Applications of Newton’s Laws of Motion

Application of Newton’s laws:

- In this section we apply Newton’s laws to objects that are either in equilibrium (a= 0) or accelerating along a straight line under the action of constant external forces

- We assume that the objects behave as particles so that we need not worry about rotational motion.

- We also neglect the effects of friction in those problems involving motion; this is equivalent to stating that the surfaces are *frictionless.*

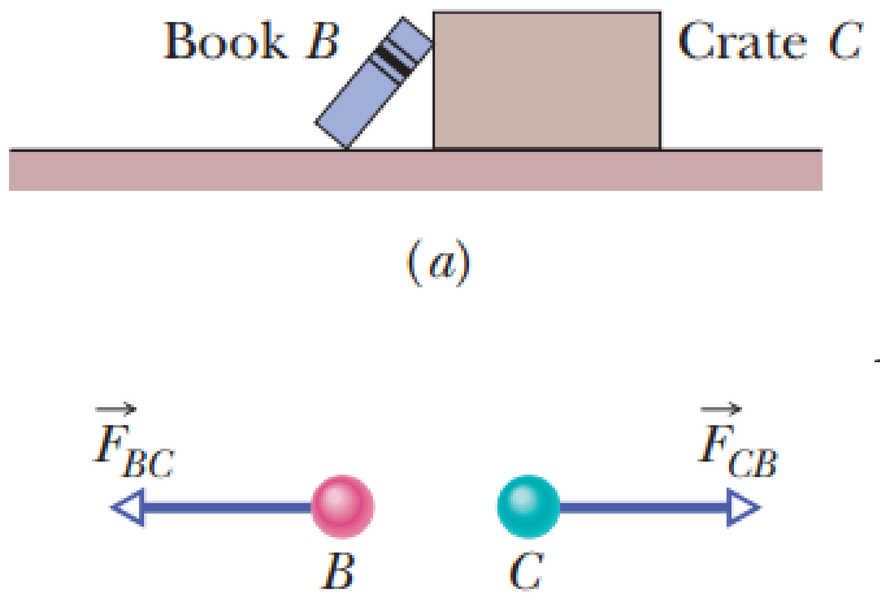
- Finally, we usually neglect the mass of any ropes involved.

<u>things not to forget when solving problems</u>

$$\vec{F}_{net} = m\vec{a},$$

which may be written in the component versions

$$F_{net,x} = ma_x \quad F_{net,y} = ma_y \quad \text{and} \quad F_{net,z} = ma_z.$$



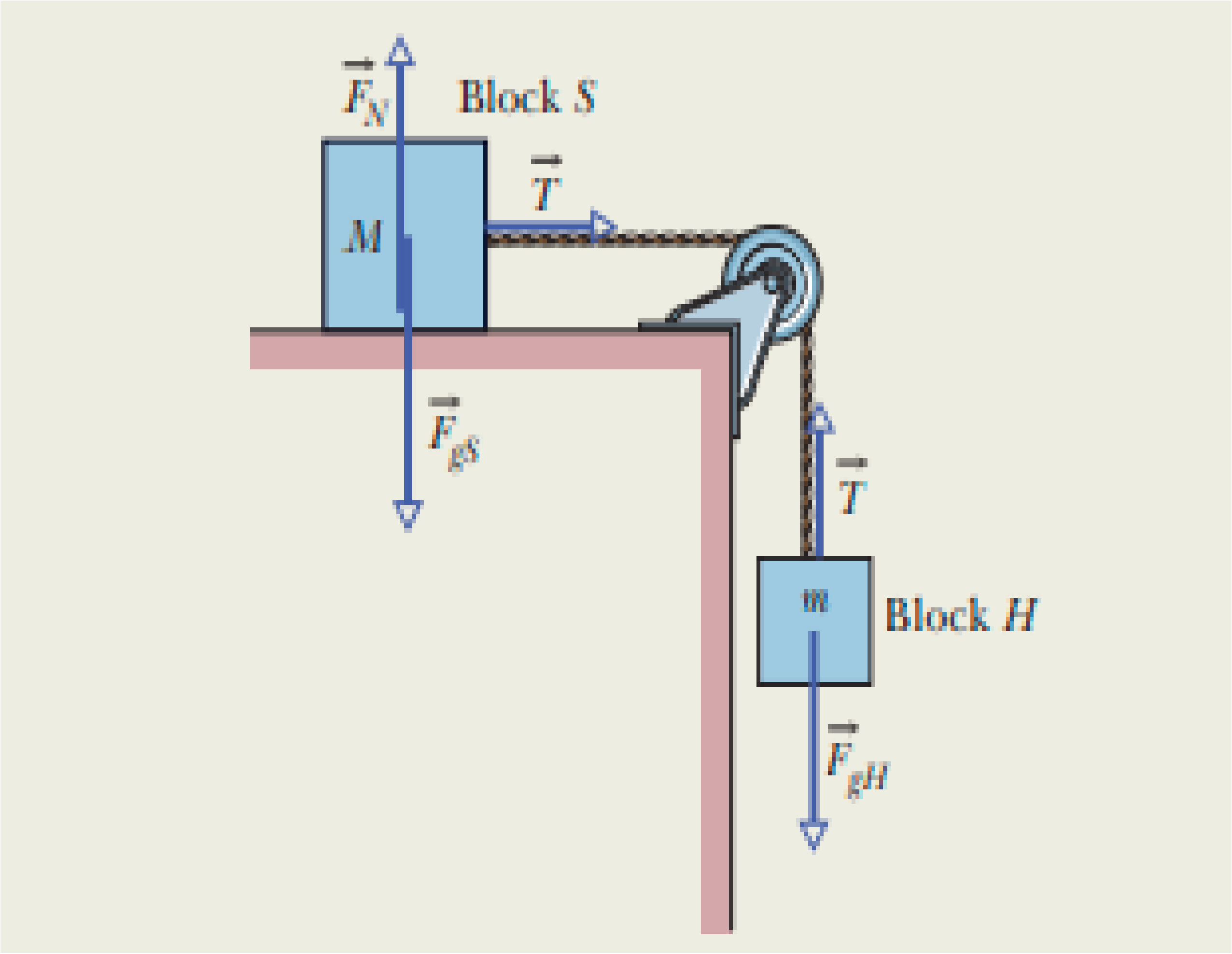
$$\vec{F}_{BC} = -\vec{F}_{CB}$$

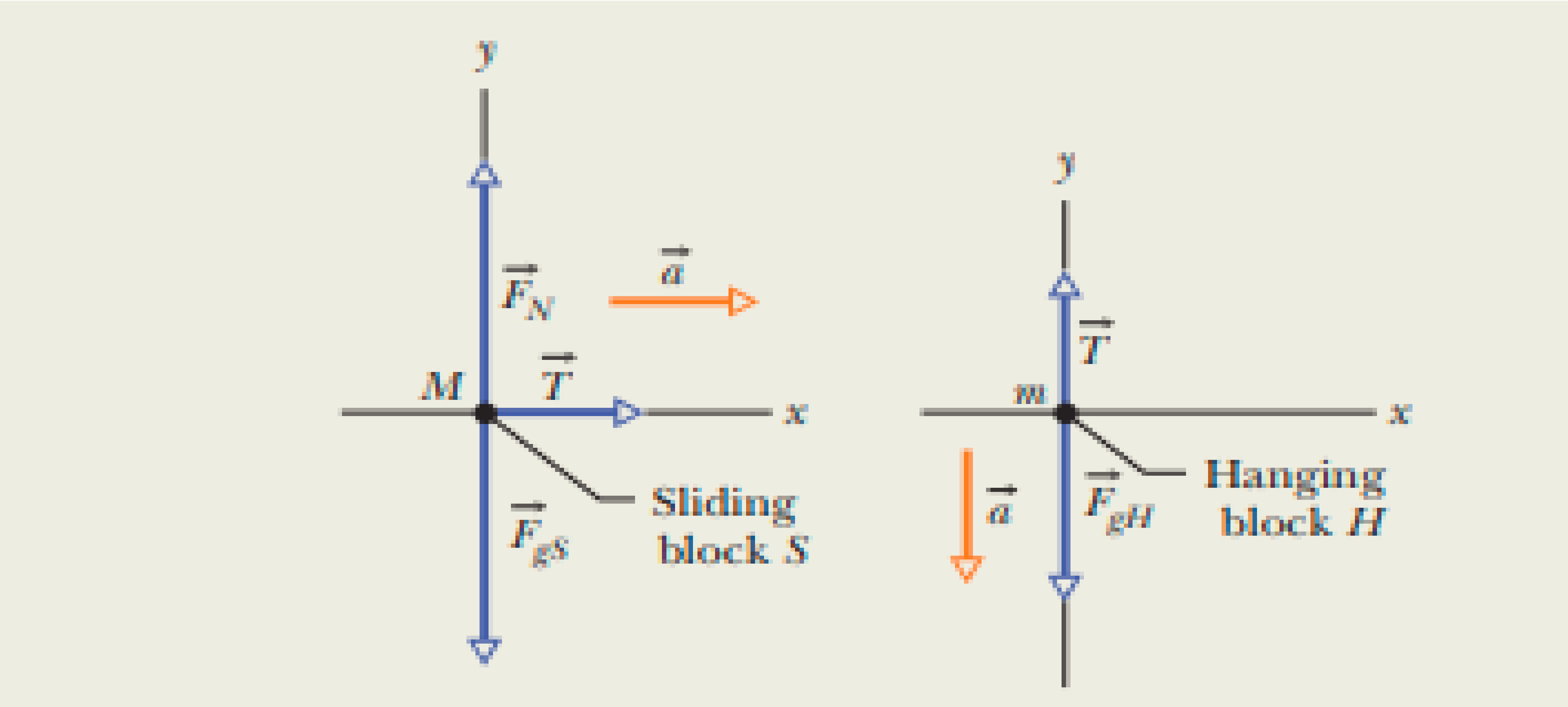
Application 1:

Block on table, block hanging

Practice Problem 1: Sample problem 5.03

Figure shows a block S(the sliding block) with mass M = 3.3 kg. The block is free to move along a horizontal frictionless surface and connected, by a cord that wraps over a frictionless pulley, to a second block H (the hanging block), with mass m = 2.1 kg. The cord and pulley have negligible masses compared to the blocks (they are "massless"). The hanging block H falls as the sliding block S accelerates to the right. Find (a) the acceleration of block S, (b) the acceleration of block H, and (c) the tension in the cord.





Free-body diagram of block S and H

Solution(in class)

Answers:

a_H= 3.8 m/s^2

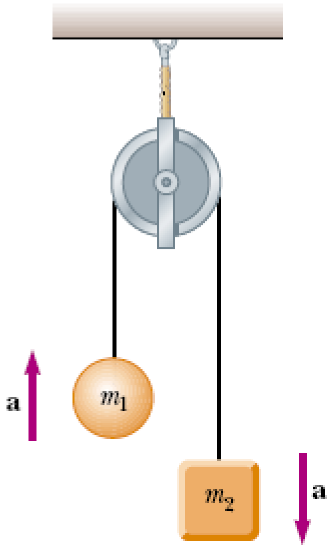
a_S=3.8 m/s^2

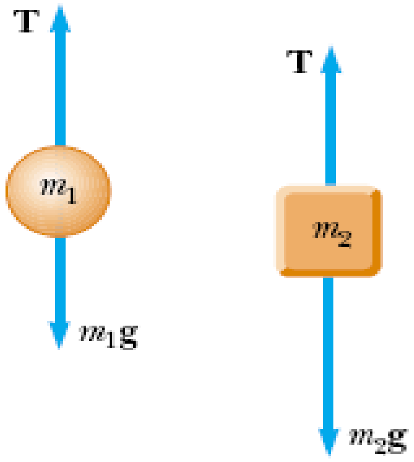
T= 13N

$$a = \frac{m}{M+m} g.$$

$$T = \frac{Mm}{M+m} g.$$

Practice Problem 2:The Atwood Machine





$$\sum F_y = T - m_1 g = m_1 a_y$$

$$\sum F_y = m_2 g - T = m_2 a_y$$

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

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

Application 2:

Problems involving ramps (inclined planes)

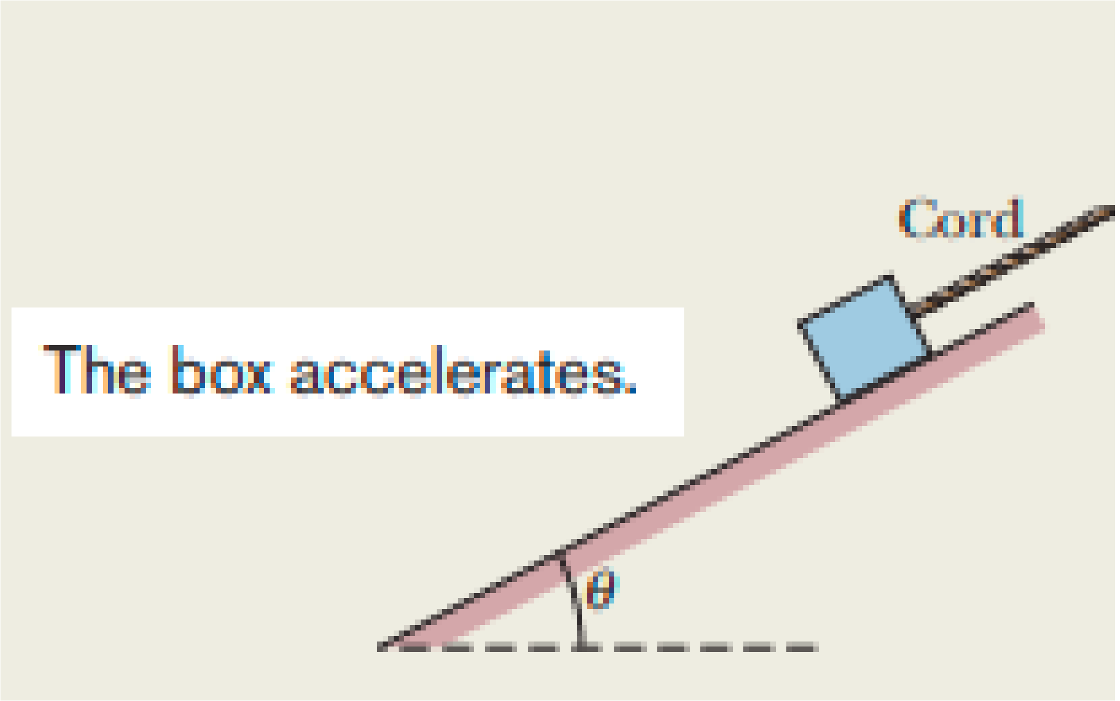
We work with

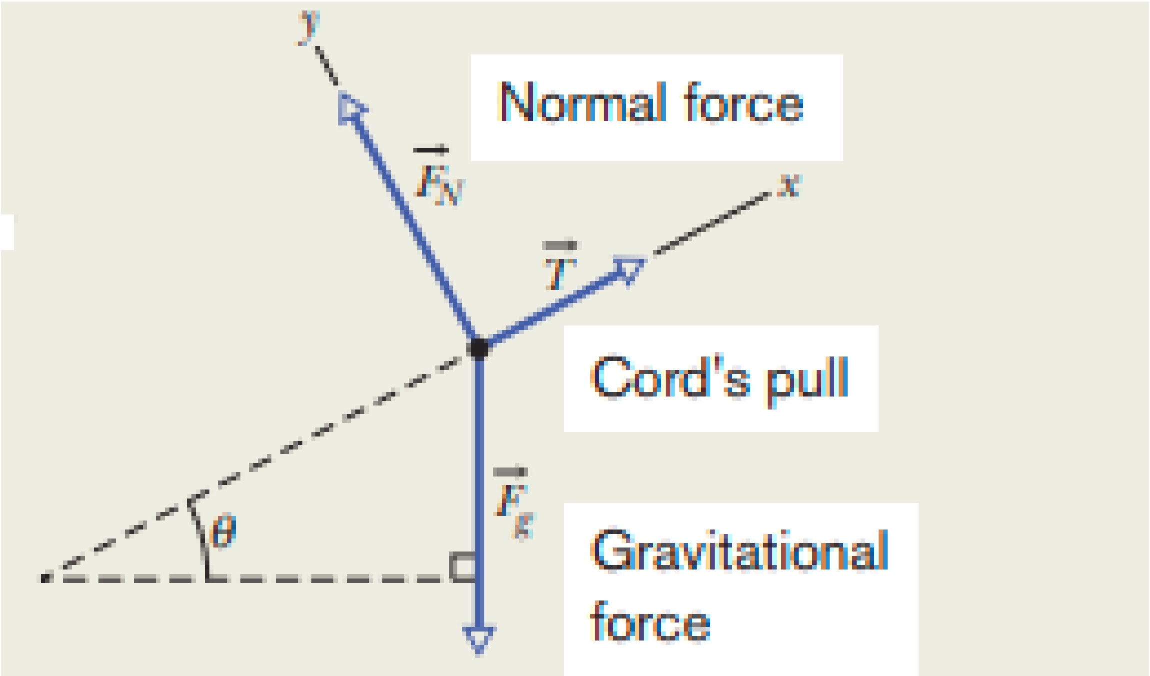
(a) a tilted coordinate system

(b) the components of the gravitational force, not the full force.

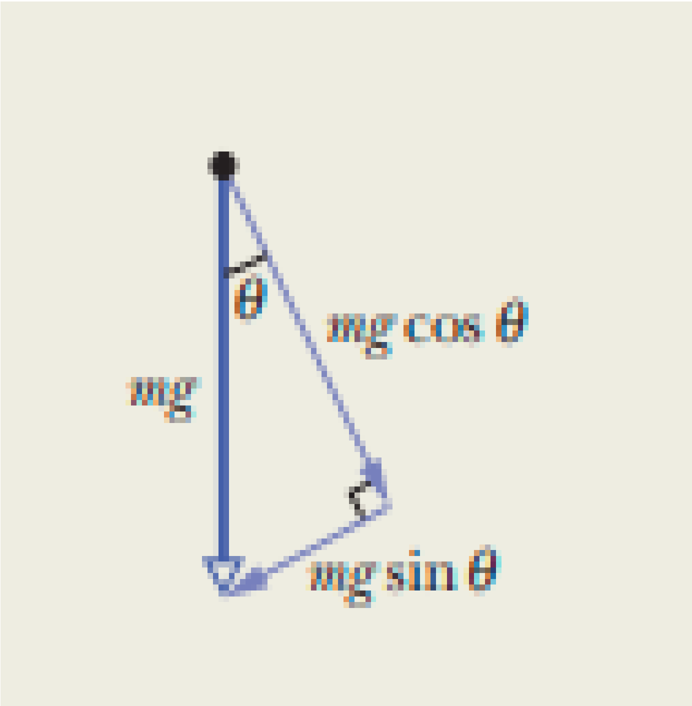
Practice Problem 3: Sample Problem 5.04

In Figure, a cord pulls a box of sea biscuits up along a frictionless plane inclined at angle $\theta = 30.0°$. The box has mass $m = 5.00$ kg, and the force from the cord has magnitude $T = 25.0$ N. What is the box's acceleration a along the inclined plane?

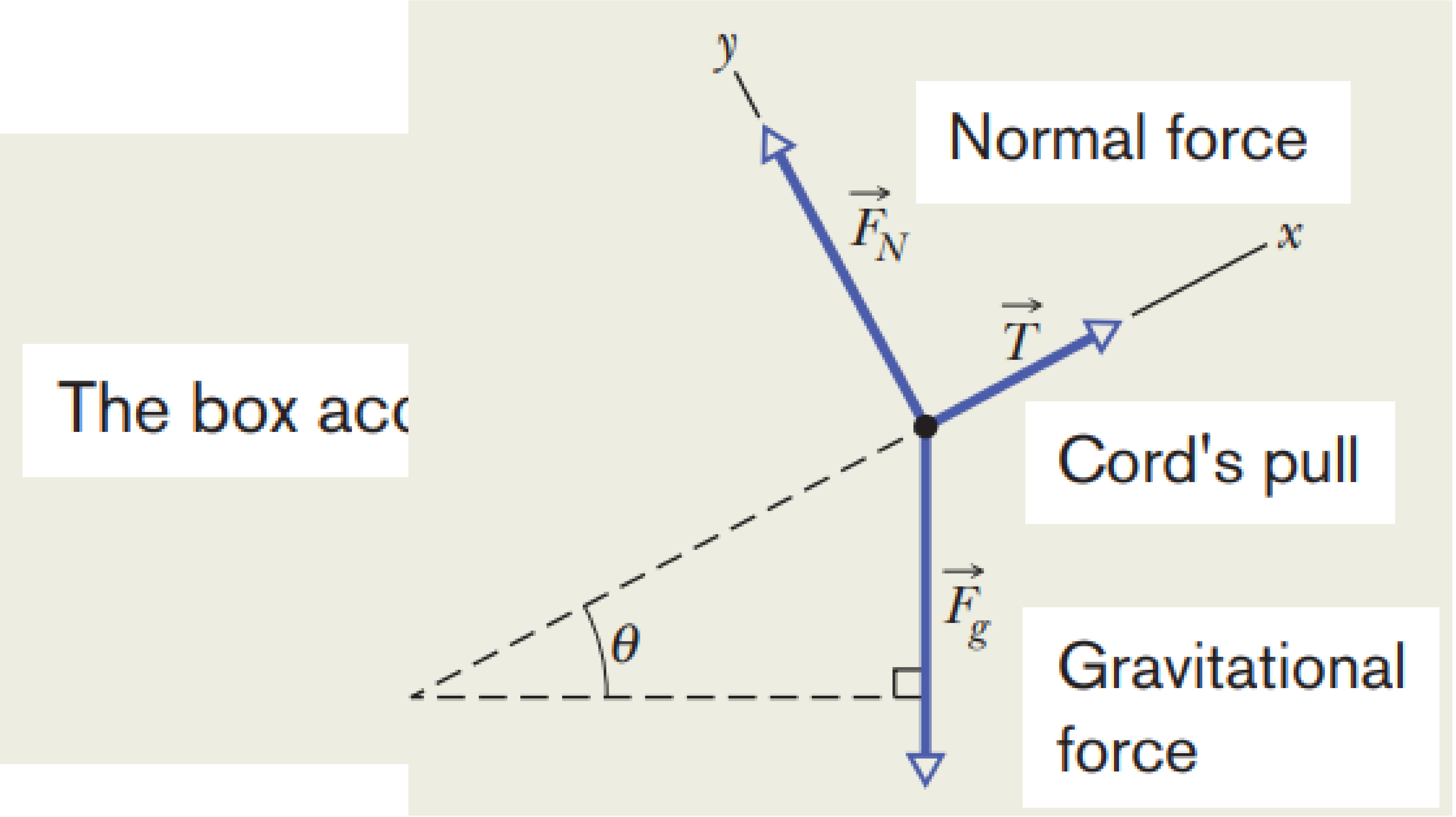




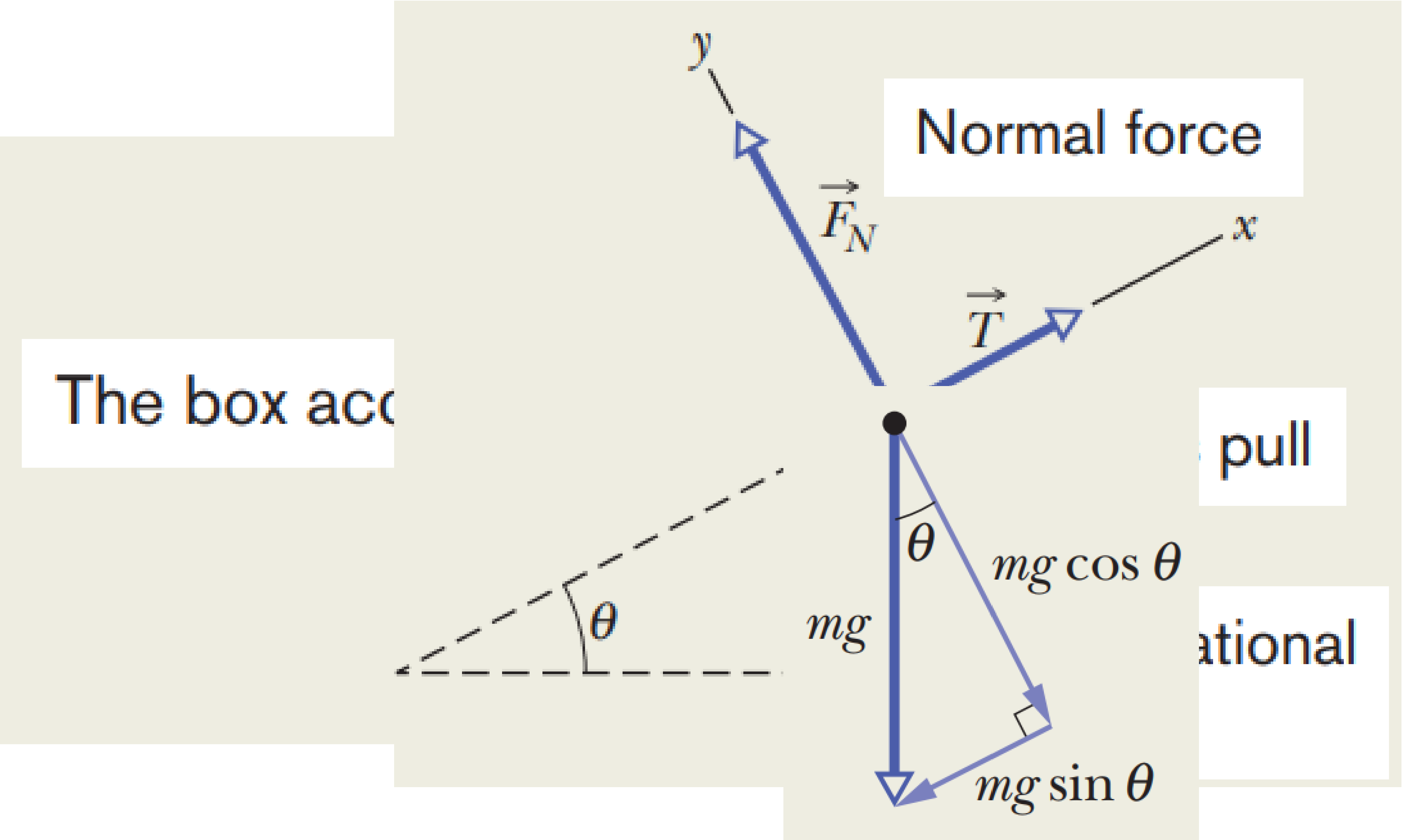
Free-body diagram



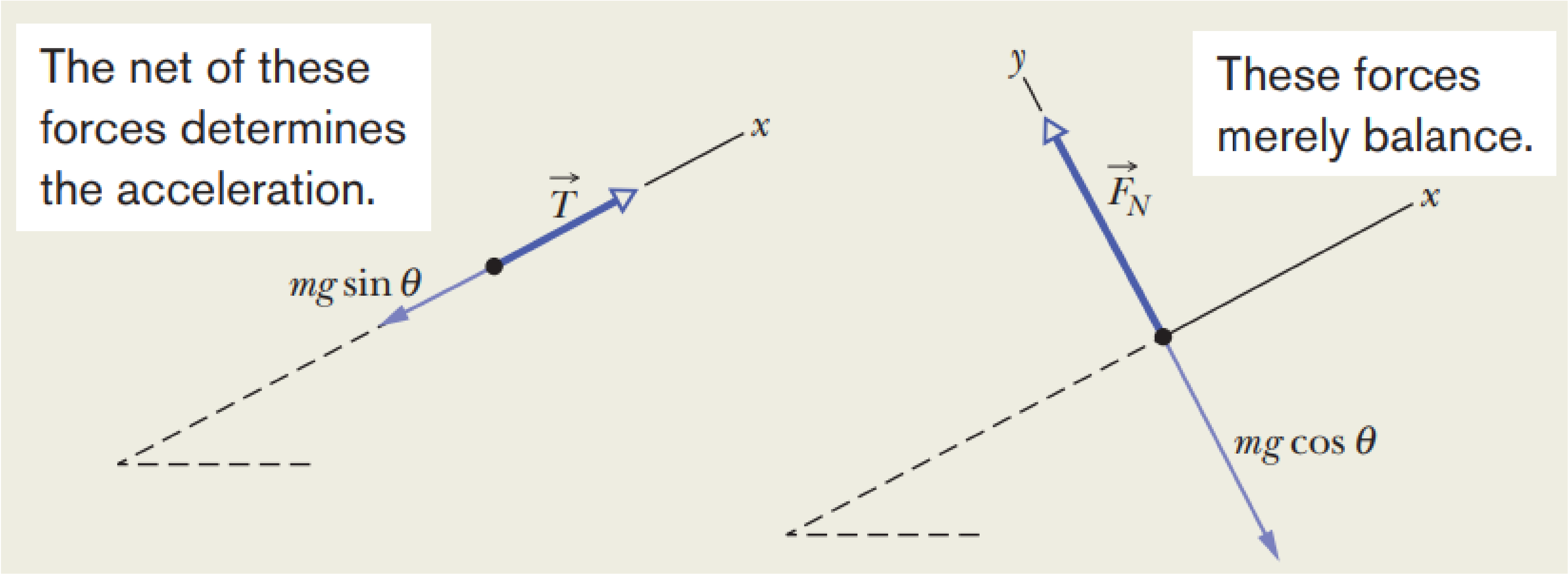
Components of Gravitational Force



y
Normal force
$\vec{F}_N$
x
$\vec{T}$
The box acc
Cord's pull
$\vec{F}_g$
θ
Gravitational force



y
Normal force
$\vec{F}_N$
x
$\vec{T}$
The box acc
pull
θ
mg cos θ
θ
mg
ational
mg sin θ


The net of these forces determines the acceleration.
$\vec{T}$
x
$mg \sin \theta$
y
These forces merely balance.
$\vec{F}_N$
x
$mg \cos \theta$

Solution(in class)

Answers:

$a = 0.100\ m/s^2$

Practice Problem 4:The Runaway Car

Suppose a car is released from rest at the top of the incline, and the distance from the front edge of the car to the bottom is d. How long does it take the front edge to reach the bottom, and what is its speed just as it gets there?

Because a_x = constant,
we can apply
$x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2$,
to analyze the car's motion

replace displacement by $x_f - x_i = d$

Put, $v_{xi} = 0$, we get $d = \frac{1}{2}a_x t^2$

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

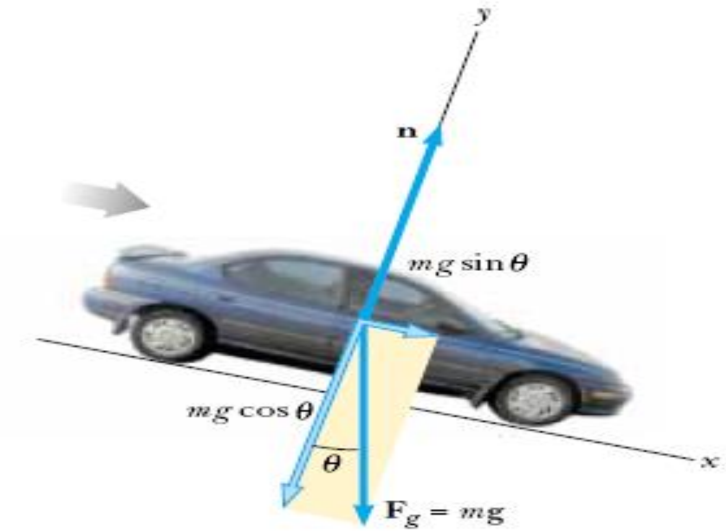
(2) $\sum F_y = n - mg\cos\theta = 0$

Solving (1) for a_x $\boxed{a_x = g\sin\theta}$

put the value of a_x in $d = \frac{1}{2}a_x t^2$ and find time, as follows

$$t = \sqrt{\frac{2d}{a_x}}$$

$$t = \sqrt{\frac{2d}{g\sin\theta}}$$



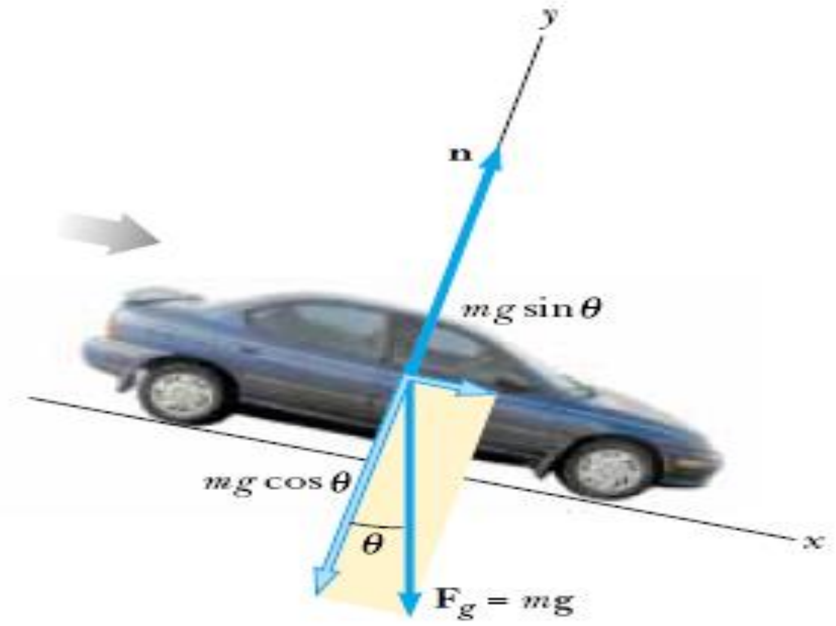
Calculation for Final Velocity

Using $v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$

with $v_{xi} = 0, \quad x_f - x_i = d$

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

$$v_{xf} = \boxed{\sqrt{2gd \sin \theta}}$$



Conclusion

We see that the time t needed to reach the bottom and the speed v_{xf}, are independent of the car's mass.

Application 3:

Forces within an elevator cab

Practice Problem 5: Sample Problem 5.06:

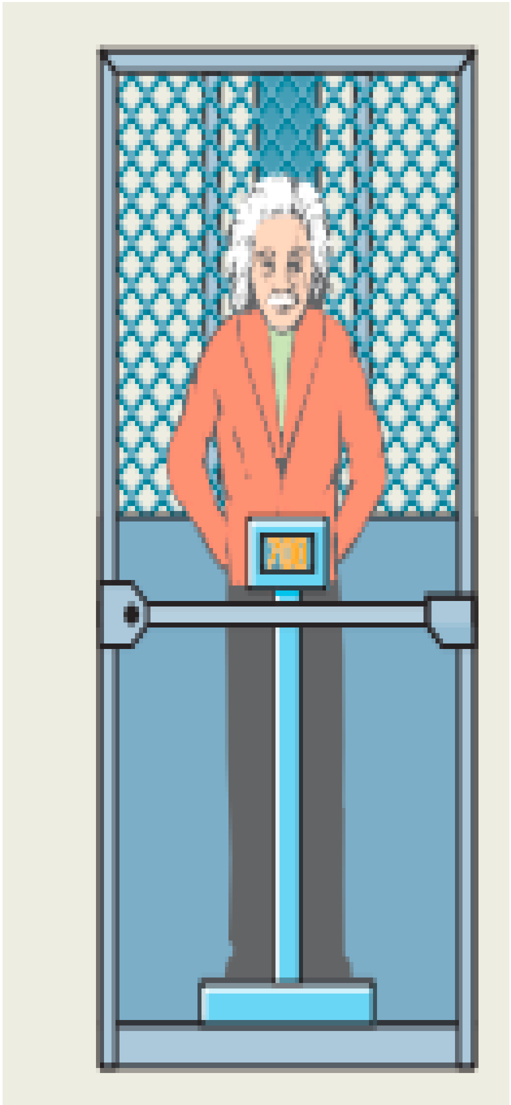
Suppose that you weigh yourself while on an elevator that is moving. Would you weigh more than, less than, or the same as when the scale is on a stationary floor?

In Fig, a passenger of mass m= 72.2 kg stands on a platform scale in an elevator cab. We are concerned with the scale readings when the cab is stationary and when it is moving up or down.

(a) Find a general solution for the scale reading, whatever the vertical motion of the cab.

(b) What does the scale read if the cab is stationary or moving upward at a constant 0.50 m/s?

(c) What does the scale read if the cab accelerates upward at 3.20 m/s^2 and downward at 3.20 m/s^2 ?



Solution(in class)

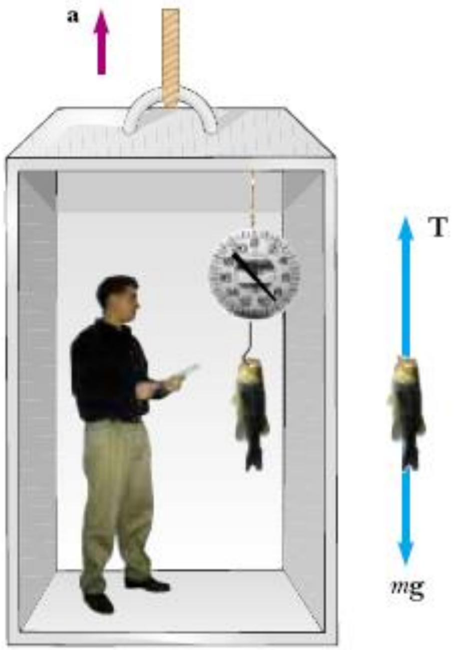
Answers:

$a. F_N = m(g + a)$

$b. F_N = 708\ N$

$c. F_N = 939N\ (for\ upward)$ and $F_N = 477\text{N (for downward)}$

Practice Problem 6:Weighing a fish in an Elevator



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

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

Application 4:

Acceleration of block pushing on block

Practice Problem 7:

(a) Determine the magnitude of the acceleration of the two-block system.

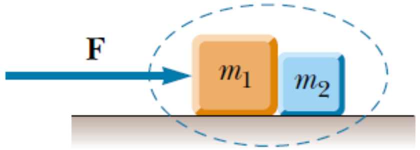
Solution

we know that both blocks must experience the same acceleration because they remain in contact with each other.

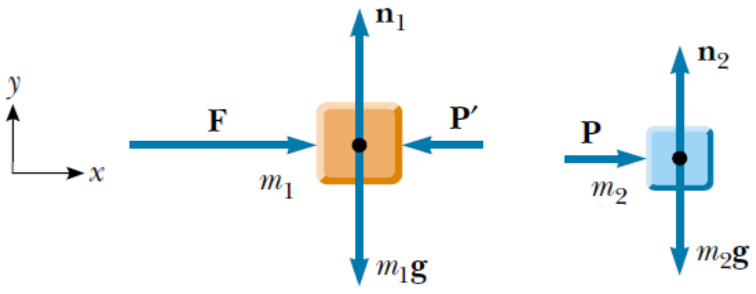
F is the only external horizontal force acting on the system (the two blocks), we have

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

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



(a)



(b) (c)

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

To solve this part of the problem,we must treat each block separately with its own free-body diagram,We denote the contact force by **P**.

From Figure c,we see that the only horizontal force acting on block 2 is the contact force **P** (the force exerted by block 1 on block 2), which is directed to the right. Applying Newton's second law to block 2 gives

$$\sum F_x = P = m_2 a_x \qquad (2)$$

Substituting into (2) the value of a_x given by (1), we obtain

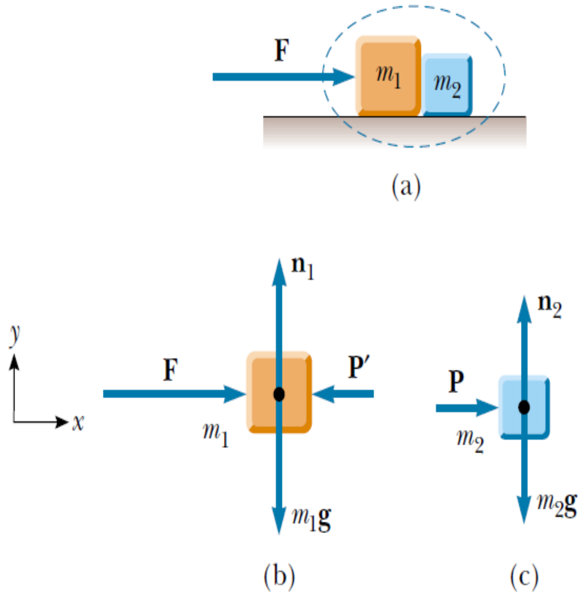
$$\boxed{P = m_2 a_x = \left(\frac{m_2}{m_1 + m_2}\right) F} \qquad (3)$$

$$P = m_2 a_x = \left(\frac{m_2}{m_1 + m_2}\right) F$$

From this result, we see that the contact force **P** exerted by block 1 on block 2 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.

It is instructive to check this expression for P by considering the forces acting on block 1, shown in Figure b. The horizontal forces acting on this block are the applied force **F** to the right and the contact force **P′** to the left (the force exerted by block 2 on block 1). From Newton's third law, **P′** is the reaction to **P**, so that $|\mathbf{P}'| = |\mathbf{P}|$. Applying Newton's second law to block 1 produces

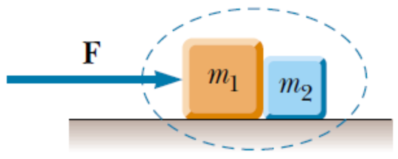
$$(4) \qquad \sum F_x = F - P' = F - P = m_1 a_x$$



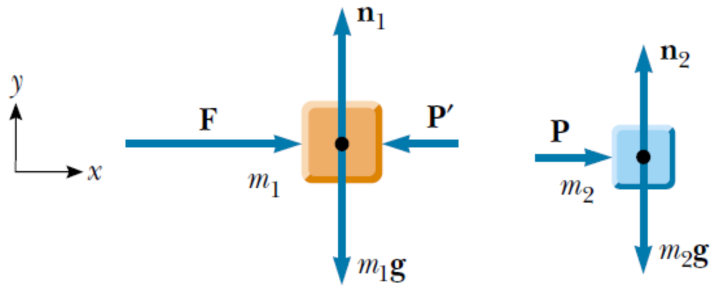
(4) $$\sum F_x = F - P' = F - P = m_1 a_x$$

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

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



(a)



(b) (c)

Practice Problem 8:

Exercise If $m_1 = 4.00$ kg, $m_2 = 3.00$ kg, and $F = 9.00$ N, find the magnitude of the acceleration of the system and the magnitude of the contact force.

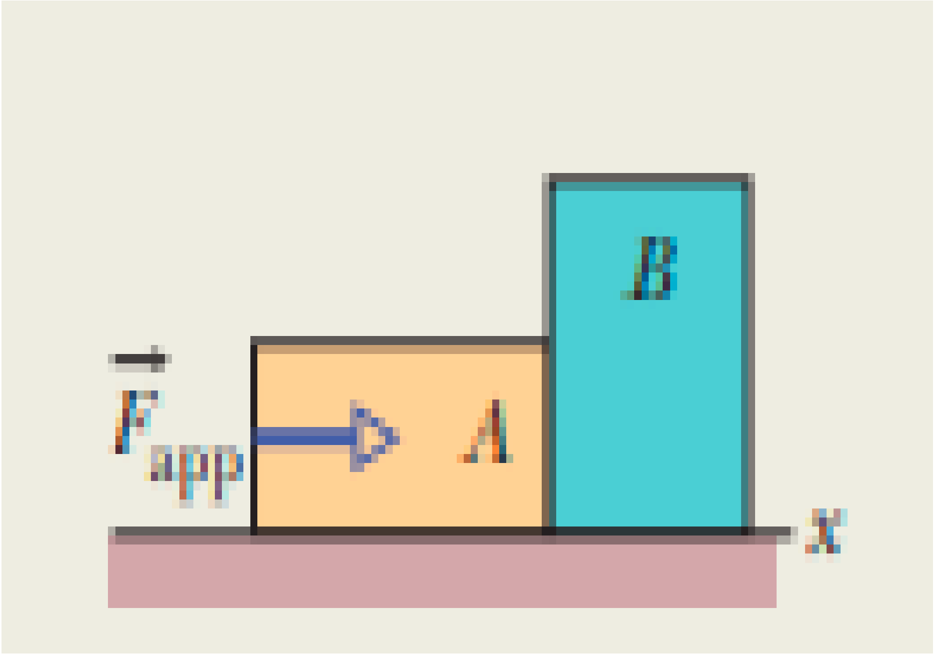
Answer $a_x = 1.29\ \text{m/s}^2$; $P = 3.86$ N.

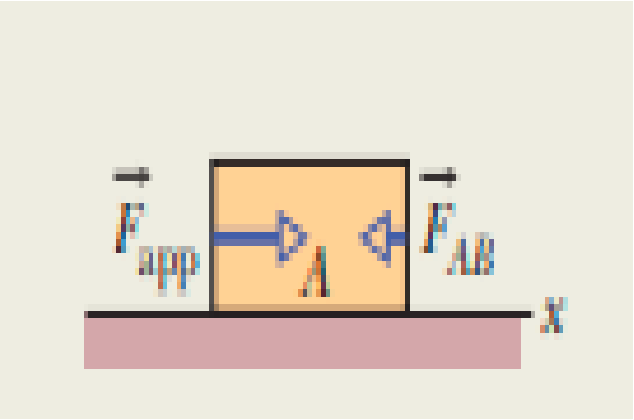
Practice Problem 9: Sample Problem 5.07

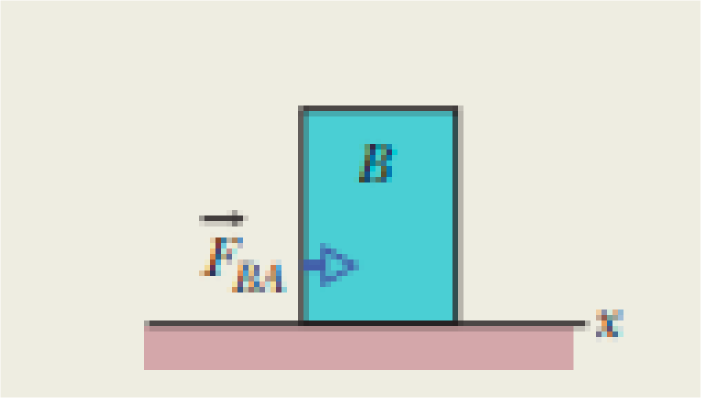
- Some homework problems involve objects that move together, because they are either shoved together or tied together. Here is an example in which you apply Newton's second law to the composite of two blocks and then to the individual blocks. In Fig, a constant horizontal force $\mathbf{F_{app}}$ of magnitude 20 N is applied to block A of mass m_A = 4.0 kg, which pushes against block B of mass m_B = 6.0 kg. The blocks slide over a frictionless surface, along an x axis.

(a) What is the acceleration of the blocks?

(b) What is the (horizontal) force $\mathbf{F_{BA}}$ on block B from block A ?







Free-body diagram of block A and B

Solution(in class)

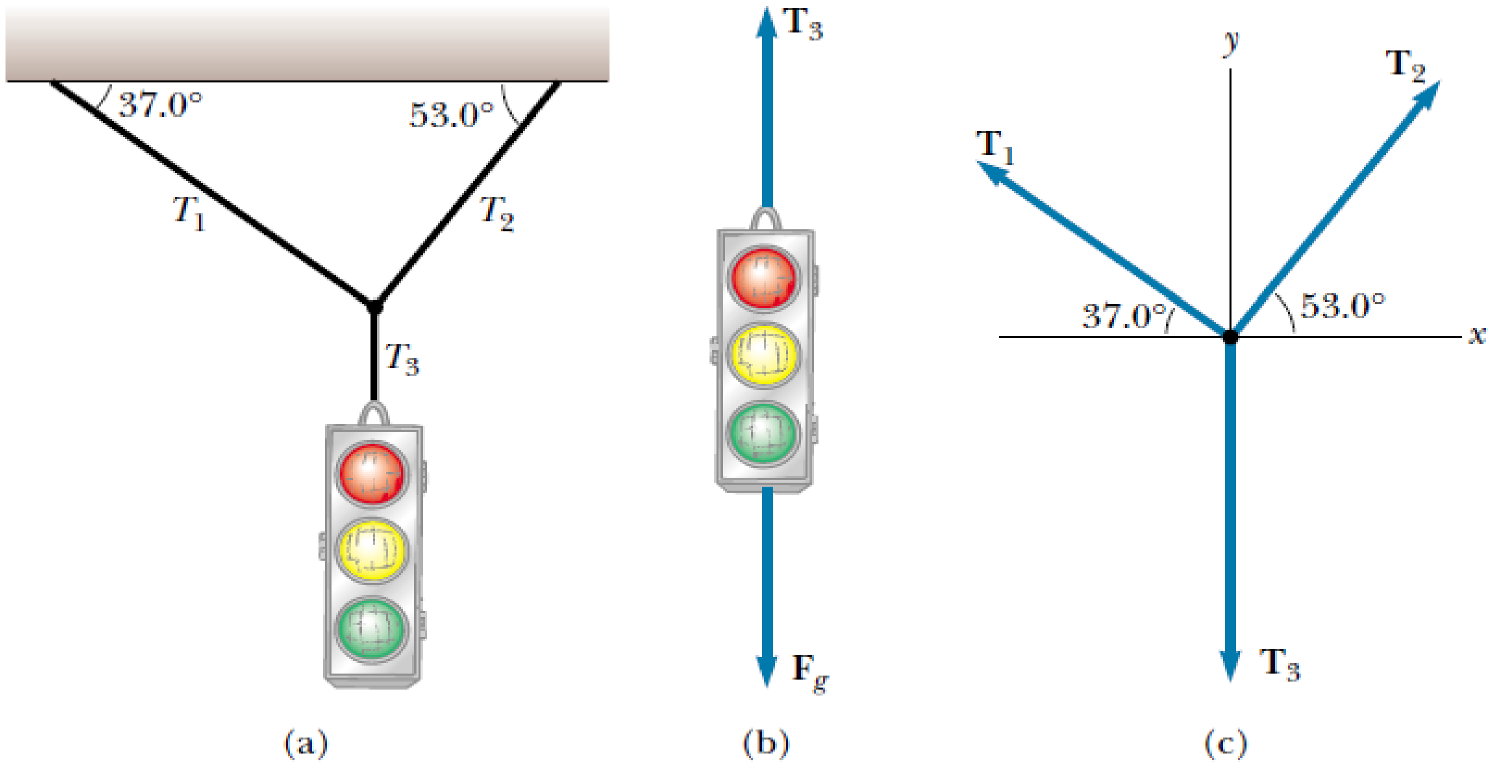
Answers:

a = 2.0 m/s^2 in the positive direction of x axis

F_{BA} = 12 N in the positive direction of x axis

Practice Problem 10:

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support. The upper cables make angles of 37.0° and 53.0° with the horizontal. Find the tension in the three cables.

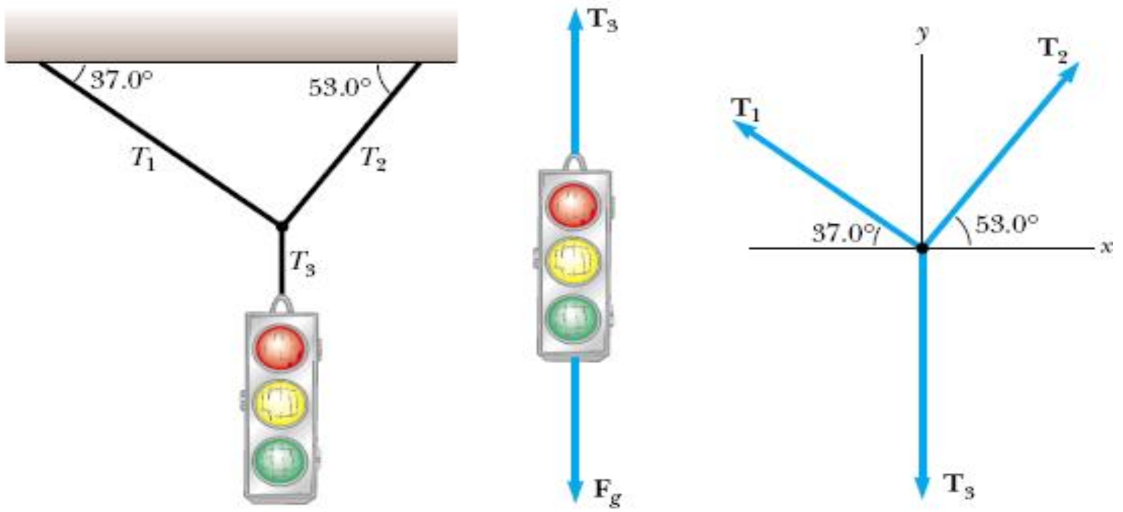


(a) A traffic light suspended by cables. (b) Free-body diagram for the traffic light. (c) Free-body diagram for the knot where the three cables are joined.

Solution:

In Figure (b) the force $\mathbf{T}_3$ exerted by the vertical cable supports the light, and so $T_3 = F_g =$ 125 N. Next, we choose the coordinate axes shown in Figure (c) and resolve the forces acting on the knot into their components:

Force	x Component	y Component
$\mathbf{T}_1$	$-T_1 \cos 37.0°$	$T_1 \sin 37.0°$
$\mathbf{T}_2$	$T_2 \cos 53.0°$	$T_2 \sin 53.0°$
$\mathbf{T}_3$	0	-125 N



Solution:

Knowing that the knot is in equilibrium ($\mathbf{a} = 0$) allows us to write

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

$$(2) \qquad \sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-125\ N) = 0$$

From (1) we see that the horizontal components of $\mathbf{T}_1$ and $\mathbf{T}_2$ must be equal in magnitude, and from (2) we see that the sum of the vertical components of $\mathbf{T}_1$ and $\mathbf{T}_2$ must balance the weight of the light. We solve (1) for T_2 in terms of T_1 to obtain

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

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

$$T_1 \sin 37.0° + (1.33\,T_1)(\sin 53.0°) - 125\text{ N} = 0$$

$$T_1 = \boxed{75.1\text{ N}}$$

$$T_2 = 1.33\,T_1 = \boxed{99.9\text{ N}}$$

What If? Suppose the two angles in Figure (a) are equal. What would be the relationship between T_1 and T_2?

Answer We can argue from the symmetry of the problem that the two tensions T_1 and T_2 would be equal to each other. Mathematically, if the equal angles are called θ, Equation (3) becomes

$$T_2 = T_1\left(\frac{\cos\theta}{\cos\theta}\right) = T_1$$

which also tells us that the tensions are equal. Without knowing the specific value of θ, we cannot find the values of T_1 and T_2. However, the tensions will be equal to each other, regardless of the value of θ.

Homework questions(1/2)

- Practice problems:
- End of chapter 5 textbook " Fundamentals of Physics"by Halliday & Resnick Jearl Walker 10th Edition" from page 114 onwards
- Questions: 1,5,6,12,
- Problems: 2,5,9,17,19,23,27, 30,34,51,55,57

Answer of even problems:

2: $a.\ a = 0, b. a = (4.0\frac{m}{s^2})\hat{j}$, c. $a = (3.0\frac{m}{s^2})\hat{i}$

30: a = -1.61 x10 ^6 m/s^2 and F = 2.1 x10^2 N

34: F = 566 N and F_N = 1.13 x 10^3 N

Homework questions(2/2)

- Practice problems:
- End of chapter 6 textbook “ Fundamentals of Physics”by Halliday & Resnick Jearl Walker 10th Edition”
- Problems: 6,19 and 27
- Sample Problem 6.02

Answer of even problems:

6: $\mu_k = 0.61$

Adapted from:

Book:

Fundamentals of Physics by Halliday Resnick & Jearl Walker 10^{th} edition