FORCE AND MOTION—I

Prepared By
Md Saif Kabir
Lecturer,OAA

Newton's Laws

Newton's First Law: If no force acts on a body, the body's velocity cannot change; that is, the body cannot accelerate.

Newton's First Law: If no *net* force acts on a body ($\vec{F}_{net} = 0$), the body's velocity cannot change; that is, the body cannot accelerate.

Newton's Second Law: The net force on a body is equal to the product of the body's mass and its acceleration.

$$\vec{F}_{net} = m\vec{a} \qquad \text{(Newton's second law).} \tag{5-1}$$

$$F_{net,x} = ma_x, \quad F_{net,y} = ma_y, \quad \text{and} \quad F_{net,z} = ma_z. \tag{5-2}$$

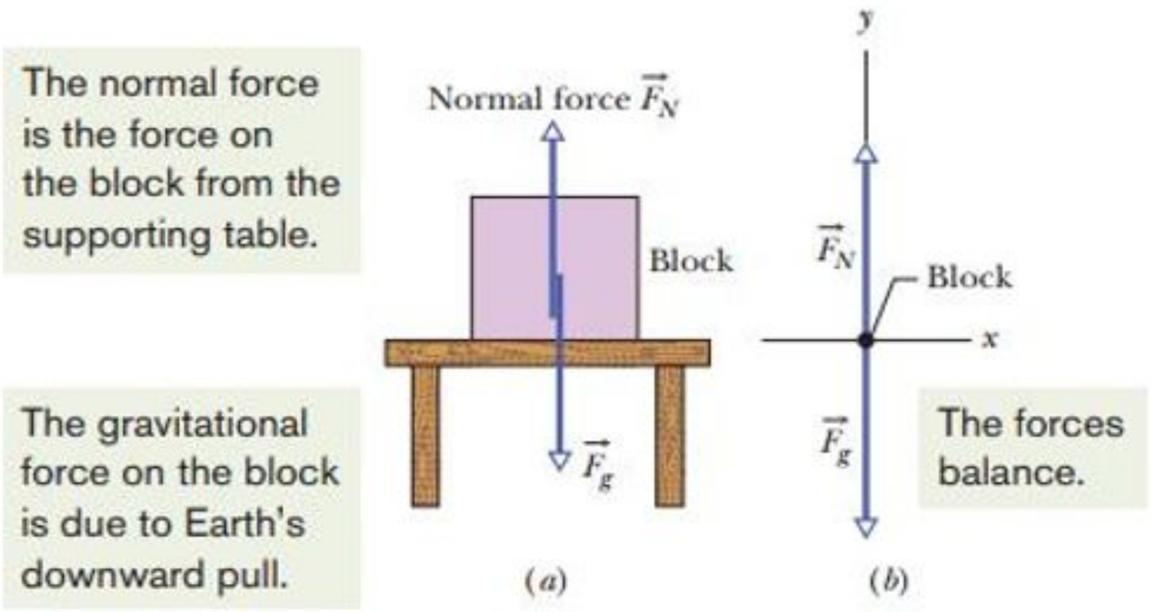


Fig. 5-7 (*a*) A block resting on a table experiences a normal force $\vec{F}_N$ perpendicular to the tabletop. (*b*) The free-body diagram for the block.

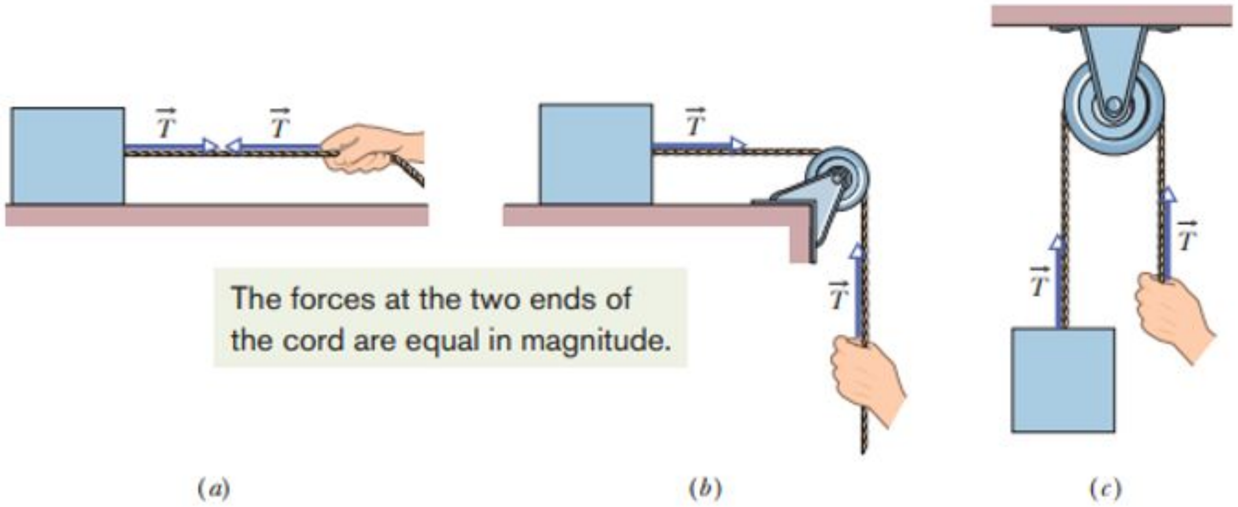


Figure 5-12 shows a block *S* (the *sliding block*) with mass $M = 3.3$ kg. The block is free to move along a horizontal frictionless surface and connected, by a cord that wraps over a frictionless pulley, to a second block *H* (the *hanging block*), with mass $m = 2.1$ kg. The cord and pulley have negligible 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.

Q *What is this problem all about?*

You are given two bodies—sliding block and hanging block—but must also consider *Earth*, which pulls on both

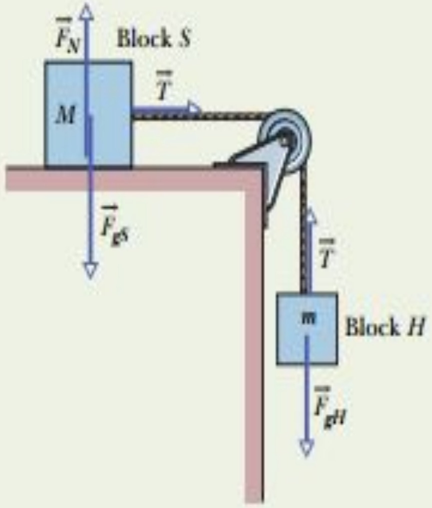


Fig. 5-13 The forces acting on the two blocks of Fig. 5-12.

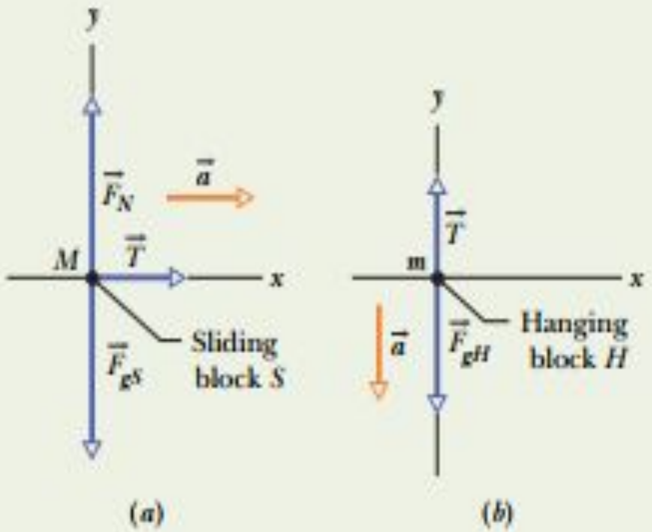


Fig. 5-14 (*a*) A free-body diagram for block *S* of Fig. 5-12. (*b*) A free-body diagram for block *H* of Fig. 5-12.

$\xrightarrow{+ve}$ $\xleftarrow{-ve}$ $\uparrow$ +ve $\downarrow$ -ve

$T = Ma$ ___ ①

$T - F_{gH} = -ma$ ___ ② [a=-ve]

Substituting ① in ②,

$Ma - F_{gH} = -ma$

$\Rightarrow Ma - mg = -ma$

$\Rightarrow a = \frac{m}{M+m} \times g = \frac{2.1}{3.3+2.1} \times 9.8$

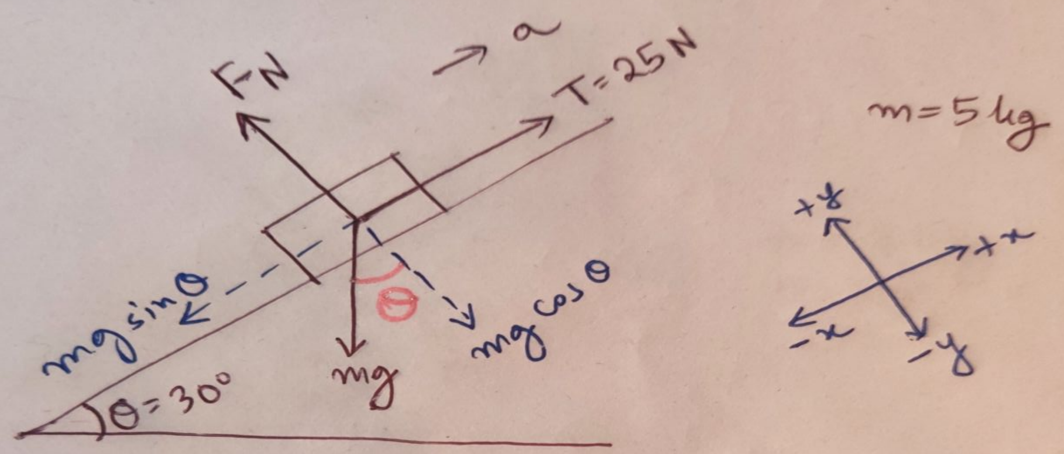
$= 3.8 \ m/s^2$

a) $a_S = 3.81 \ m/s^2 \ (\rightarrow)$

b) $a_H = -3.81 \ m/s^2 \ (\downarrow)$

c) $T = Ma = 3.3 \times 3.8 = 13N$

In Fig. 5-15*a*, a cord pulls on a box of sea biscuits up along a frictionless plane inclined at $\theta = 30°$. 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 component a along the inclined plane?



$$T - mg\sin\theta = ma \qquad [a = +ve]$$

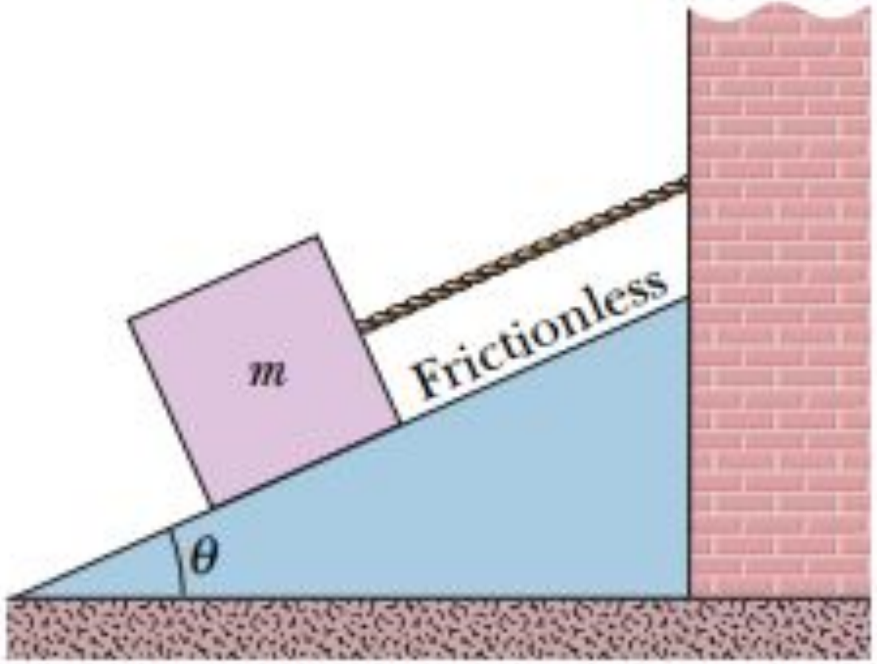
$$\Rightarrow 25 - 5 \times 9.8 \sin 30 = 5 \times a$$

$$\Rightarrow a = 0.1 \ m/s^2$$

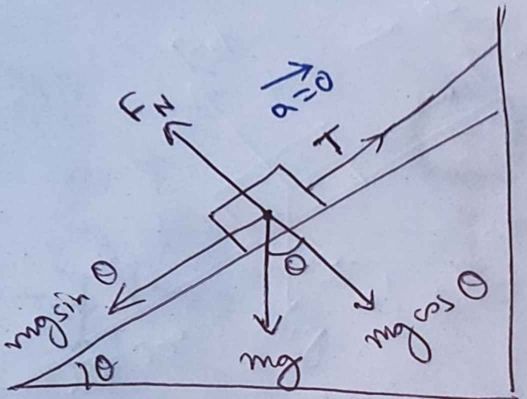
$$F_N - mg\cos\theta = 0$$

$$\Rightarrow F_N = mg\cos\theta$$

•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.



•18 In April 1974, John



$m = 8.5kg$
$\theta = 30°$

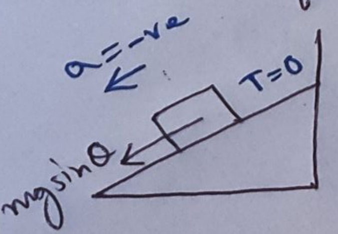
a) $T - mg\sin\theta = 0$ [a=0]

$\Rightarrow T = mg\sin\theta = 8.5g \times \sin 30$
$= 41.65N$

b) $F_N - mg\cos\theta = 0$

$\Rightarrow F_N = mg\cos\theta = 8.5 \times 9.8 \times \cos 30$
$= 72.14N$

c) If the cord is cut, Tension = 0

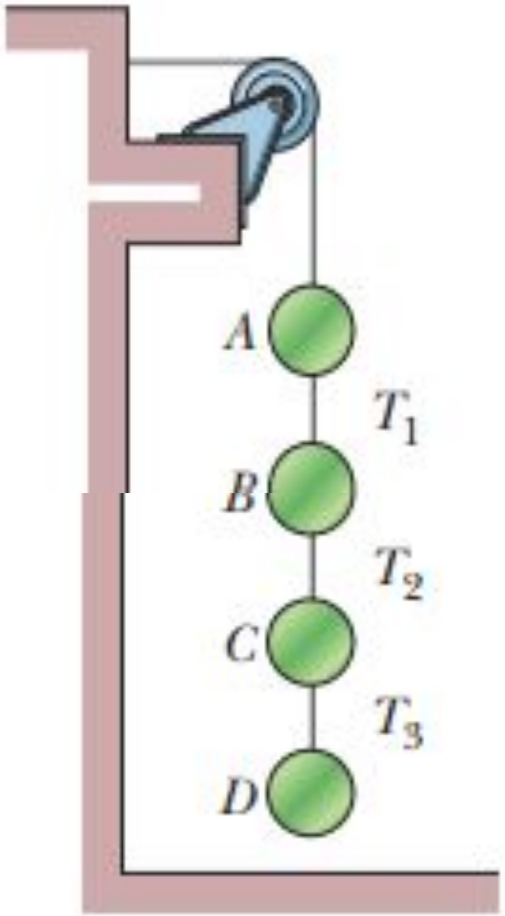


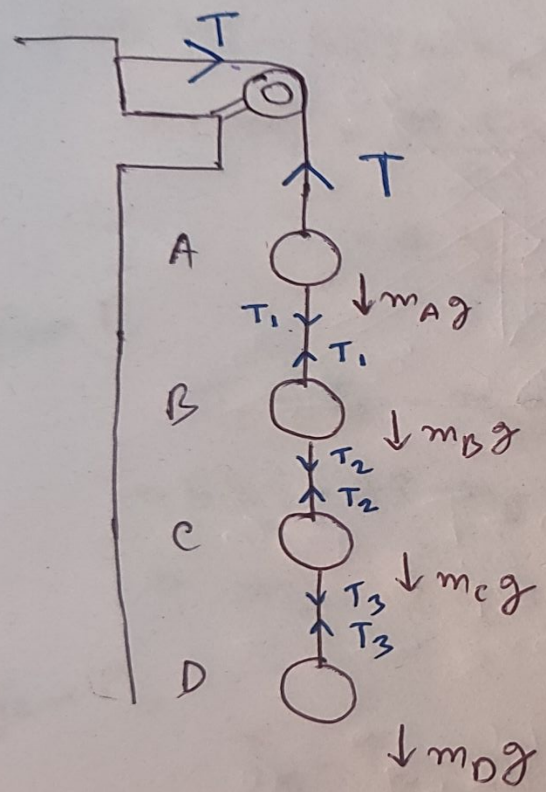
$0 - mg\sin\theta = -ma$

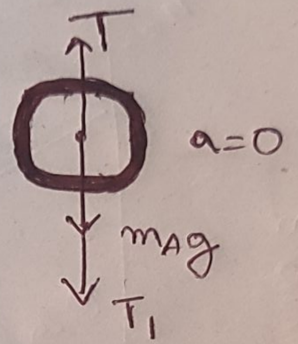
$\Rightarrow a = g\sin\theta = 9.8\sin 30$
$= 4.9\ m/s^2$

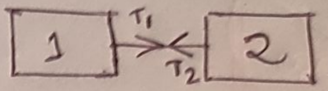
$\therefore a = -4.9 m/s^2$ / $4.9\ m/s^2$ down the plane.

•13 Figure 5-33 shows an arrangement in which four disks are suspended by cords. The longer, top cord loops over a frictionless pulley and pulls with a force of magnitude 98 N on the wall to which it is attached. The tensions in the three shorter cords are $T_1 = 58.8$ N, $T_2 = 49.0$ N, and $T_3 = 9.8$ N. What are the masses of (a) disk A, (b) disk B, (c) disk C, and (d) disk D?





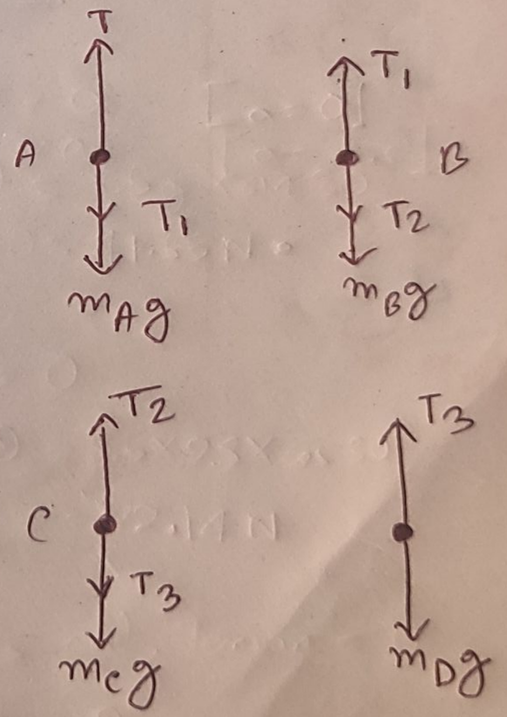




(tension → always away from the object)

$T = 98N$, $T_1 = 58.8\,N$

$T_2 = 49N$, $T_3 = 9.8\,N$



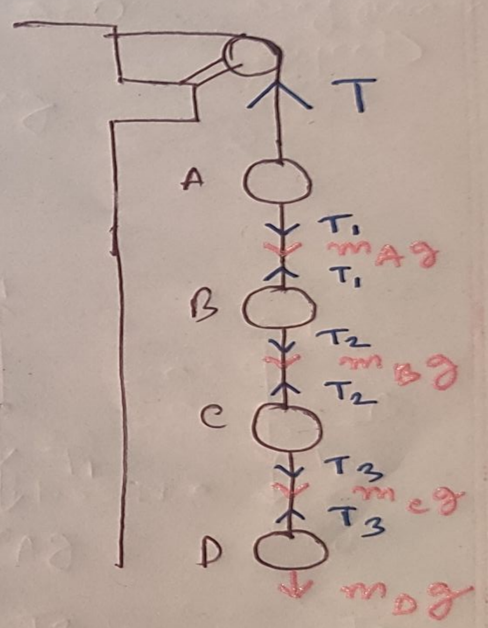
Free body force diagram

from A, $T - T_1 - m_A g = 0$

$\Rightarrow 98 - 58.8 - m_A \times 9.8 = 0$

$\Rightarrow m_A = \dfrac{98 - 58.8}{9.8}$

$= 4$ kg



from B,

$T_1 - T_2 - m_B g = 0$

$\Rightarrow 58.8 - 49 - m_B \times 9.8 = 0$

$\Rightarrow m_B = 1$ kg

from C,

$T_2 - T_3 - m_C g = 0$

$\Rightarrow 49 - 9.8 - m_C \times 9.8 = 0$

$\Rightarrow m_C = 4$ kg

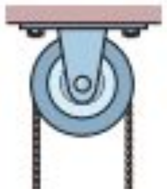
from D, $T_3 - m_D g = 0$

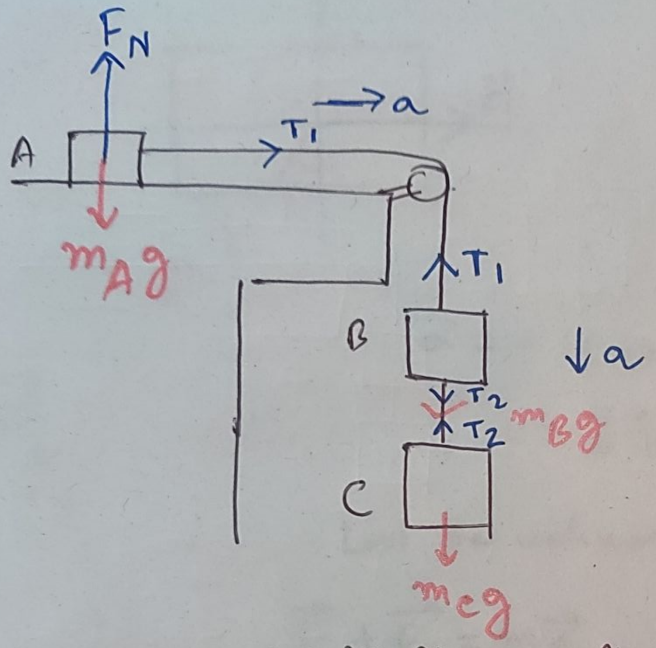
$\Rightarrow 9.8 - m_D \times 9.8 = 0$

$\Rightarrow m_D = 1$ kg

••50 GO In Fig. 5-46, three ballot boxes are connected by cords, one of which wraps over a pulley having negligible friction on its axle and negligible mass. The three masses are $m_A = 30.0$ kg, $m_B = 40.0$ kg, and $m_C = 10.0$ kg. When the assembly is released from rest, (a) what is the tension in the cord connecting B and C, and (b) how far does A move in the first 0.250 s (assuming it does not reach the pulley)?

Fig. 5-46 Problem 50.





for A,

$T_1 = m_A a$ — (1)

for B,

$T_1 - T_2 - m_B g = -m_B a$ — (2)

for C,

$T_2 - m_C g = -m_C a$ — (3)

Substituting equation (1) in (2), we get,

$m_A a - T_2 - m_B g = -m_B a$ — (4)

$T_2 - m_C g = -m_C a$ — (3)

(+)

$m_A a - m_B g - m_C g = -m_B a - m_C a$

$\Rightarrow a = \dfrac{(m_B + m_C)g}{m_A + m_B + m_C} = \dfrac{30+10}{30+40+10} \times 9.8$

$= 4.9 \, m/s^2$

$\therefore T_2 = m_C g - m_C a = m_C(g - a)$

$= 10(9.8 - 4.9) = 49 N$

••7 SSM There are two forces on the 2.00 kg box in the overhead view of Fig. 5-31, but only one is shown. For $F_1 = 20.0$ N, $a = 12.0\ \text{m/s}^2$, and $\theta = 30.0°$, find the second force (a) in unit-vector notation and as (b) a magnitude and (c) an angle relative to the positive direction of the x axis.

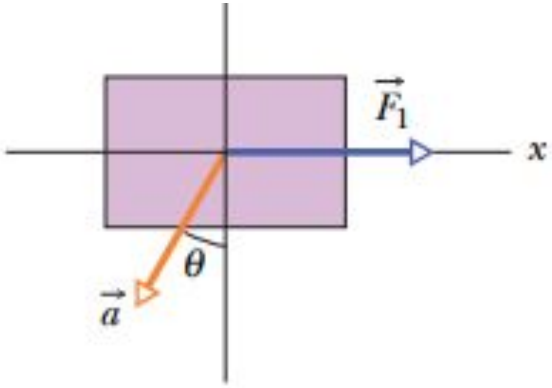
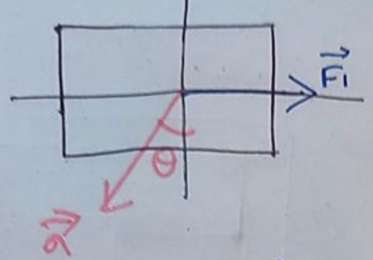


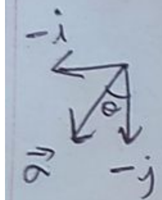
Fig. 5-31 Problem 7.



$a = 12\ \text{m/s}^2$

$\theta = 30°$

$\vec{F_1} = 20\,\hat{i}$ N



$\vec{a} = -12 \sin 30\ \hat{i} - 12 \cos 30\ \hat{j}\ \text{m/s}^2$

$= -6\,\hat{i} - 10.4\,\hat{j}\ \text{m/s}^2$

Let the unknown force be $\vec{F_2}$

a) $\vec{F_1} + \vec{F_2} = m\vec{a}$

$\Rightarrow \vec{F_2} = m\vec{a} - \vec{F_1}$

$= 2\,(-6\hat{i} - 10.4\hat{j}) - 20\hat{i}$

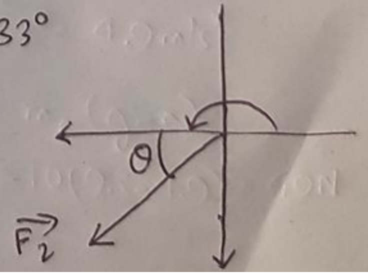
$= -32\hat{i} - 20.8\,\hat{j}$ N

b) $|\vec{F_2}| = \sqrt{(-32)^2 + (-20.8)^2} = 38.2$ N

c) $\theta = \tan^{-1}\left(\frac{-20.8}{-32}\right) = 33°$

$\therefore$ Angle $= 180 + 33$

$= 213°$



••34 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?

••35 The velocity of a 3.00 kg particle is given by $\vec{v} = (8.00t\hat{i} + 3.00t^2\hat{j})$ m/s, with time t in seconds. At the in-

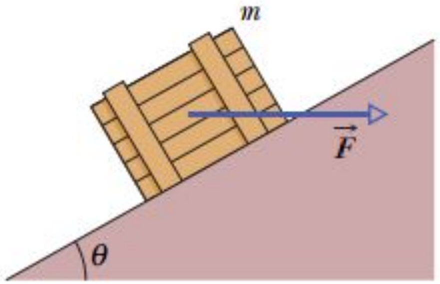
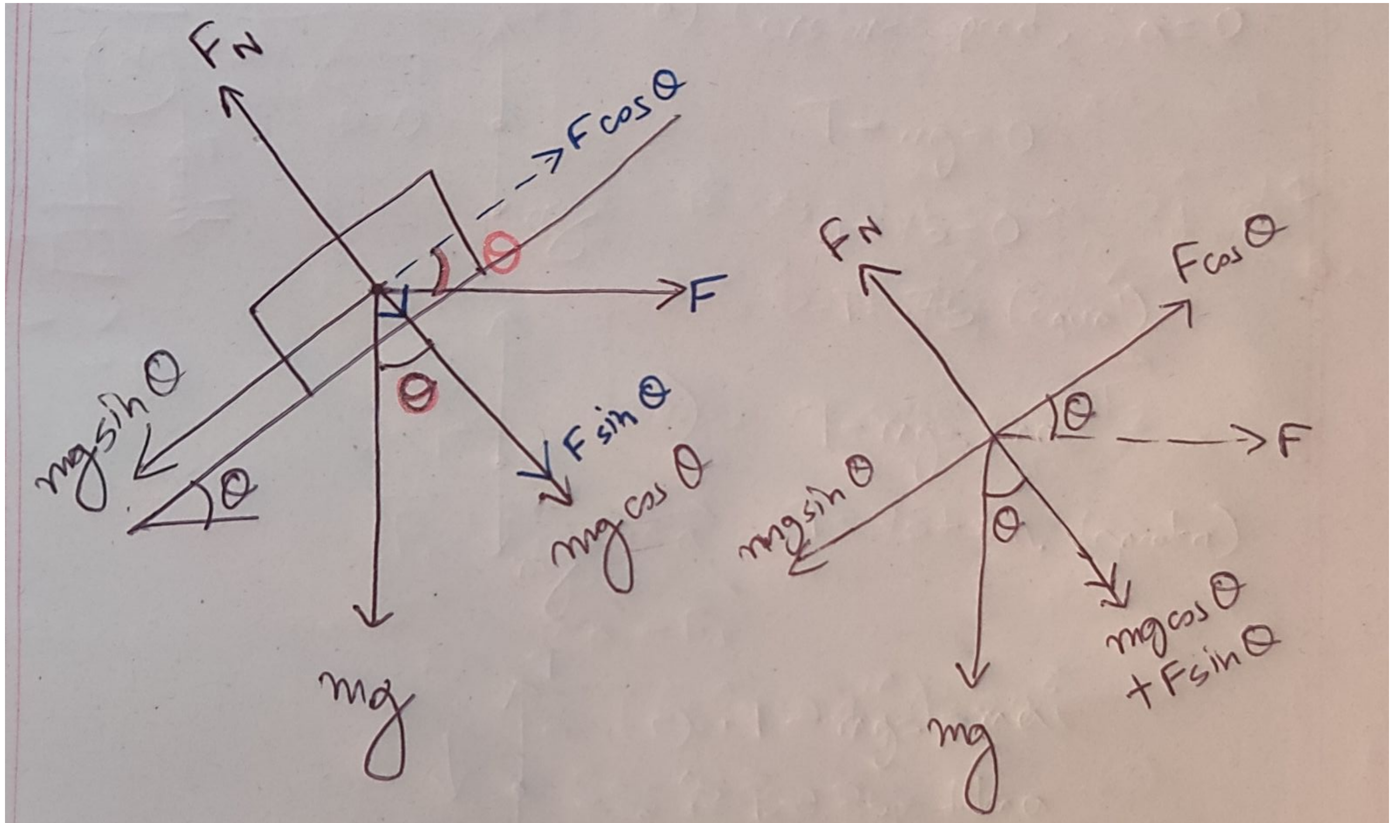
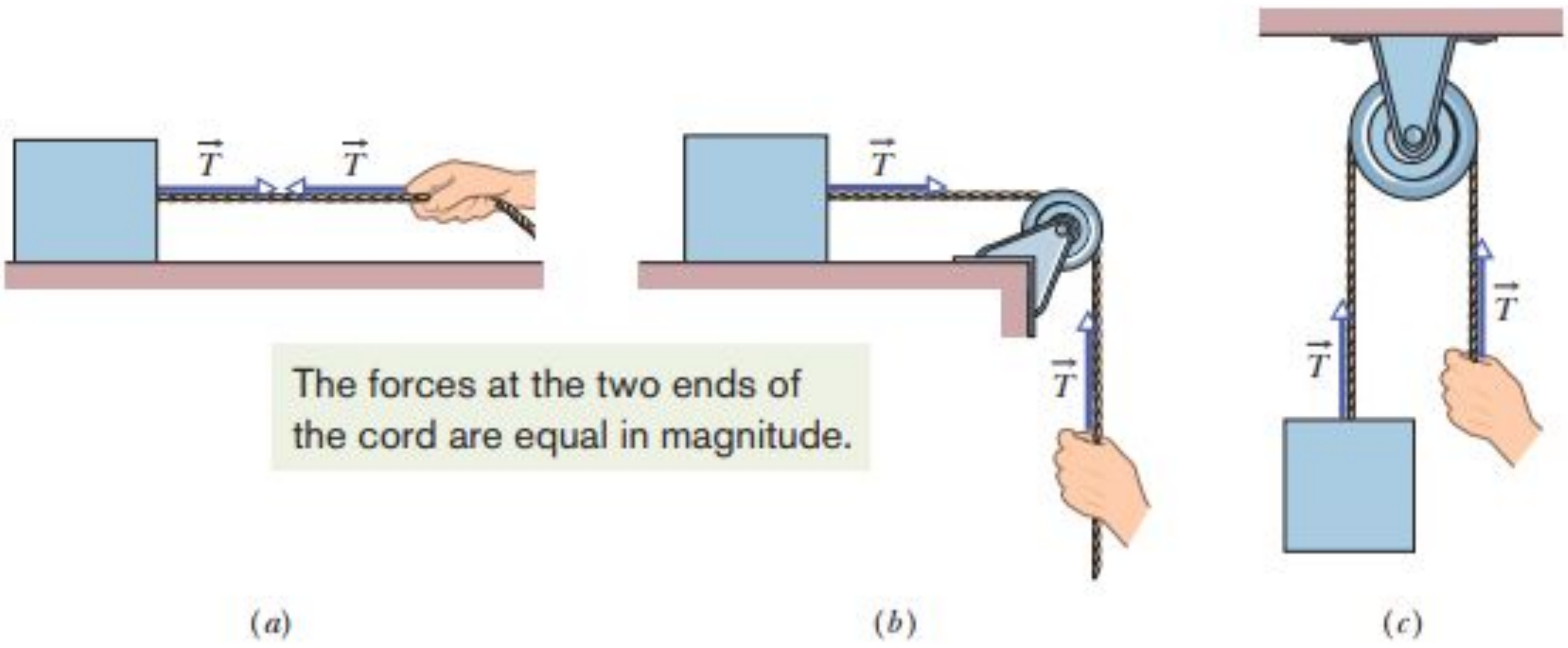


Fig. 5-40 Problem 34.

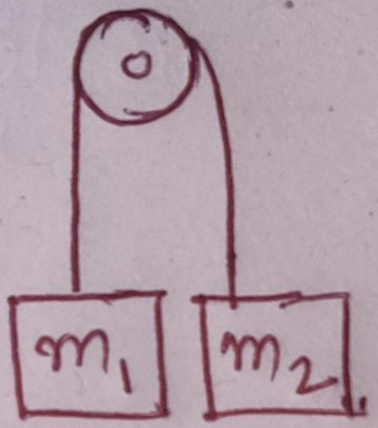


$F\cos\theta - mg\sin\theta = 0$ [a=0, at constant speed]

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



$\vec{T}$
$\vec{T}$
$\vec{T}$
$\vec{T}$
$\vec{T}$
$\vec{T}$
The forces at the two ends of the cord are equal in magnitude.
(a)
(b)
(c)



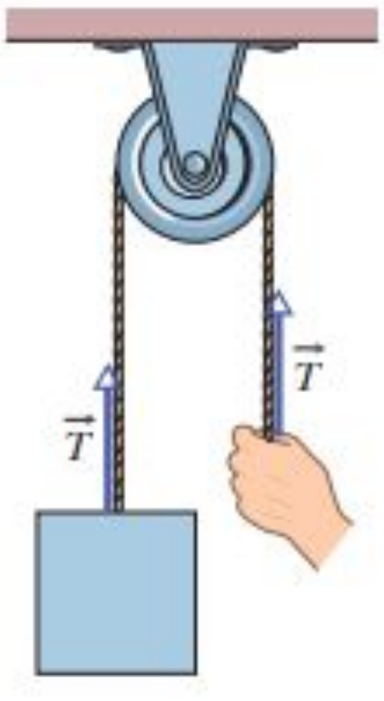
① If $m_1 = m_2$ → stationeny $(a=0)$

② If $m_1 > m_2$ m_1 falls down

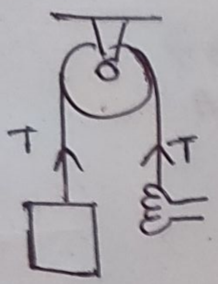
③ If $m_2 > m_1$ m_2 falls down

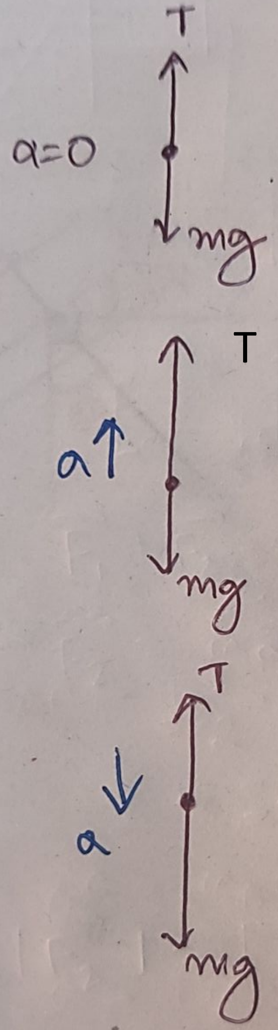
CHECKPOINT 4

The suspended body in Fig. 5-9*c* weighs 75 N. Is T equal to, greater than, or less than 75 N when the body is moving upward (a) at constant speed, (b) at increasing speed, and (c) at decreasing speed?



(c)





(a) Constant speed, $\therefore a=0$

$T - mg = 0$

$\Rightarrow T - 75 = 0$

$\Rightarrow T = 75$ (equal)

b) $T - mg = ma$

$T = 75 + ma$ (greater)

c) $T - mg = -ma$

$\Rightarrow T - 75 = -ma$

$\Rightarrow T = 75 - ma$ (less)

••**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.

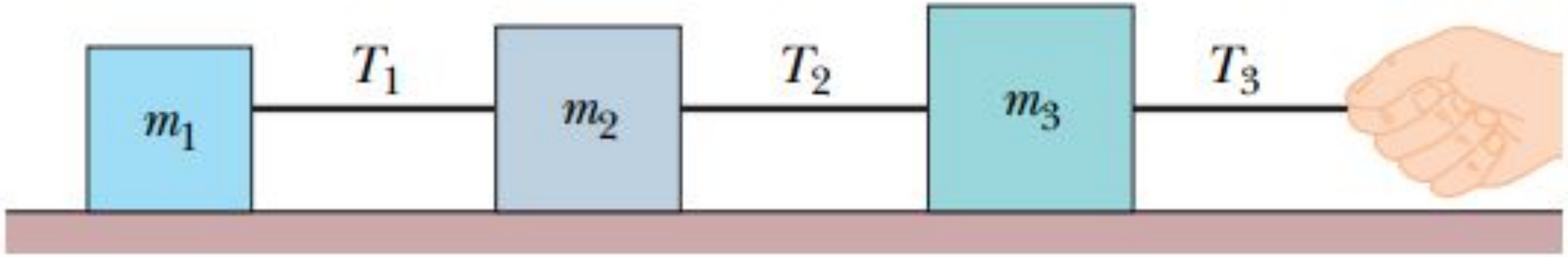
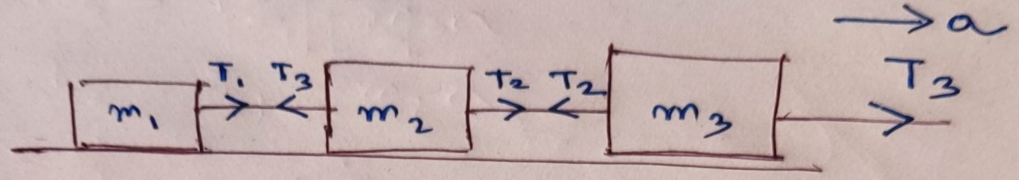


Fig. 5-48 Problem 53.

(53)



a) $$T_3 - T_2 = m_3 a \quad \text{——} (1)$$

$$T_2 - T_1 = m_2 a \quad \text{——} (2)$$

$$T_1 = m_1 a \quad \text{——} (3)$$

(+)

$$T_3 = m_3 a + m_2 a + m_1 a$$

$$\Rightarrow T_3 = a(m_3 + m_2 + m_1)$$

$$\Rightarrow a = \frac{T_3}{m_3 + m_2 + m_1} = \frac{65}{31+24+12} = 0.97 \, m/s^2$$

b) $$T_1 = m_1 a$$
$$= 12 \times 0.97 \, N$$
$$= 11.64 \, N$$

c) $$T_2 = m_2 a + T_1$$
$$= 24 \times 0.97 + 11.64 \, N$$
$$= 34.92 \, N$$

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?

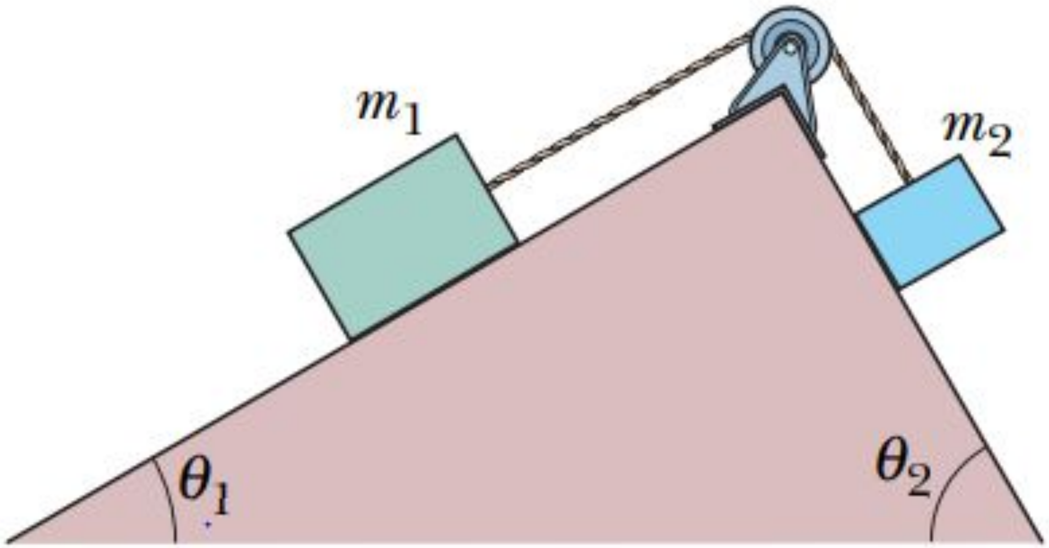
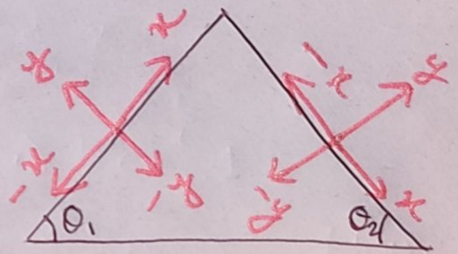
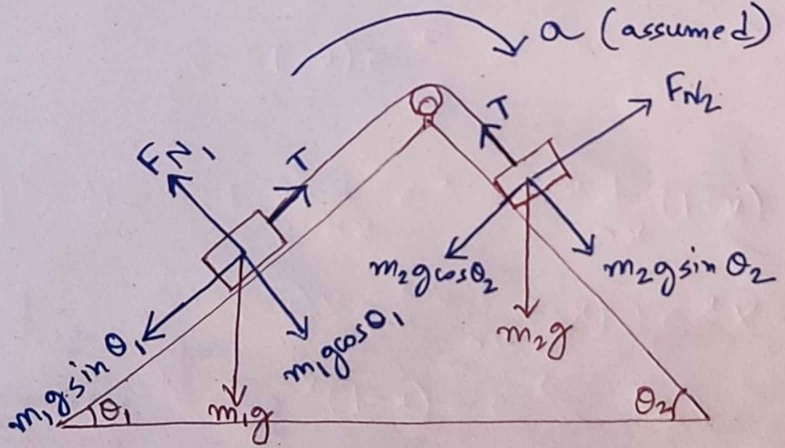


Fig. 5-60 Problem 71.





$\theta_1 = 30°$
$\theta_2 = 60°$

$m_1 = 3\,kg$
$m_2 = 2\,kg$

m_1

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

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

(+)

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

$$\Rightarrow m_2 g\sin\theta_2 - m_1 g\sin\theta_1 = a(m_1 + m_2)$$

$$\Rightarrow a = \frac{m_2 g\sin\theta_2 - m_1 g\sin\theta_1}{m_1 + m_2} = \frac{2\times 9.8\sin 60 - 3\times 9.8\sin 30}{2+3}$$

$$= 0.45\ m/s^2$$

$$T = m_1 a + m_1 g\sin\theta_1$$

$$= 3\times 0.45 + 3\times 9.8\sin 30\ N$$

$$= 16.05\ N$$