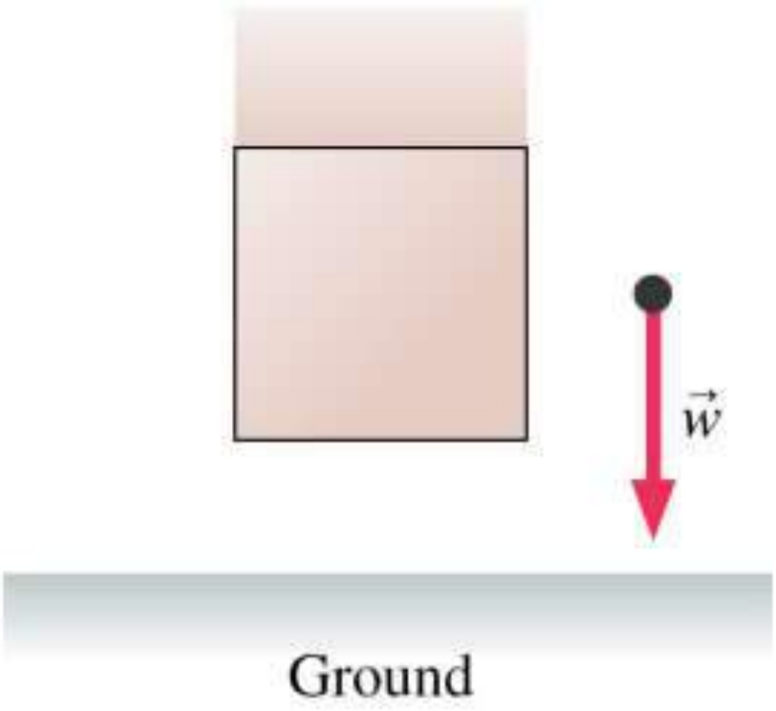
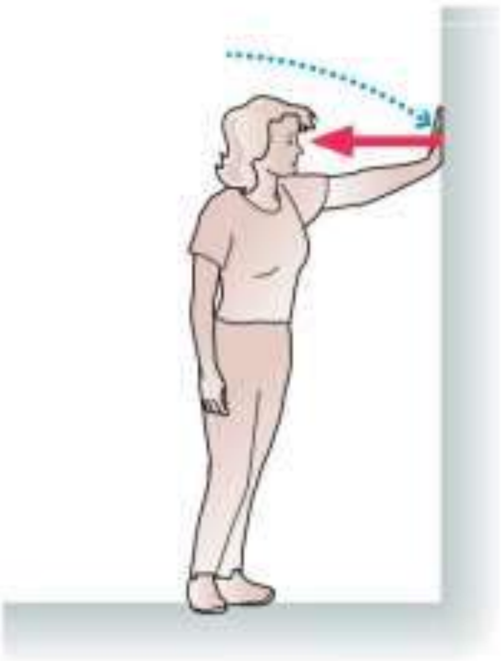
Problems ch 5

APPLICATIONS OF NEWTONS LAW

Force: Properties

1. Push or Pull
2. Acts on an object
3. Force is a vector
4. Force is either a contact force or long range force


$\vec{w}$
Ground



Major forces

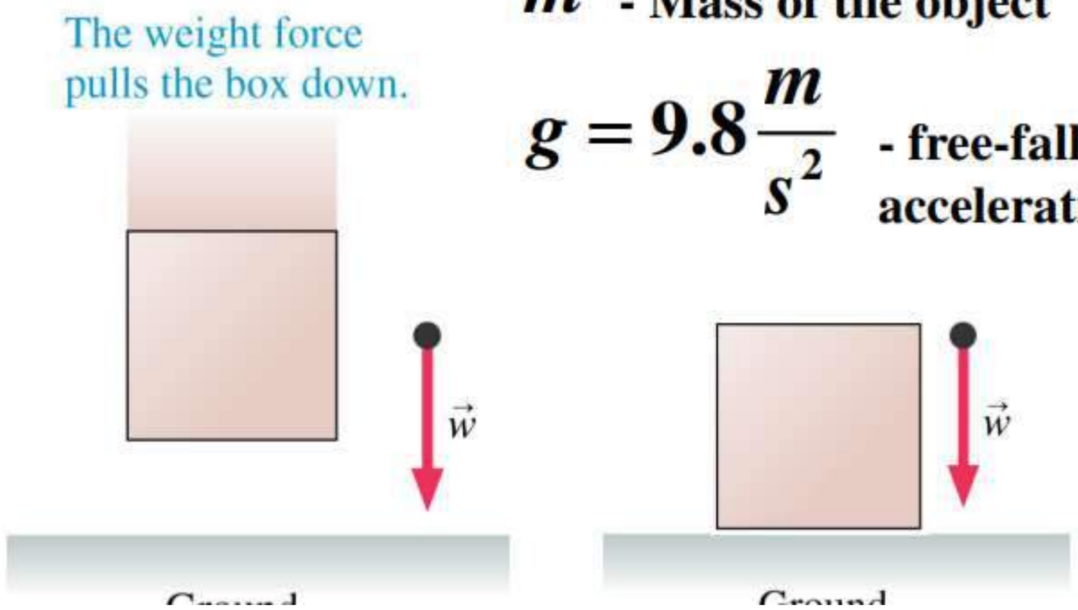
1. **Weight – gravitational force**

pulls the objects down – **determines its direction**

magnitude: $$\vec{w} = m\vec{g}$$

m - **Mass of the object**

$$g = 9.8\frac{m}{s^2}$$ - **free-fall acceleration**



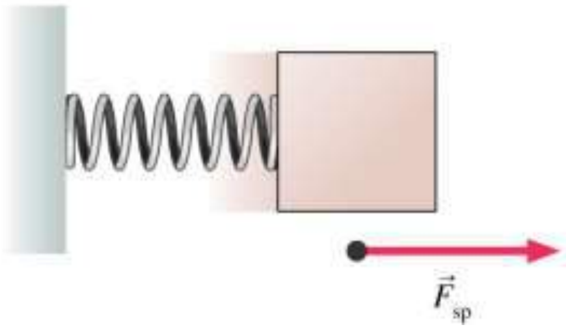
2. **Spring Force**

$$\boxed{F_{sp} = kx}$$

k - **coefficient, which depends only on geometric parameters of the spring**

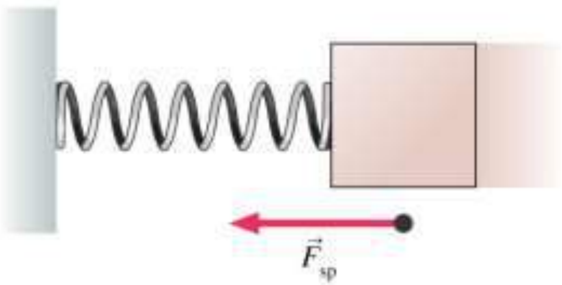
$x = |\Delta l|$ - **change in the length of the spring**

A compressed spring exerts a pushing force on an object.



pu

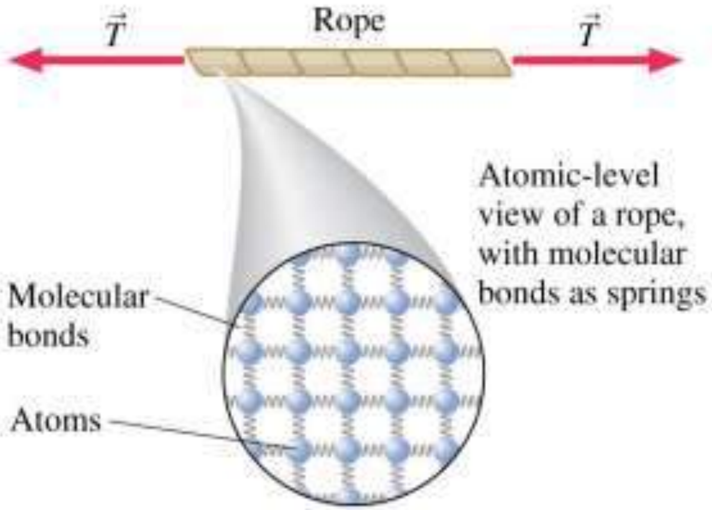
A stretched spring exerts a pulling force on an object.



3. Tension Force $\vec{T}$

direction is always in the direction of the rope

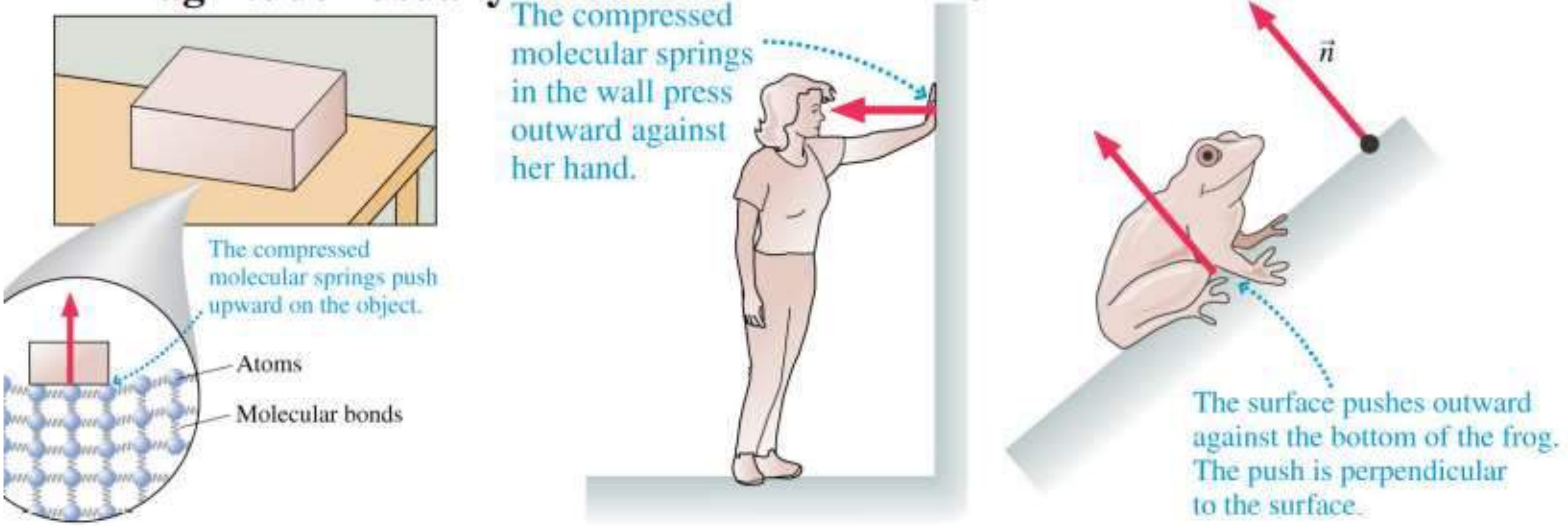
magnitude - usually found from the condition of equilibrium



4. Normal Force $\vec{n}$

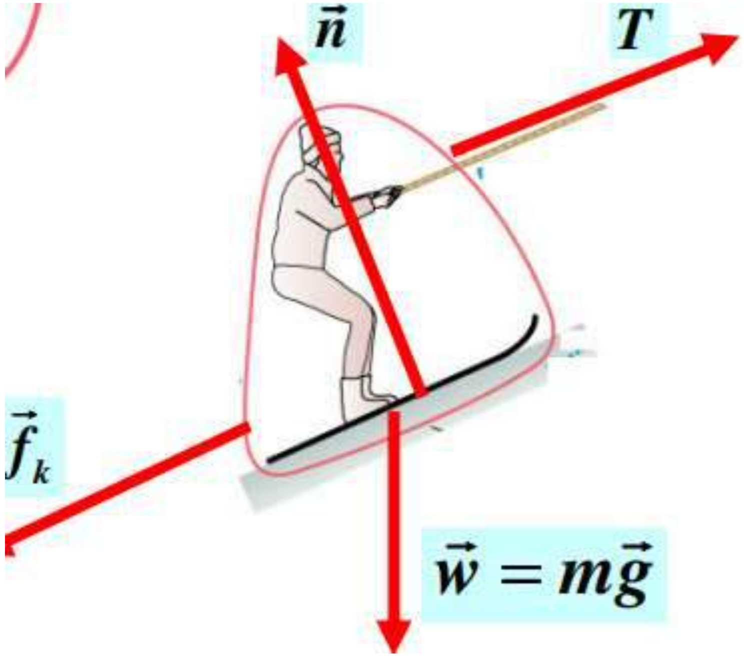
direction is always perpendicular to the surface

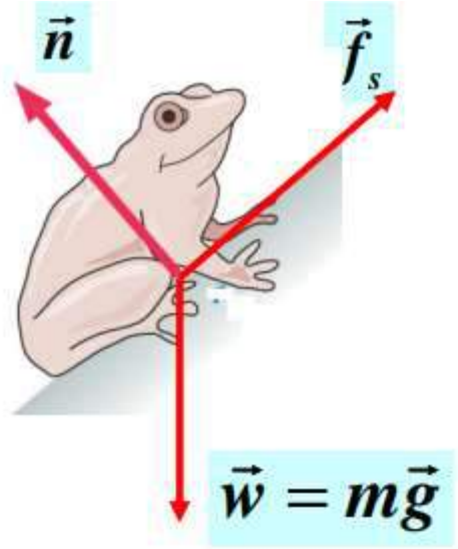
magnitude - usually found from the condition of equilibrium



5. Friction

- kinetic friction $\vec{f}_k$
- static friction $\vec{f}_s$





Free-Body Diagram

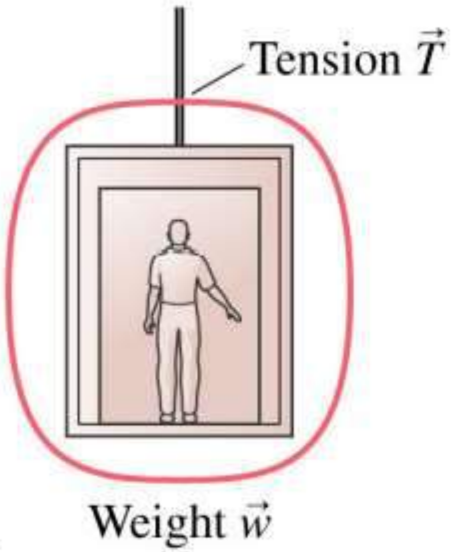
1) Object – as a particle

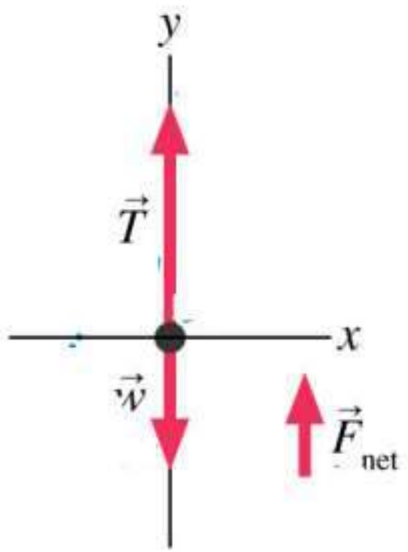
2) Identify all the forces

3) Find the net force (vector sum of all individual forces)

4) Find the acceleration of the object (second Newton's law)

5) With the known acceleration find kinematics of the object



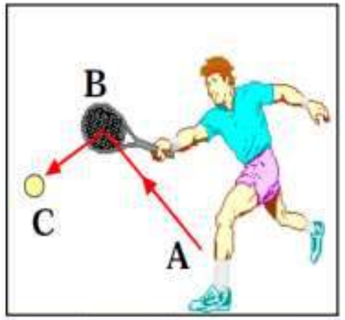


Newton's Laws of Motion

It was Isaac Newton (1642-1727) who realized the importance of force and its connection with motion.

<u>Three Laws of motion</u>

- **1st Law: inertia**
- **2nd Law: change in motion**
- **3rd Law: action and reaction pairs**



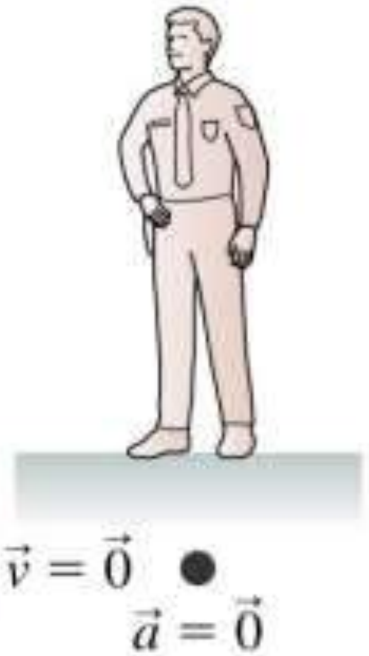
Newton's First Law

An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

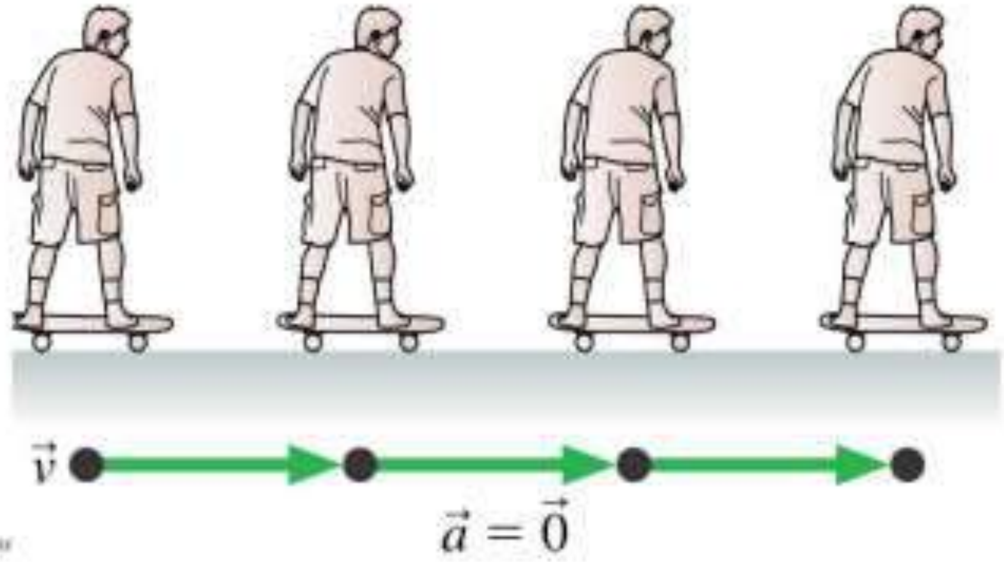
$\vec{F}_{net} = 0$ **then** $\vec{a} = 0$ **velocity is constant**

$\vec{F}_{net} = 0$ then $\vec{a} = 0$ velocity is constant

Static equilibrium



Dynamic equilibrium



Inertial reference frames

Inertial reference frame is the coordinate system in which Newton's laws are valid.

The earth is an inertial reference frame

Any other coordinate systems, which are traveling with constant velocity with respect to the earth is an inertial reference frame

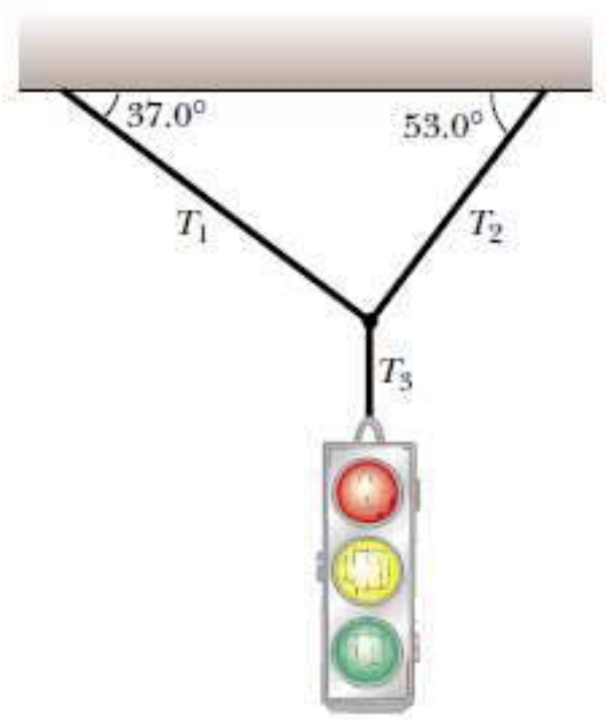
Car traveling with constant velocity is an inertial reference frame

Car traveling with acceleration is NOT an inertial reference frame (violation of Newton's law)

Problem solving

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?

Problem 1



Problem 1

$$(1) \qquad \sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0$$

$$(2) \qquad \sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-122 \text{ N}) = 0$$

$$(3) \qquad T_2 = T_1\left(\frac{\cos 37.0°}{\cos 53.0°}\right) = 1.33T_1$$

This value for T_2 is substituted into (2) to yield

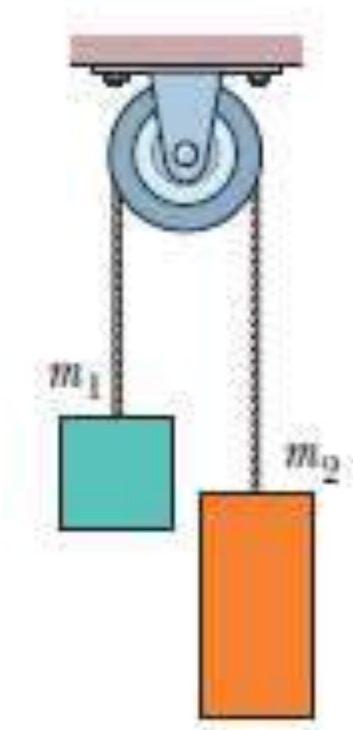
$$T_1 \sin 37.0° + (1.33T_1)(\sin 53.0°) - 122 \text{ N} = 0$$

$$T_1 = 73.4 \text{ N}$$

$$T_2 = 1.33T_1 = 97.4 \text{ N}$$

Solution

••51 GO Figure 5-47 shows two blocks connected by a cord (of negligible mass) that passes over a frictionless pulley (also of negligible mass). The arrangement is known as *Atwood's machine*. One block has mass $m_1 = 1.30$ kg; the other has mass $m_2 = 2.80$ kg. What are (a) the magnitude of the blocks' acceleration and (b) the tension in the cord?



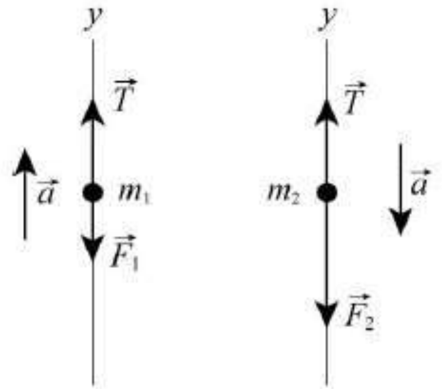
Problem 2

Solution

51. The free-body diagrams for m_1 and m_2 are shown in the figures below. The only forces on the blocks are the upward tension $\vec{T}$ and the downward gravitational forces $\vec{F}_1 = m_1 g$ and $\vec{F}_2 = m_2 g$. Applying Newton's second law, we obtain:

$$T - m_1 g = m_1 a$$

$$m_2 g - T = m_2 a$$



which can be solved to yield

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

Substituting the result back, we have

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

(a) With $m_1 = 1.3$ kg and $m_2 = 2.8$ kg, the acceleration becomes

$$a = \left(\frac{2.80\,\text{kg} - 1.30\,\text{kg}}{2.80\,\text{kg} + 1.30\,\text{kg}}\right)(9.80\,\text{m/s}^2) = 3.59\ \text{m/s}^2 \approx 3.6\ \text{m/s}^2.$$

(b) Similarly, the tension in the cord is

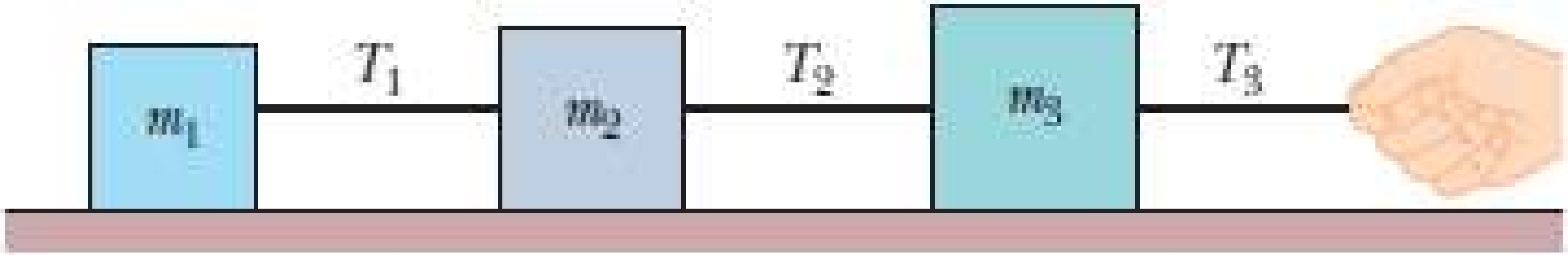
$$T = \frac{2(1.30\,\text{kg})(2.80\,\text{kg})}{1.30\,\text{kg} + 2.80\,\text{kg}}(9.80\,\text{m/s}^2) = 17.4\ \text{N} \approx 17\ \text{N}.$$

solution

••53 In Fig. 5-48, three connected blocks are pulled to the right on a horizontal frictionless table by a force of magnitude $T_3 = 65.0$ N. If $m_1 = 12.0$ kg, $m_2 = 24.0$ kg, and $m_3 = 31.0$ kg, calculate (a) the magnitude of the system's acceleration, (b) the tension T_1, and (c) the tension T_2.

and 65.

Problem 3



m_1
T_1
m_2
T_2
m_3
T_3

53. We apply Newton's second law first to the three blocks as a single system and then to the individual blocks. The $+x$ direction is to the right in Fig. 5-48.

(a) With $m_{sys} = m_1 + m_2 + m_3 = 67.0$ kg, we apply Eq. 5-2 to the x motion of the system, in which case, there is only one force $\vec{T}_3 = +\vec{T}_3\ \hat{\mathrm{i}}$. Therefore,

$$T_3 = m_{sys}a \quad \Rightarrow \quad 65.0\,\mathrm{N} = (67.0\,\mathrm{kg})a$$

which yields $a = 0.970\ \mathrm{m/s^2}$ for the system (and for each of the blocks individually).

(b) Applying Eq. 5-2 to block 1, we find

$$T_1 = m_1 a = (12.0\mathrm{kg})\left(0.970\mathrm{m/s^2}\right) = 11.6\mathrm{N}.$$

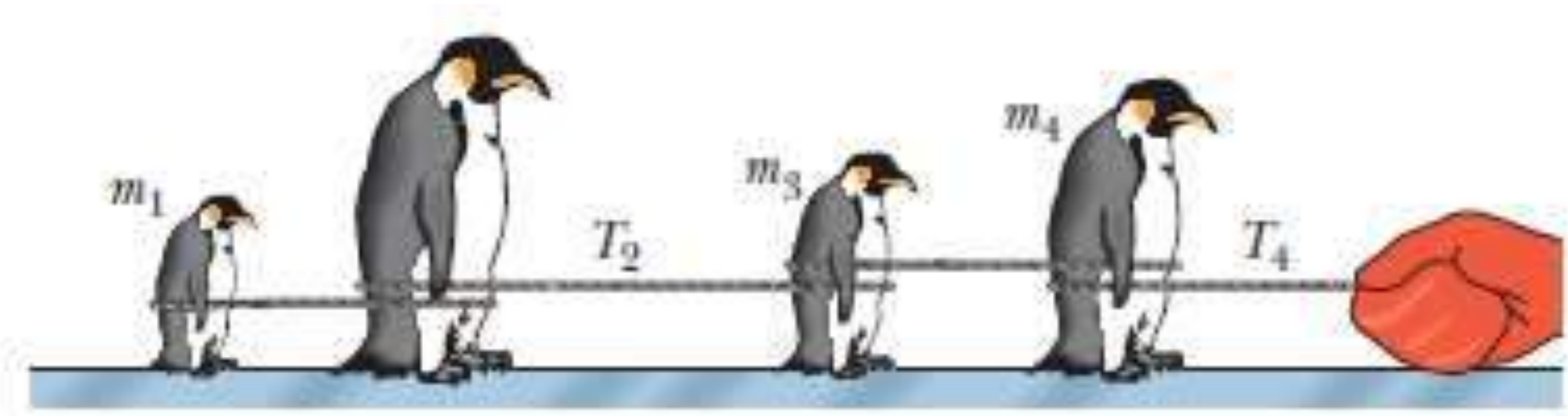
(c) In order to find T_2, we can either analyze the forces on block 3 or we can treat blocks 1 and 2 as a system and examine its forces. We choose the latter.

$$T_2 = (m_1 + m_2)a = (12.0\,\mathrm{kg} + 24.0\,\mathrm{kg})\left(0.970\,\mathrm{m/s^2}\right) = 34.9\ \mathrm{N}.$$

Solution

••54 GO Figure 5-49 shows four penguins that are being playfully pulled along very slippery (frictionless) ice by a curator. The masses of three penguins and the tension in two of the cords are $m_1 = 12$ kg, $m_3 = 15$ kg, $m_4 = 20$ kg, $T_2 = 111$ N, and $T_4 = 222$ N. Find the penguin mass m_2 that is not given.

Problem 6



Problem

54. First, we consider all the penguins (1 through 4, counting left to right) as one system, to which we apply Newton's second law:

$$T_4 = (m_1 + m_2 + m_3 + m_4)a \;\Rightarrow\; 222\text{N} = (12\text{kg} + m_2 + 15\text{kg} + 20\text{kg})a.$$

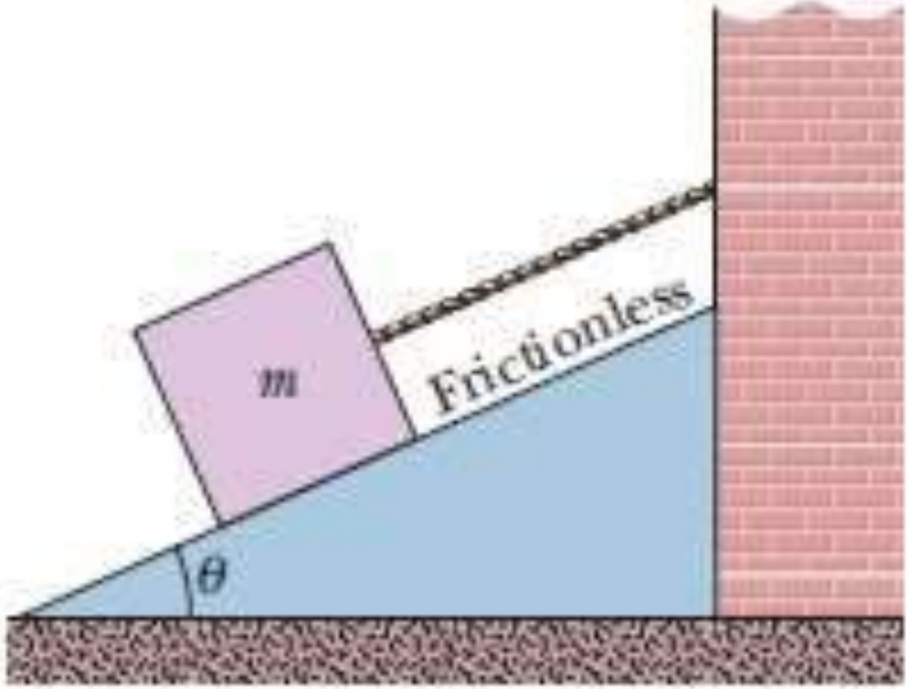
Second, we consider penguins 3 and 4 as one system, for which we have

$$T_4 - T_2 = (m_3 + m_4)a$$
$$111\text{N} = (15\text{ kg} + 20\text{kg})a \;\Rightarrow\; a = 3.2\text{ m/s}^2.$$

Substituting the value, we obtain $m_2 = 23$ kg.

Solution

•17 SSM WWW In Fig. 5-36, let the mass of the block be 8.5 kg and the angle θ be 30°. Find (a) the tension in the cord and (b) the normal force acting on the block. (c) If the cord is cut, find the magnitude of the resulting acceleration of the block.



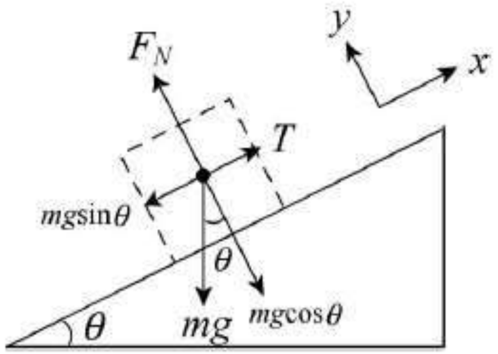
Problem 5

Solution

EXPRESS The free-body diagram of the problem is shown to the right. Since the acceleration of the block is zero, the components of Newton's second law equation yield

$$T - mg\sin\theta = 0$$
$$F_N - mg\cos\theta = 0,$$

where T is the tension in the cord, and F_N is the normal force on the block.



ANALYZE (a) Solving the first equation for the tension in the string, we find

$$T = mg\sin\theta = (8.5\ \text{kg})(9.8\ \text{m/s}^2)\sin 30° = 42\ \text{N}.$$

(b) We solve the second equation above for the normal force F_N:

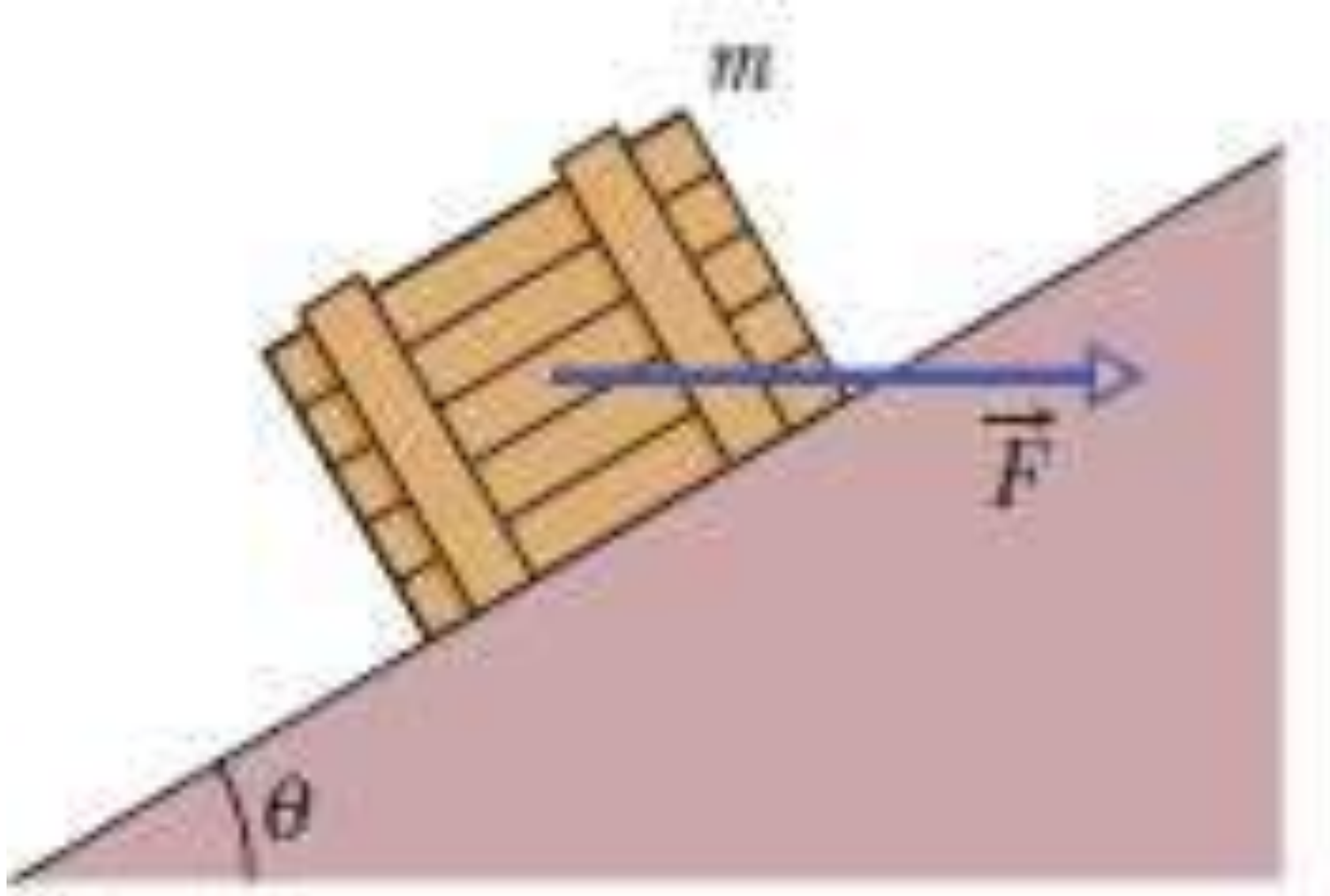
$$F_N = mg\cos\theta = (8.5\ \text{kg})(9.8\ \text{m/s}^2)\cos 30° = 72\ \text{N}.$$

(c) When the cord is cut, it no longer exerts a force on the block and the block accelerates. The x component of the second law becomes $-mg\sin\theta = ma$, so the acceleration becomes

$$a = -g\sin\theta = -(9.8\ \text{m/s}^2)\sin 30° = -4.9\ \text{m/s}^2.$$

••34 GO In Fig. 5-40, a crate of mass $m = 100$ kg is pushed at constant speed up a frictionless ramp ($\theta = 30.0°$) by a horizontal force $\vec{F}$. What are the magnitudes of (a) $\vec{F}$ and (b) the force on the crate from the ramp?

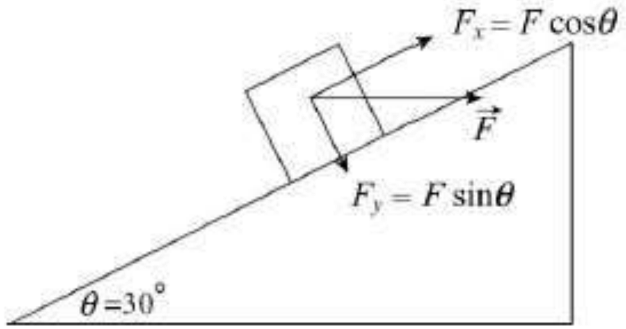
Problem 4



m
F
θ

34. We resolve this horizontal force into appropriate components.

(a) Newton's second law applied to the x-axis produces



$$F\cos\theta - mg\sin\theta = ma.$$

For $a = 0$, this yields $F = 566$ N.

(b) Applying Newton's second law to the y axis (where there is no acceleration), we have

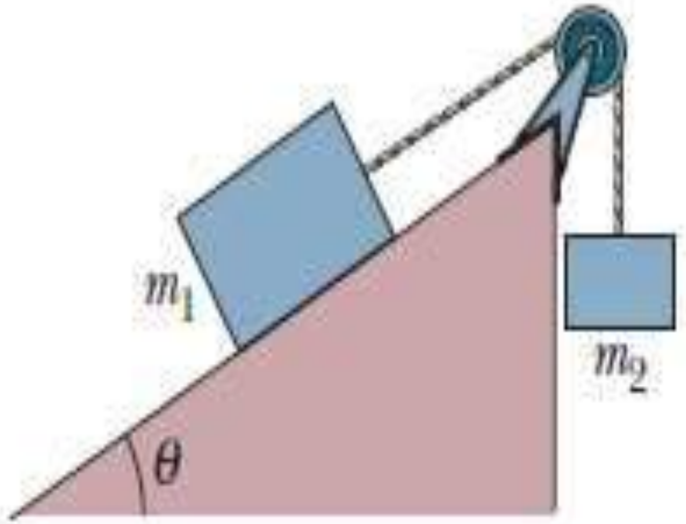
$$F_N - F\sin\theta - mg\cos\theta = 0$$

which yields the normal force $F_N = 1.13 \times 10^3$ N.

Solution

Problem

••57 ILW A block of mass $m_1 = 3.70$ kg on a frictionless plane inclined at angle $\theta = 30.0°$ is connected by a cord over a massless, frictionless pulley to a second block of mass $m_2 = 2.30$ kg (Fig. 5-52). What are (a) the magnitude of the acceleration of each block, (b) the direction of the acceleration of the hanging block, and (c) the tension in the cord?



Solution

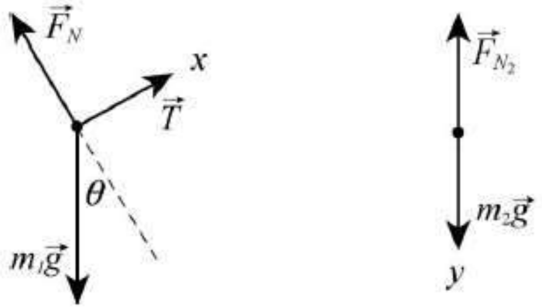
57. The free-body diagram for each block is shown below. T is the tension in the cord and $\theta = 30°$ is the angle of the incline. For block 1, we take the $+x$ direction to be up the incline and the $+y$ direction to be in the direction of the normal force $\vec{F}_N$ that the plane exerts on the block. For block 2, we take the $+y$ direction to be down. In this way, the accelerations of the two blocks can be represented by the same symbol a, without

Solution conti...

ambiguity. Applying Newton's second law to the x and y axes for block 1 and to the y axis of block 2, we obtain

$$T - m_1 g \sin\theta = m_1 a$$
$$F_N - m_1 g \cos\theta = 0$$
$$m_2 g - T = m_2 a$$

respectively. The first and third of these equations provide a simultaneous set for obtaining values of a and T. The second equation is not needed in this problem, since the normal force is neither asked for nor is it needed as part of some further computation (such as can occur in formulas for friction).



(a) We add the first and third equations above:

$$m_2 g - m_1 g \sin\theta = m_1 a + m_2 a.$$

Consequently, we find

$$a = \frac{(m_2 - m_1 \sin\theta)g}{m_1 + m_2} = \frac{[2.30\text{ kg} - (3.70\text{ kg})\sin 30.0°](9.80\text{ m/s}^2)}{3.70\text{ kg} + 2.30\text{ kg}} = 0.735\text{m/s}^2.$$

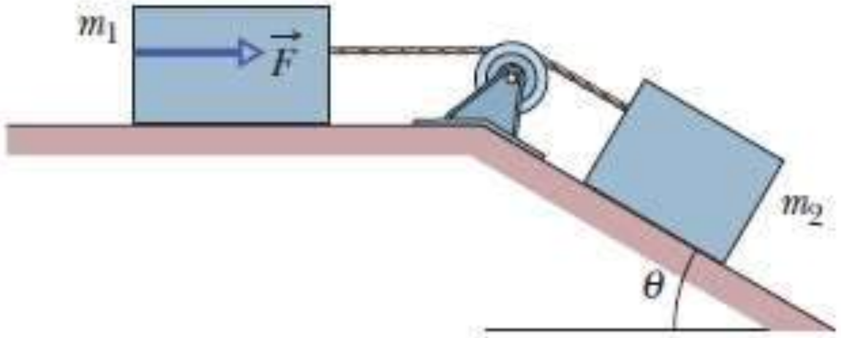
(b) The result for a is positive, indicating that the acceleration of block 1 is indeed up the incline and that the acceleration of block 2 is vertically down.

(c) The tension in the cord is

$$T = m_1 a + m_1 g \sin\theta = (3.70\text{ kg})(0.735\text{ m/s}^2) + (3.70\text{ kg})(9.80\text{ m/s}^2)\sin 30.0° = 20.8\text{N}.$$

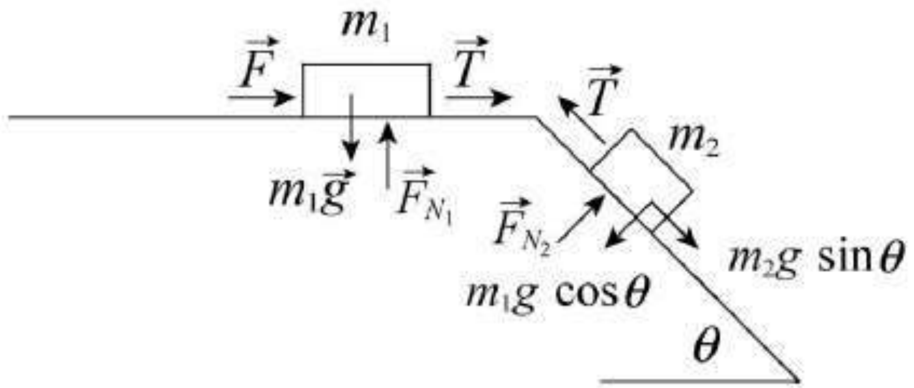
Problem

•••64 GO Figure 5-56 shows a box of mass $m_2 = 1.0$ kg on a frictionless plane inclined at angle $\theta = 30°$. It is connected by a cord of negligible mass to a box of mass $m_1 = 3.0$ kg on a horizontal frictionless surface. The pulley is frictionless and massless. (a) If the magnitude of horizontal force $\vec{F}$ is 2.3 N, what is the tension in the connecting cord? (b) What is the largest value the magnitude of $\vec{F}$ may have without the cord becoming slack?



Solution

64. The $+x$ direction for $m_2 = 1.0$ kg is "downhill" and the $+x$ direction for $m_1 = 3.0$ kg is rightward; thus, they accelerate with the same sign.



(a) We apply Newton's second law to the x axis of each box:

$$m_2 g \sin\theta - T = m_2 a$$
$$F + T = m_1 a$$

Sol.cont

Adding the two equations allows us to solve for the acceleration:

$$a = \frac{m_2 g \sin\theta + F}{m_1 + m_2}$$

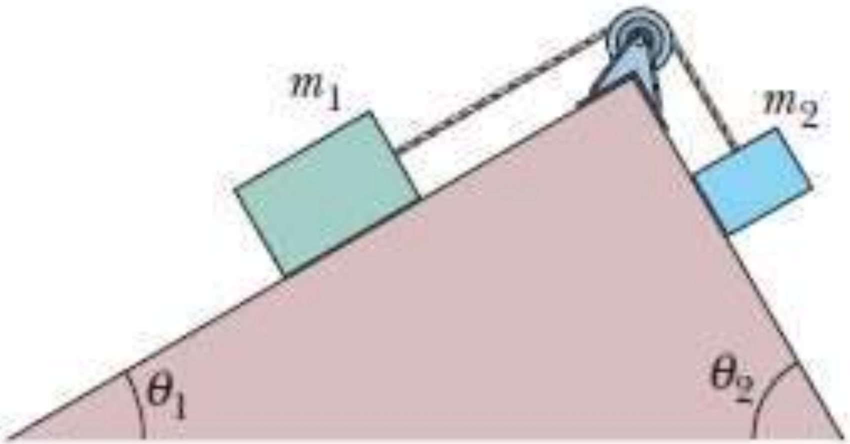
With $F = 2.3$ N and $\theta = 30°$, we have $a = 1.8$ m/s^2. We plug back in and find $T = 3.1$ N.

(b) We consider the "critical" case where the F has reached the *max* value, causing the tension to vanish. The first of the equations in part (a) shows that $a = g\sin 30°$ in this case; thus, $a = 4.9$ m/s^2. This implies (along with $T = 0$ in the second equation in part (a)) that

$$F = (3.0\text{ kg})(4.9\text{ m/s}^2) = 14.7\text{ N} \approx 15\text{ N}$$

in the critical case.

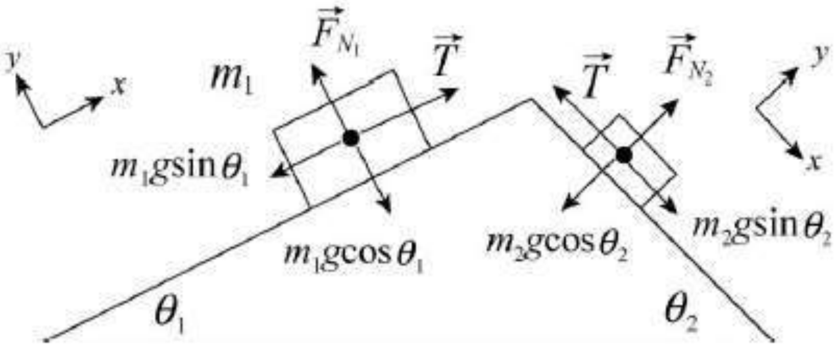
71 **SSM** Figure 5-60 shows a box of dirty money (mass $m_1 = 3.0$ kg) on a frictionless plane inclined at angle $\theta_1 = 30°$. The box is connected via a cord of negligible mass to a box of laundered money (mass $m_2 = 2.0$ kg) on a frictionless plane inclined at angle $\theta_2 = 60°$. The pulley is frictionless and has negligible mass. What is the tension in the cord?



Solution

EXPRESS The $+x$ axis is "uphill" for $m_1 = 3.0$ kg and "downhill" for $m_2 = 2.0$ kg (so they both accelerate with the same sign). The x components of the two masses along the x axis are given by $m_1 g \sin\theta_1$ and $m_2 g \sin\theta_2$, respectively. The free-body diagram is shown below. Applying Newton's second law, we obtain

$$T - m_1 g \sin\theta_1 = m_1 a$$
$$m_2 g \sin\theta_2 - T = m_2 a$$



Solution conti

Adding the two equations allows us to solve for the acceleration:

$$a=\left(\frac{m_2\sin\theta_2-m_1\sin\theta_1}{m_2+m_1}\right)g$$

ANALYZE With $\theta_1=30°$ and $\theta_2=60°$, we have a = 0.45 m/s^2. This value is plugged back into either of the two equations to yield the tension

$$T=\frac{m_1m_2g}{m_2+m_1}(\sin\theta_2+\sin\theta_1)=16.1\,\text{N}$$

Problem

•••67 Figure 5-58 shows three blocks attached by cords that loop over frictionless pulleys. Block B lies on a frictionless table; the masses are $m_A = 6.00$ kg, $m_B = 8.00$ kg, and $m_C = 10.0$ kg. When the blocks are released, what is the tension in the cord at the right?

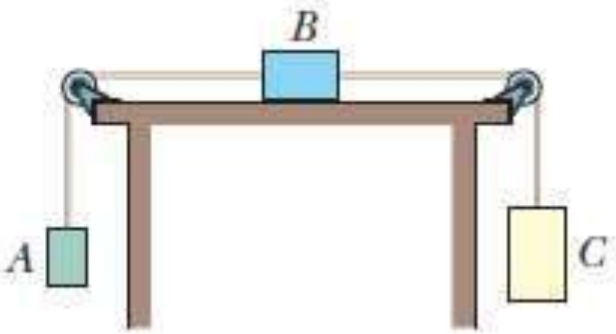


Figure 5-58 Problem 67.

Solution

67. First we analyze the entire *system* with "clockwise" motion considered positive (that is, downward is positive for block C, rightward is positive for block B, and upward is positive for block A): $m_C g - m_A g = Ma$ (where M = mass of the *system* = 24.0 kg). This yields an acceleration of

$$a = g(m_C - m_A)/M = 1.63 \text{ m/s}^2.$$

Next we analyze the forces just on block C: $m_C g - T = m_C a$. Thus the tension is

$$T = m_C g(2m_A + m_B)/M = 81.7 \text{ N}.$$