8}{5} = \frac{19.6}{5}$$

$$= 3.92 \ m/s^2$$

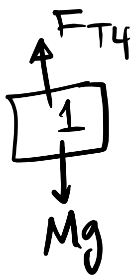
$$F_T = m_A a$$

$$= 3 \times 3.92$$

$$= 11.76 \ N$$

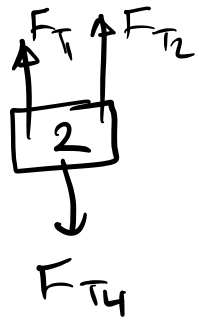
→ constant velocity

What minimum force $F$ is needed to lift the piano? what is the tension in each string?




$F_{T4} - Mg = 0$

$F_{T4} = Mg$



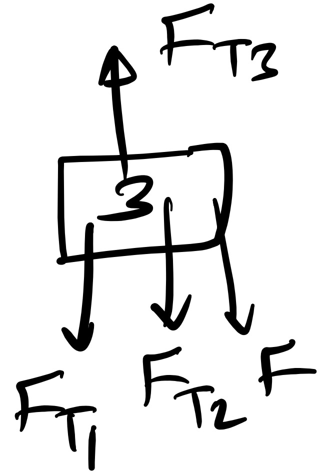

$F_{T_1} + F_{T_2} = F_{T4}$

$2F_{T_1} = F_{T4} = Mg$

$F_{T_1} = \frac{Mg}{2}$

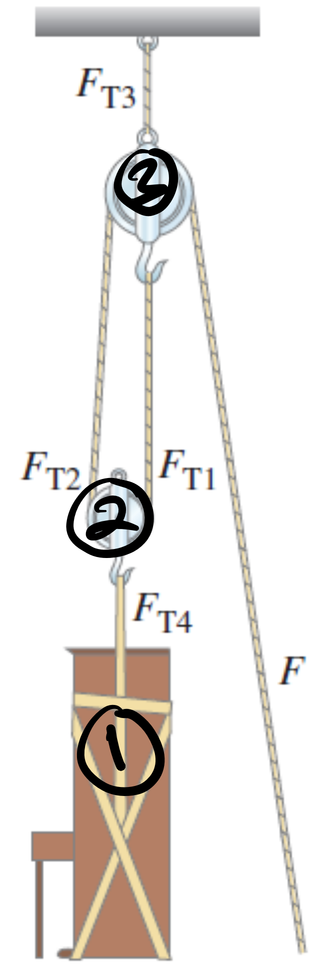
$F_{T_2} = \frac{Mg}{2}$

$F = \frac{Mg}{2}$




$F_{T3} = F_{T_1} + F_{T_2} + F$

$= \frac{3Mg}{2}$



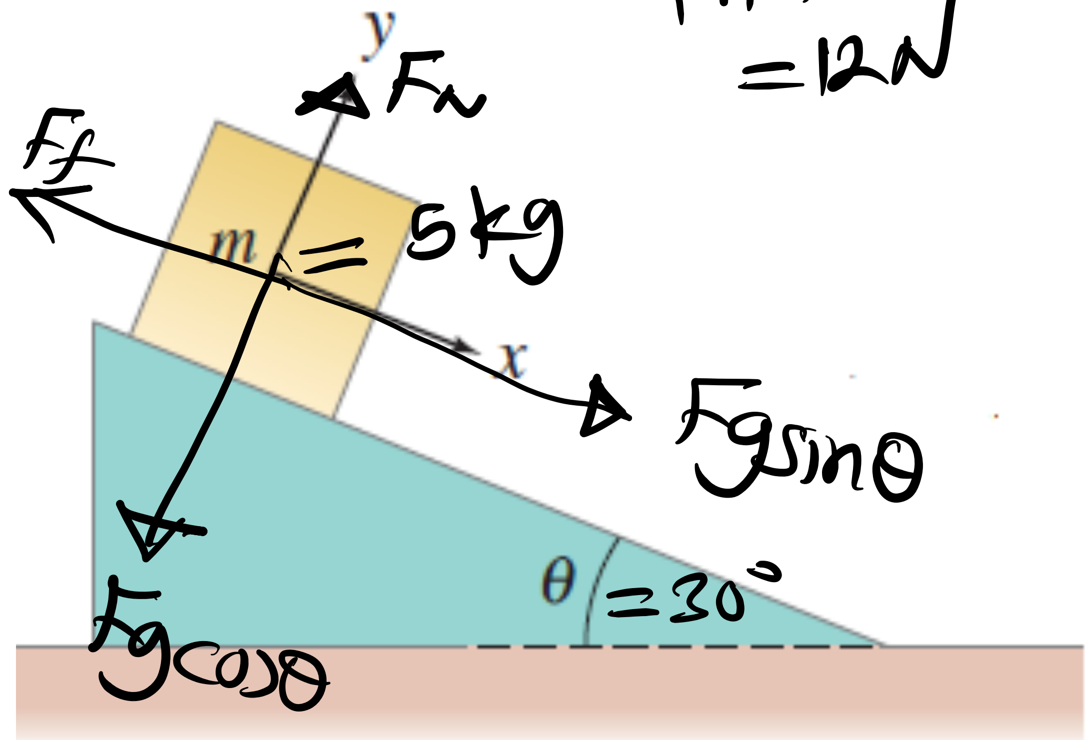

$F = F_{T_1} = F_{T_2}$

# Inclined planes

friction force = 12N

Find $F_N$?

$a$?



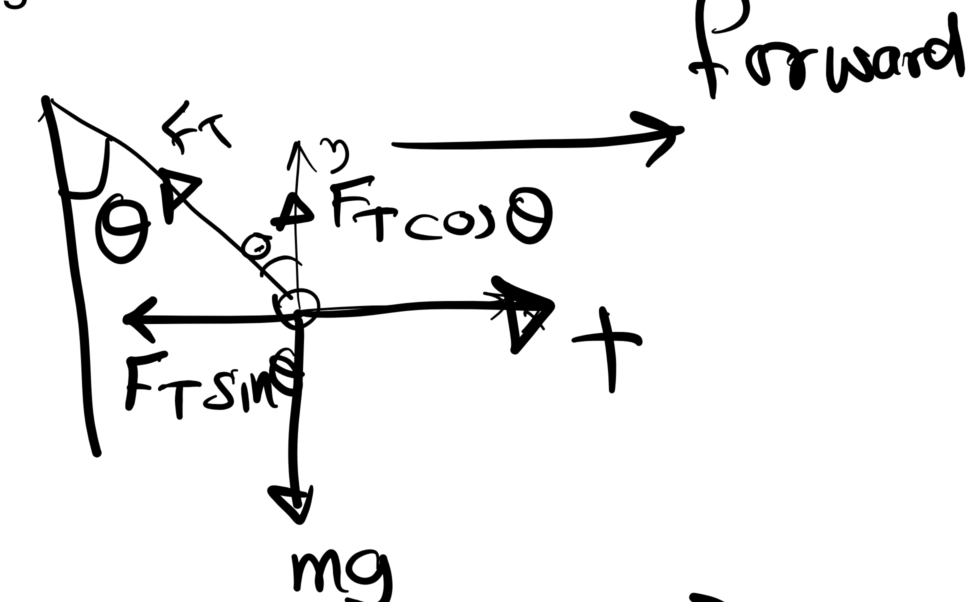

$$F_N = mg\cos\theta$$
$$= 5 \times 9.8 \times \cos 30^\circ$$

$$mg\sin\theta - F_f = ma$$
$$5 \times 9.8 \sin 30^\circ - 12 = 5a$$
$$a = 2.5\ m/s^2$$

An object is hanging by a string from your rearview mirror. While you are decelerating at a constant rate from 20 m/s to rest in 6.0 s, (*a*) what angle does the string make with the vertical, and (*b*) is it toward the windshield or away from it? Repeat in case it was accelerating from 0 to 20 m/s?

$F_T \cos\theta = mg$

$F_T \sin\theta = ma$




$$\frac{F_T \sin\theta = ma}{F_T \cos\theta = mg} \quad \div$$

$$\tan\theta = \frac{a}{g}$$

$$\theta = \tan^{-1}\left(\frac{a}{g}\right) = 18.8^\circ$$

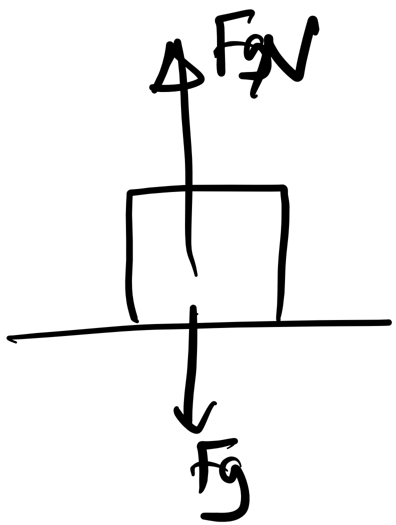
$$a = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{0-20}{6} = (-)3.33\,m/s^2$$

(−) → backward

A woman stands on a bathroom scale in a motionless elevator. When the elevator begins to move, the scale briefly reads only 0.75 of her regular weight. Calculate the acceleration of the elevator, and find the direction of acceleration.

elevator at rest

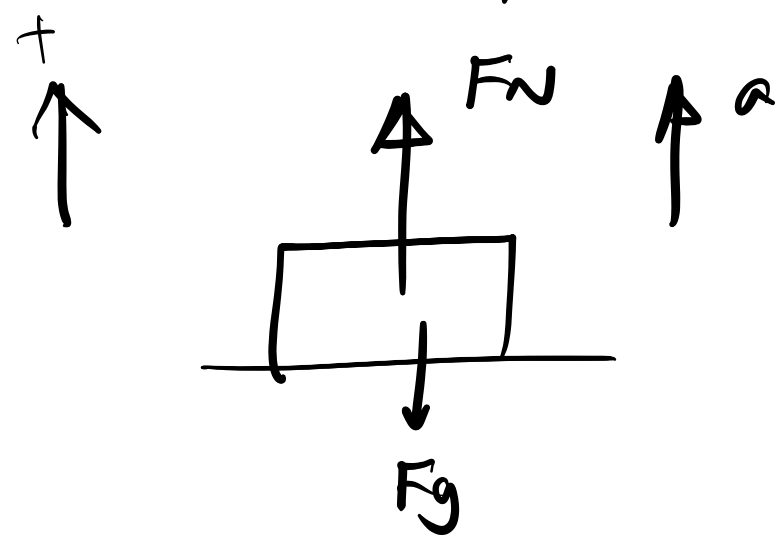
$a = 0$




$F_N - F_g = 0$

$F_N = F_g$

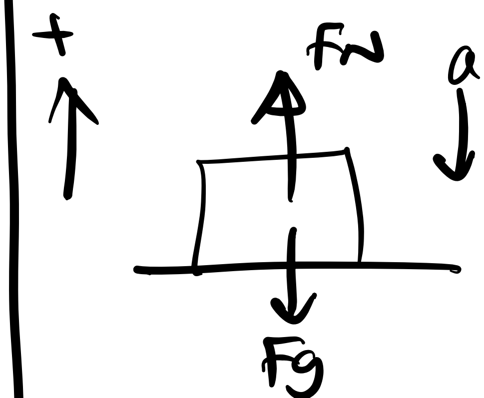
accelerating upward




$F_N - F_g = ma$

$F_N = m(a+g)$

accelerating downward




$F_N - F_g = -ma$

$F_N = m(g-a)$

the elevator is accelerating downward

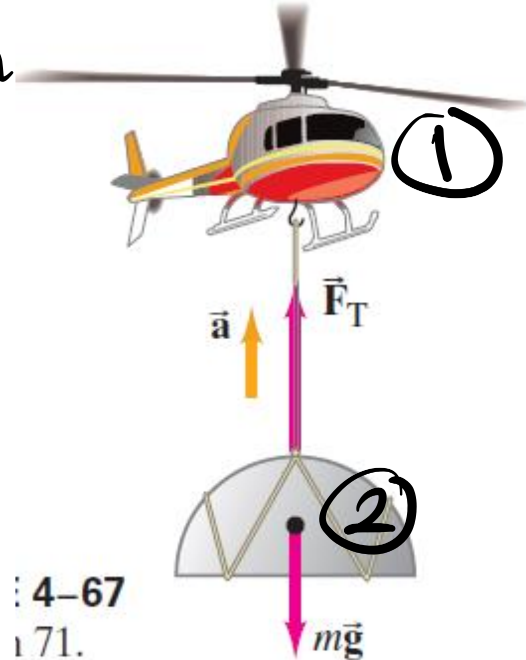
$$F_N = m(g-a)$$

$$0.75\, \cancel{m}g = \cancel{m}(g-a)$$

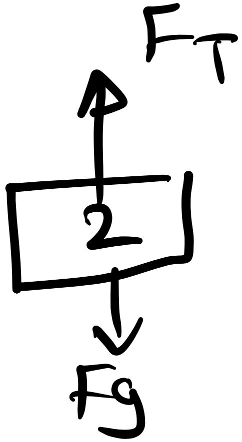
$$0.75g - g = -a$$

$$a = \frac{g}{4} = 2.45\ m/s^2$$

A 7180-kg helicopter accelerates upward at 0.8 m/s² while lifting a 1080-kg frame at a construction site (*a*) What is the lift force exerted by the air on the helicopter rotors? (*b*) What is the tension in the cable (ignore its mass) which connects the frame to the helicopter? (*c*) What force does the cable exert on the helicopter?

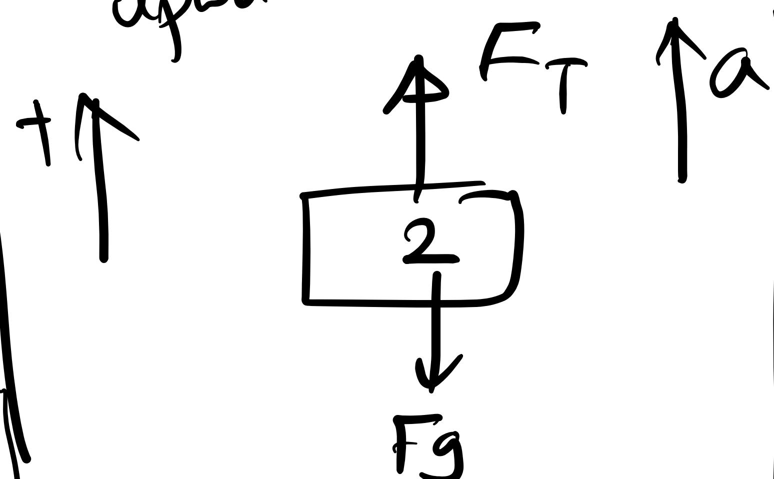



y   $a = 0$



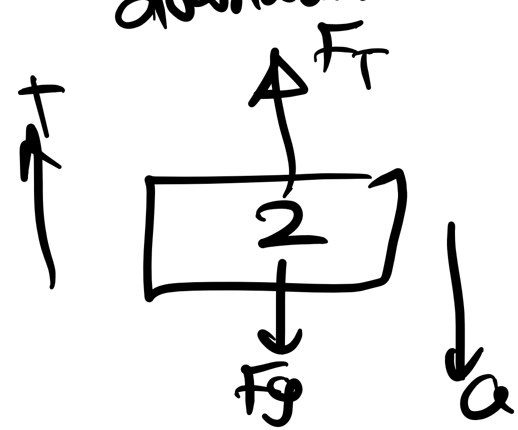

$$F_T - F_g = 0$$
$$F_T = F_g$$

y accelerating upward




$$F_T - F_g = ma$$
$$F_T = m(g + a)$$

y accelerating downward




$$F_T - mg = -ma$$
$$F_T = m(g - a)$$

(a)


$$F_L - F_T - Fg_1 = m_1 a$$

$$F_T - Fg_2 = m_2 a$$

$$F_L - F_T - m_1 g = m_1 a$$

$$+ \quad F_T - m_2 g = m_2 a$$

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

$$F_L - 7180(9.8) - 1080(9.8) = (7180 + 1080)(0.8)$$

$$F_L = 87560 \text{ N} = 8.8 \times 10^4 \text{ N}$$

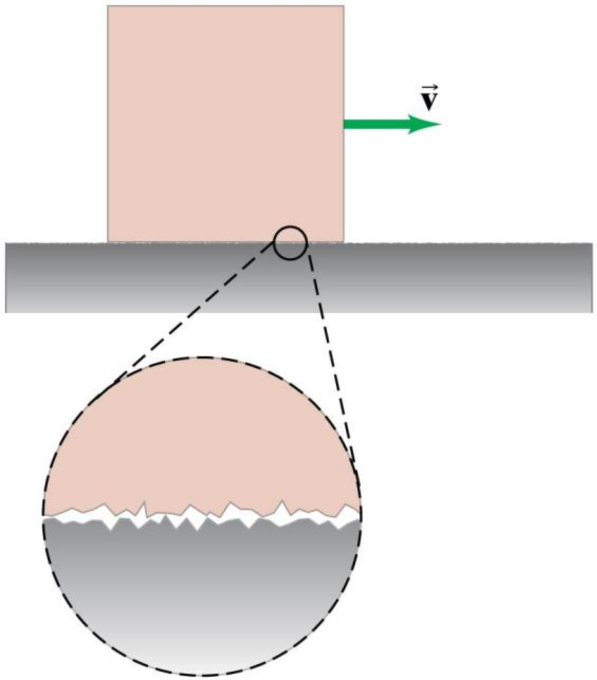
(b) $F_T = m_2 (a + g)$

$= 1080(0.8 + 9.8)$

$= 1.1 \times 10^4$ N

(c) $1.1 \times 10^4$ N

# 4-8 Problems Involving Friction, Inclines



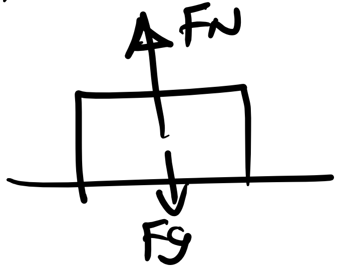

On a microscopic scale, most surfaces are rough. The exact details are not yet known, but the force can be modeled in a simple way.

# Static friction

Static friction is the frictional force between two surfaces that are not moving along each other. Static friction keeps objects on inclines from sliding, and keeps objects from moving when a force is first applied.

Case I

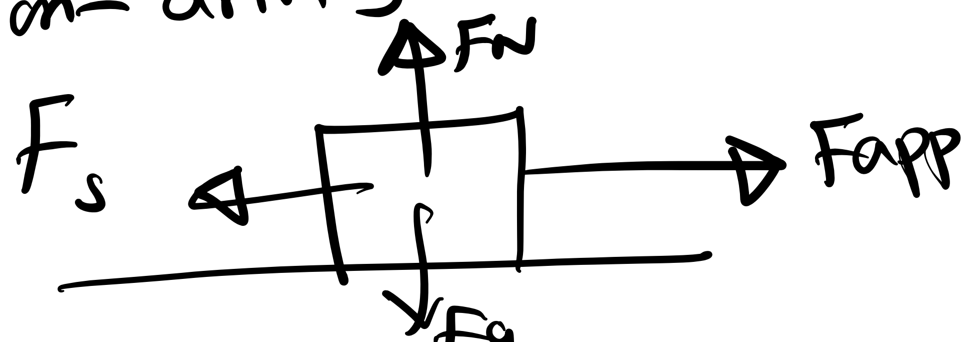
object at rest on a rough surface where the net motion-driving-force is zero




$F_s = 0$

Case II

object at rest on a rough surface and the net motion-driving-force ≠ 0



$F_{app} - F_s = 0$

$F_s = F_{app}$

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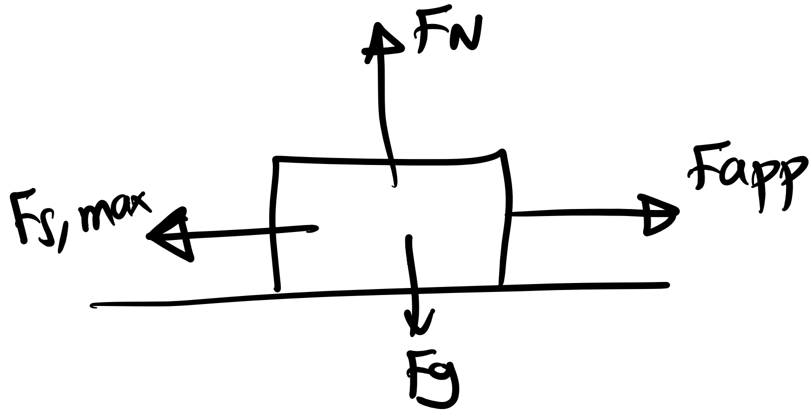
Case (III)



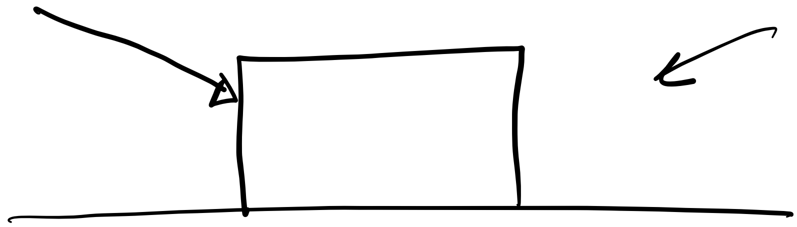

the object is about to move / on verge of motion

$F_{s,max} = F_{app}$

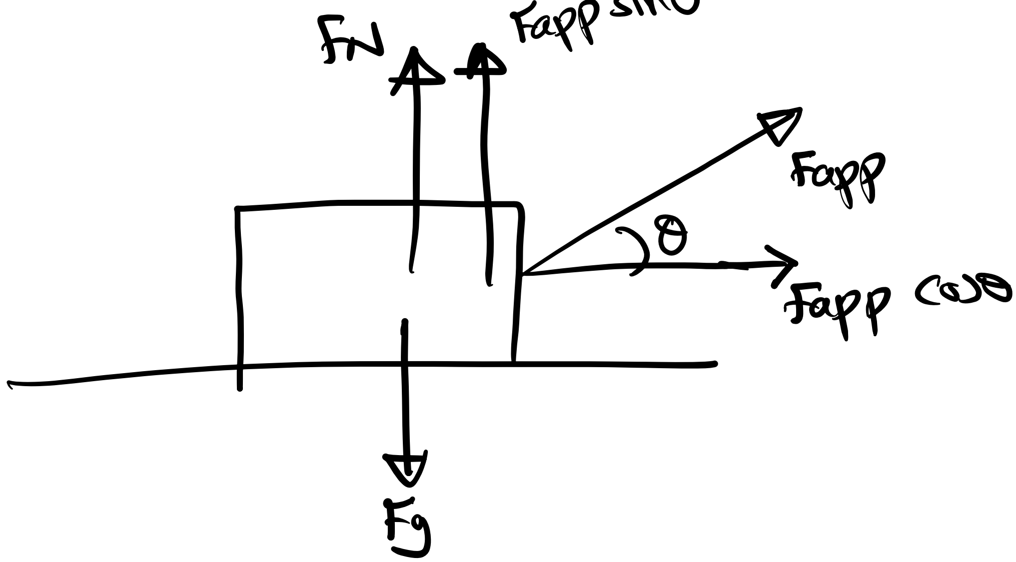
also we can use

$F_{s,max} = \mu_s F_N$

$\mu_s$ → coefficient of static friction



$F_N = mg + F_{app}\sin\theta$




$$F_N + F_{app}\sin\theta - F_g = 0$$

$$F_N = F_g - F_{app}\sin\theta$$

# Kinetic friction

Kinetic friction is the frictional force between two surfaces that are moving along each other.

$$F_k = \mu_k F_N$$

$\mu_k$: coefficient of kinetic friction

$$\mu_k < \mu_s$$

# 4-8 Problems Involving Friction, Inclines

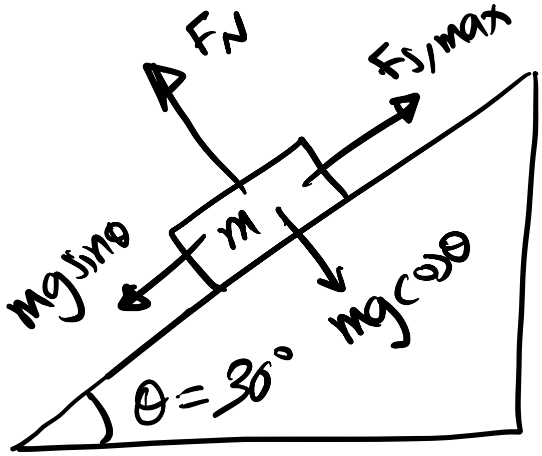
This table lists the measured values of some coefficients of friction. Note that the coefficient depends on both surfaces.

**TABLE 4–2 Coefficients of Friction**†

| Surfaces | Coefficient of Static Friction, $\mu_s$ | Coefficient of Kinetic Friction, $\mu_k$ |
|---|---|---|
| Wood on wood | 0.4 | 0.2 |
| Ice on ice | 0.1 | 0.03 |
| Metal on metal (lubricated) | 0.15 | 0.07 |
| Steel on steel (unlubricated) | 0.7 | 0.6 |
| Rubber on dry concrete | 1.0 | 0.8 |
| Rubber on wet concrete | 0.7 | 0.5 |
| Rubber on other solid surfaces | 1–4 | 1 |
| Teflon® on Teflon in air | 0.04 | 0.04 |
| Teflon on steel in air | 0.04 | 0.04 |
| Lubricated ball bearings | <0.01 | <0.01 |
| Synovial joints (in human limbs) | 0.01 | 0.01 |

† Values are approximate and intended only as a guide.

" if the object is on verge of sliding, find $\mu_s$?




" find the minimum value of $\mu_s$ that can hold the object from sliding?"

$$mg\sin\theta - F_{s,max} = 0$$

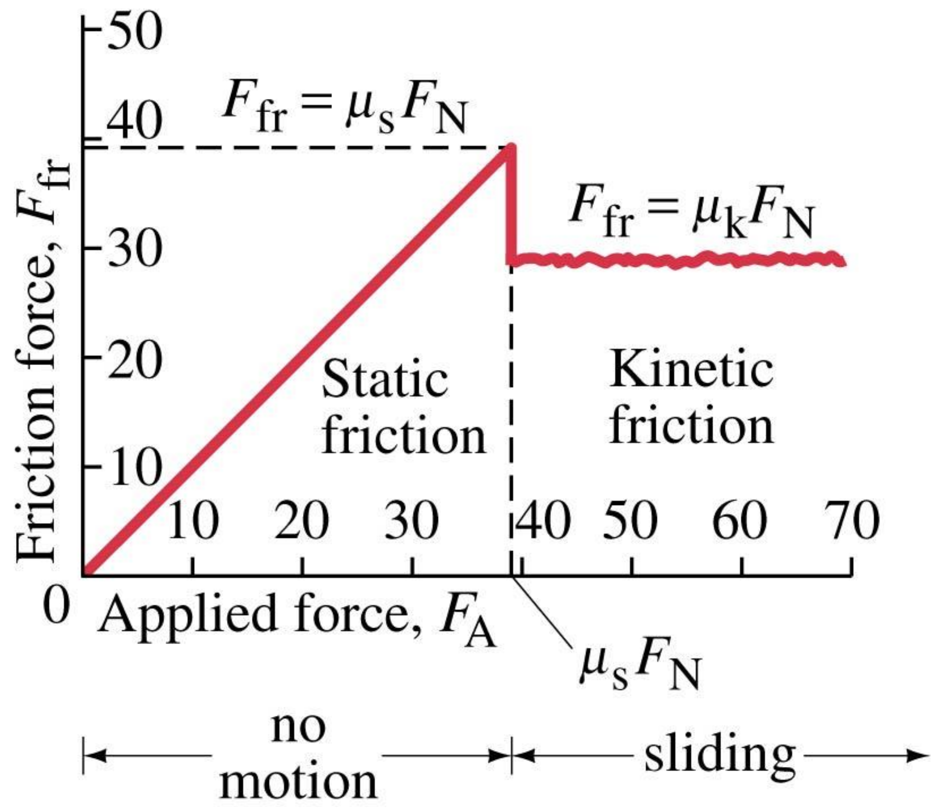
$$mg\sin\theta = \mu_s F_N$$

$$\cancel{mg}\sin\theta = \mu_s \cancel{mg}\cos\theta$$

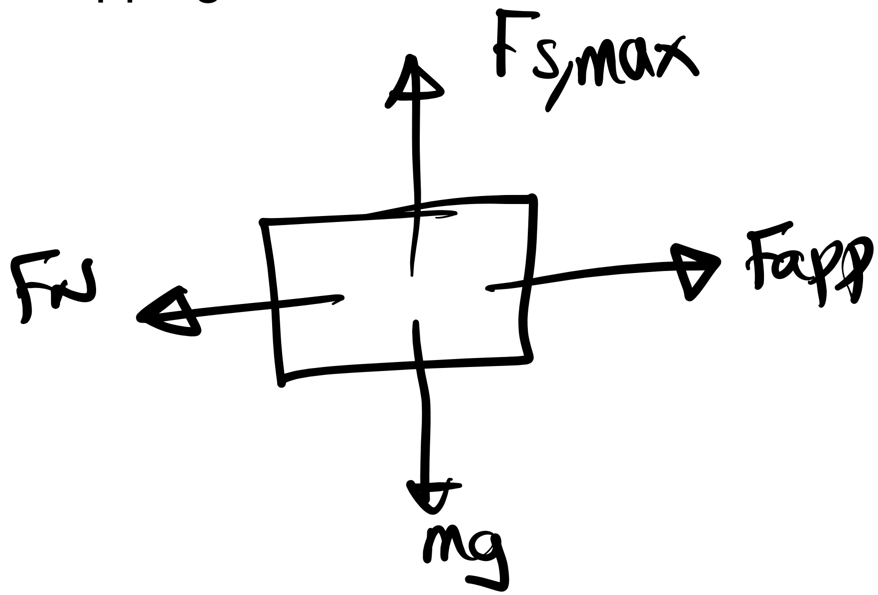
$$\mu_s = \tan\theta = \tan 30^\circ = 0.58$$

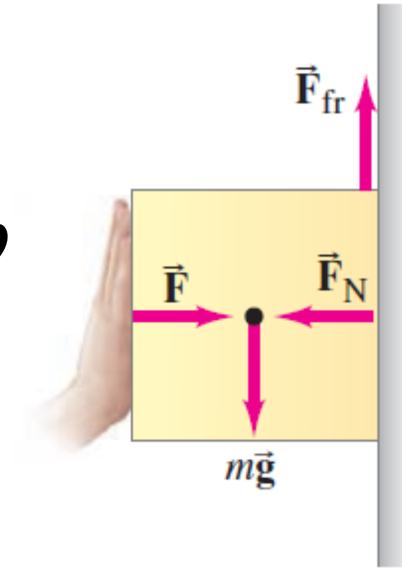
# 4-8 Problems Involving Friction, Inclines

The static frictional force increases as the applied force increases, until it reaches its maximum. Then the object starts to move, and the kinetic frictional force takes over.



You can hold a 5.0 kg box against a rough wall ($\mu_s = 0.6, \mu_k = 0.3$) and prevent it from slipping down by pressing hard horizontally. Calculate the minimum force needed to keep it from slipping down?



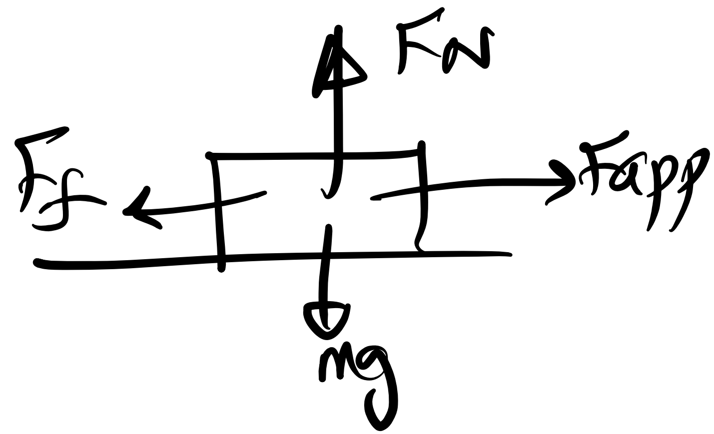




$$F_{app} = F_N$$

$$mg = F_{s,max} = \mu_s F_N$$

$$mg = \mu_s F_{app} \Rightarrow F_{app} = \frac{mg}{\mu_s} = \frac{5 \times 9.8}{0.6} = 82N$$

**36.** (I) A force of 35.0 N is required to start a 6.0-kg box moving across a horizontal concrete floor. (*a*) What is the coefficient of static friction between the box and the floor? (*b*) If the 35.0-N force continues, the box accelerates at $0.60\ \text{m/s}^2$. What is the coefficient of kinetic friction?




(a)

$$F_{s,max} = 35\ N$$

$$F_{app} = F_{s,max} = \mu_s F_N$$

$$35 = \mu_s mg$$

$$\mu_s = \frac{35}{(6)(9.8)} = 0.6$$

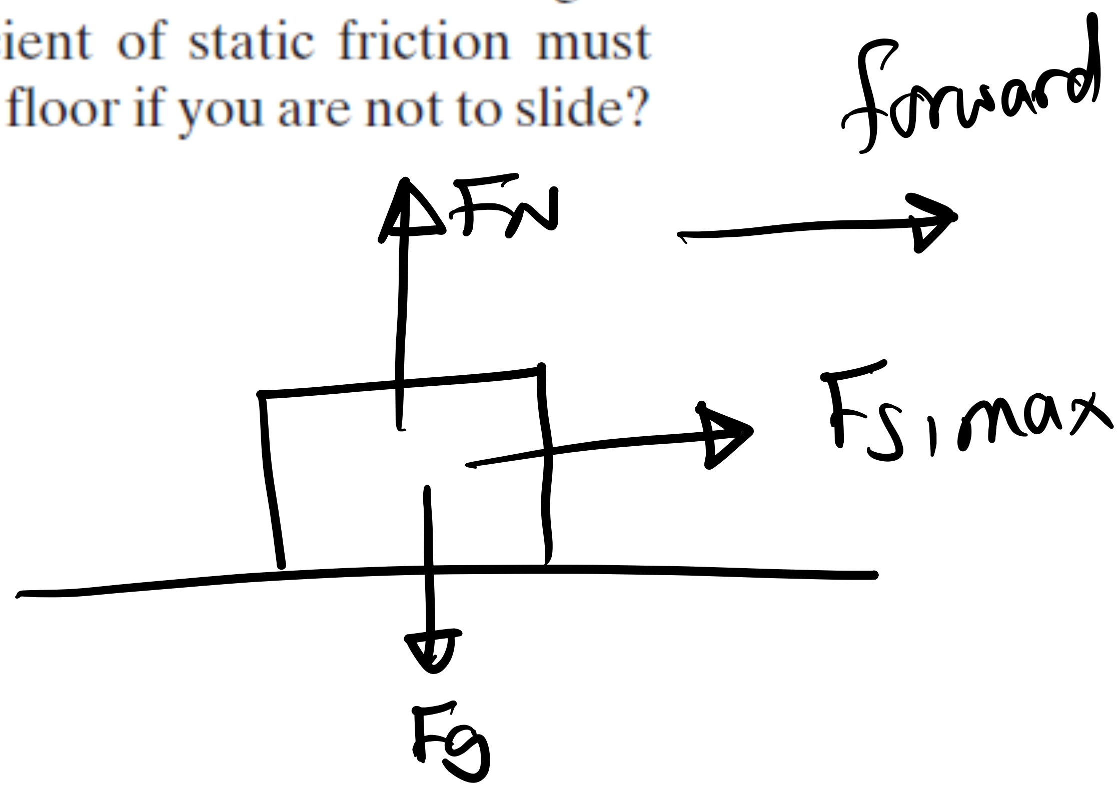
$$F_{app} - F_k = ma$$

$$F_{app} - \mu_k F_N = ma$$

$$35 - \mu_k (6)(9.8) = 6(0.6)$$

$$\mu_k = 0.52$$

**37.** (I) Suppose you are standing on a train accelerating at 0.20 $g$. What minimum coefficient of static friction must exist between your feet and the floor if you are not to slide?




$$F_N = mg$$

$$F_{s,max} = ma$$

$$\mu_s \cancel{m}g = \cancel{m}a$$

$$\mu_s = \frac{a}{g}$$

$$= \frac{0.2\cancel{g}}{\cancel{g}} = 0.2$$

**45.** (II) In Fig. 4–56 the coefficient of static friction between mass $m_A$ and the table is 0.40, whereas the coefficient of kinetic friction is 0.20. (*a*) What minimum value of $m_A$ will keep the system from starting to move? (*b*) What value(s) of $m_A$ will keep the system moving at constant speed? [Ignore masses of the cord and the (frictionless) pulley.]

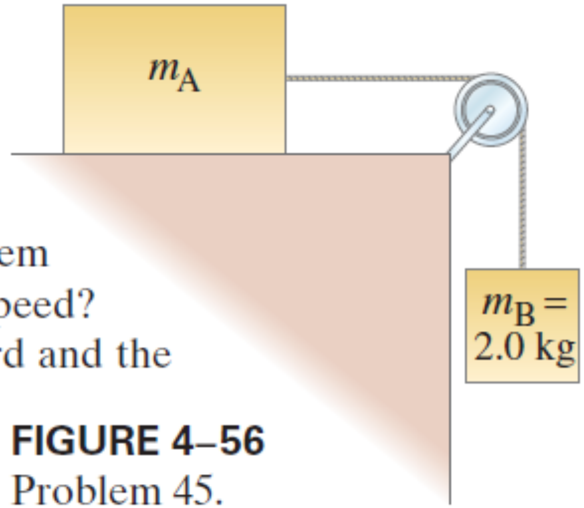
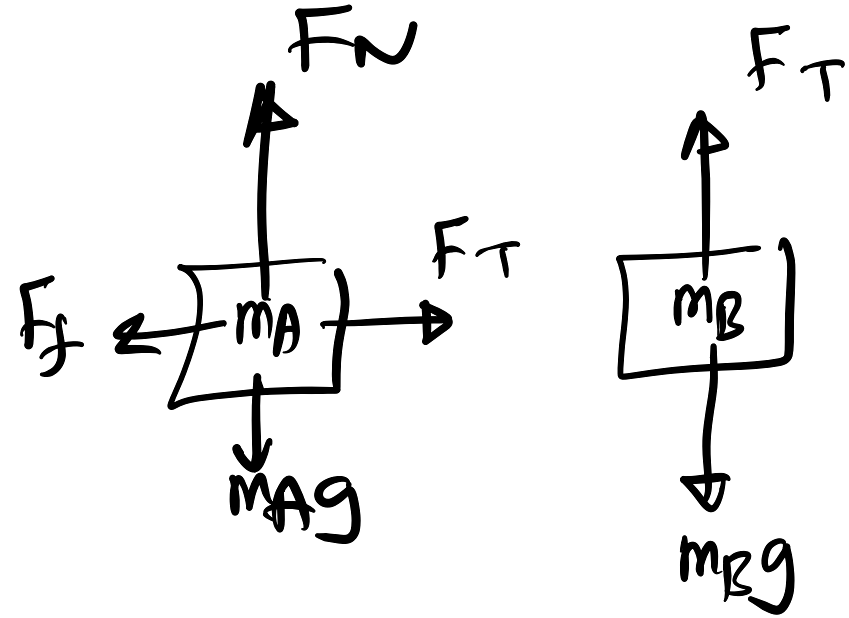



**FIGURE 4–56**
Problem 45.




(a)

$$m_B g = F_T$$

$$F_T = F_{s,max}$$

$$m_B g = F_{s,max}$$

$$m_B \not{g} = \mu_s m_A \not{g}$$

$$m = \frac{m_B}{\;}$$

(b) HW

**47.** (II) Two crates, of mass 65 kg and 125 kg, are in contact and at rest on a horizontal surface (Fig. 4–57). A 650-N force is exerted on the 65-kg crate. If the coefficient of kinetic friction is 0.18, calculate (*a*) the acceleration of the system, and (*b*) the force that each crate exerts on the other. (*c*) Repeat with the crates reversed.

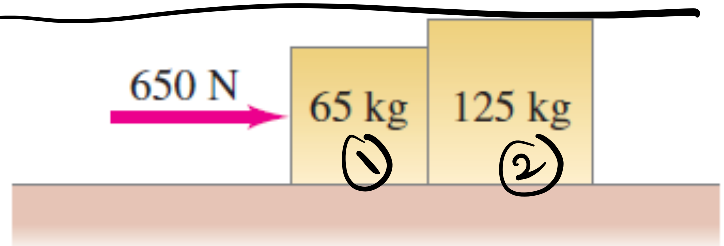
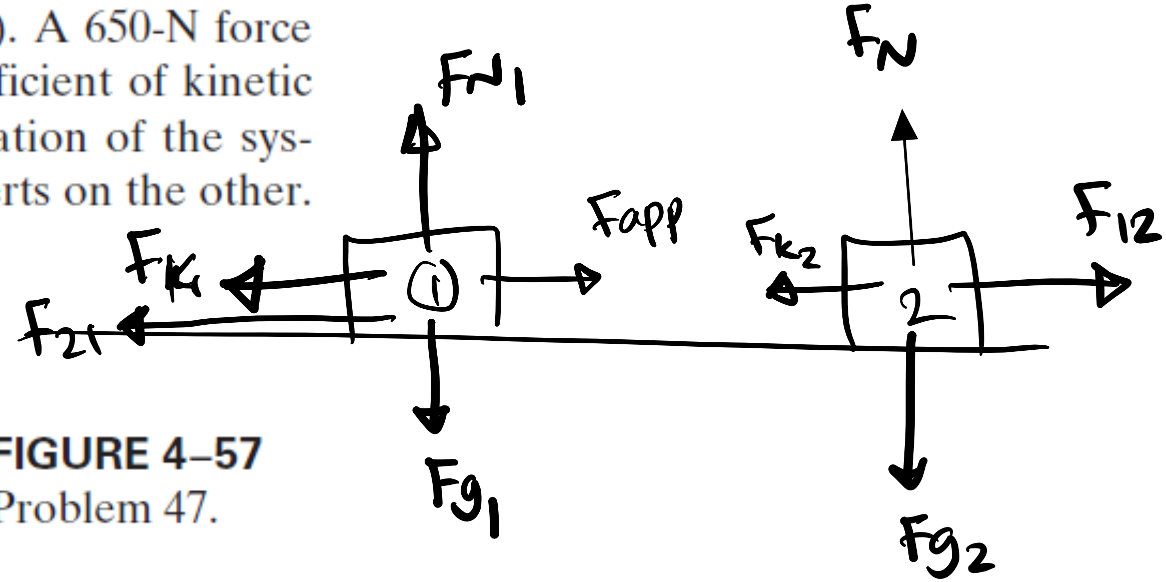



**FIGURE 4–57**
Problem 47.




$$F_{app} - F_{k_1} - F_{21} = m_1 a$$

$$F_{12} - F_{k_2} = m_2 a \quad (+)$$

$$F_{12} = \mu m_2 g + m_2 a$$

$$F_{app} - F_{k_1} - F_{k_2} = (m_1 + m_2)a$$

$$F_{app} - \mu m_1 g - \mu m_2 g = (m_1 + m_2)a$$

$$F_{app} - \mu(m_1 + m_2)g = (m_1 + m_2)a$$

$$650 - 0.18(190)(9.8) = 190a$$

$$a = 1.7 \text{ m/s}^2$$

HW

**60.** (III) Two masses $m_A = 2.0\,\text{kg}$ and $m_B = 5.0\,\text{kg}$ are on inclines and are connected together by a string as shown in Fig. 4–61. The coefficient of kinetic friction between each mass and its incline is $\mu_k = 0.30$. If $m_A$ moves up, and $m_B$ moves down, determine their acceleration. [Ignore masses of the (frictionless) pulley and the cord.]

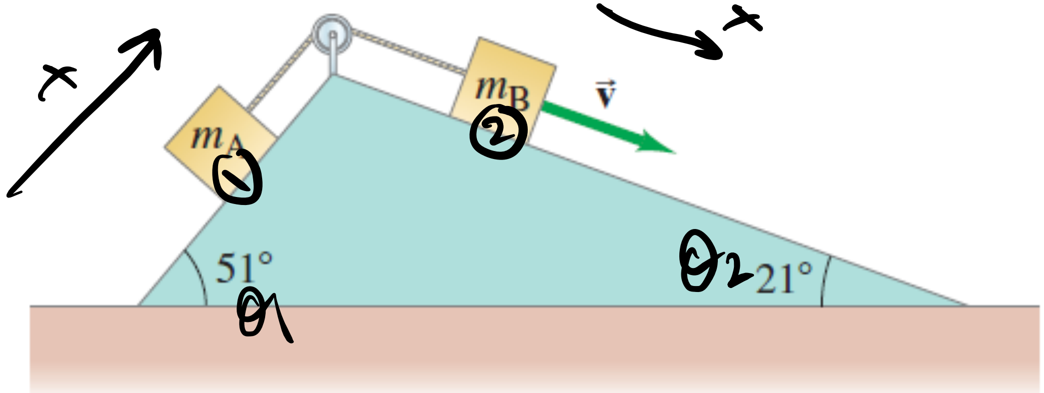
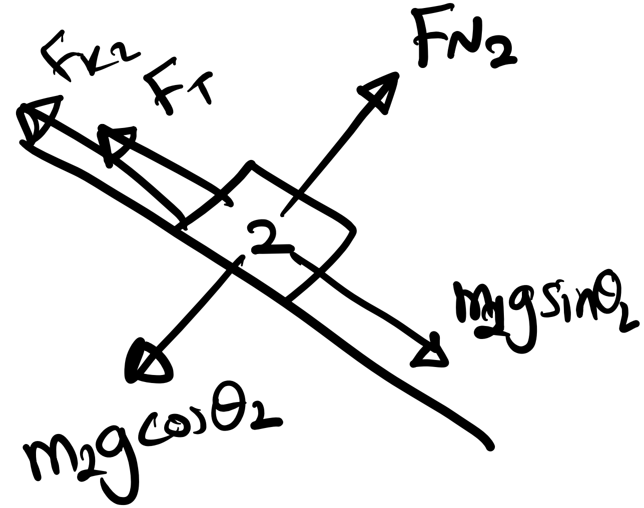
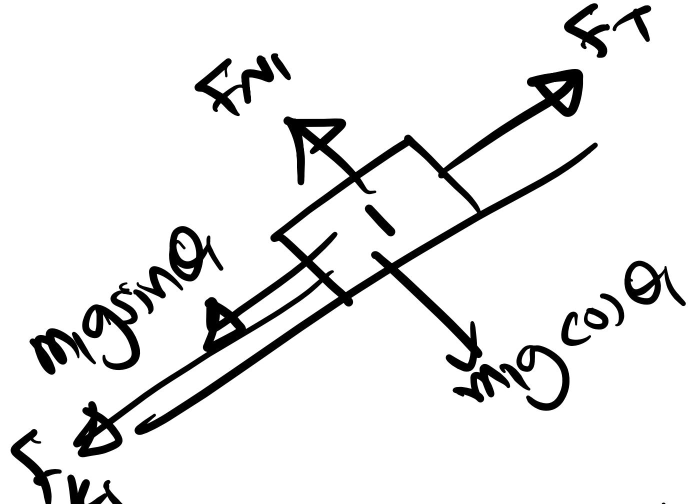



**FIGURE 4–61** Problem 60.




$$m_2 g \sin\theta_2 - F_T - F_{K2} = m_2 a$$

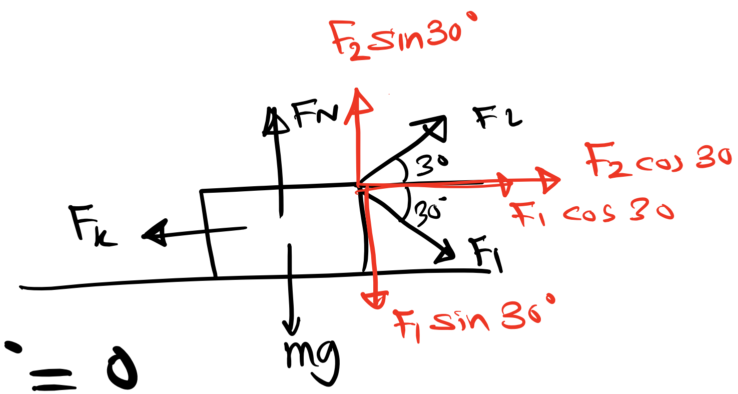
$$F_T - m_1 g \sin\theta_1 - F_{K1} = m_1 a$$

$$m_2 g \sin\theta_2 - m_1 g \sin\theta_1 - F_{K1} - F_{K2} = (m_1 + m_2) a$$

HW

Two workers move a 50 kg crate by sliding it across the floor. Worker 1 can exert a force of 380 N, and worker 2 can exert a force of 270 N. One worker must push on the crate below the horizontal and the other must pull at the same angle above the horizontal . Determine the acceleration of the crate. Assume that the coefficient of kinetic friction is $\mu_k$ =0.52 and the angle is 30.

$$F_1 \cos 30^\circ + F_2 \cos 30^\circ - F_k = ma$$




$$F_k = \mu F_N$$

$$F_N + F_2 \sin 30^\circ - mg - F_1 \sin 30^\circ = 0$$

$$F_N = mg + F_1 \sin 30^\circ - F_2 \sin 30^\circ$$

HW!

# Summary of Chapter 4

- Newton's first law: If the net force on an object is zero, it will remain either at rest or moving in a straight line at constant speed.
- Newton's second law: $\Sigma \vec{\mathbf{F}} = m\vec{\mathbf{a}}.$ (4-1)
- Newton's third law: $\vec{\mathbf{F}}_{\mathrm{GP}} = -\vec{\mathbf{F}}_{\mathrm{PG}}$ (4-2)
- Weight is the gravitational force on an object.
- The frictional force can be written $F_{\mathrm{fr}} = \mu_{\mathrm{k}} F_{\mathrm{N}}$ (kinetic friction) or $F_{\mathrm{fr}} \leq \mu_{\mathrm{s}} F_{\mathrm{N}}$ (static friction)