College Of Engineering
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جامعة الأنبار

Dept. of Chem. & Petrochemical Engineering
Subject : Physics
First Stage

Physics

Chapter-3 Force and Laws of Motion

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Equilibrium, Example

Conceptualize the traffic light

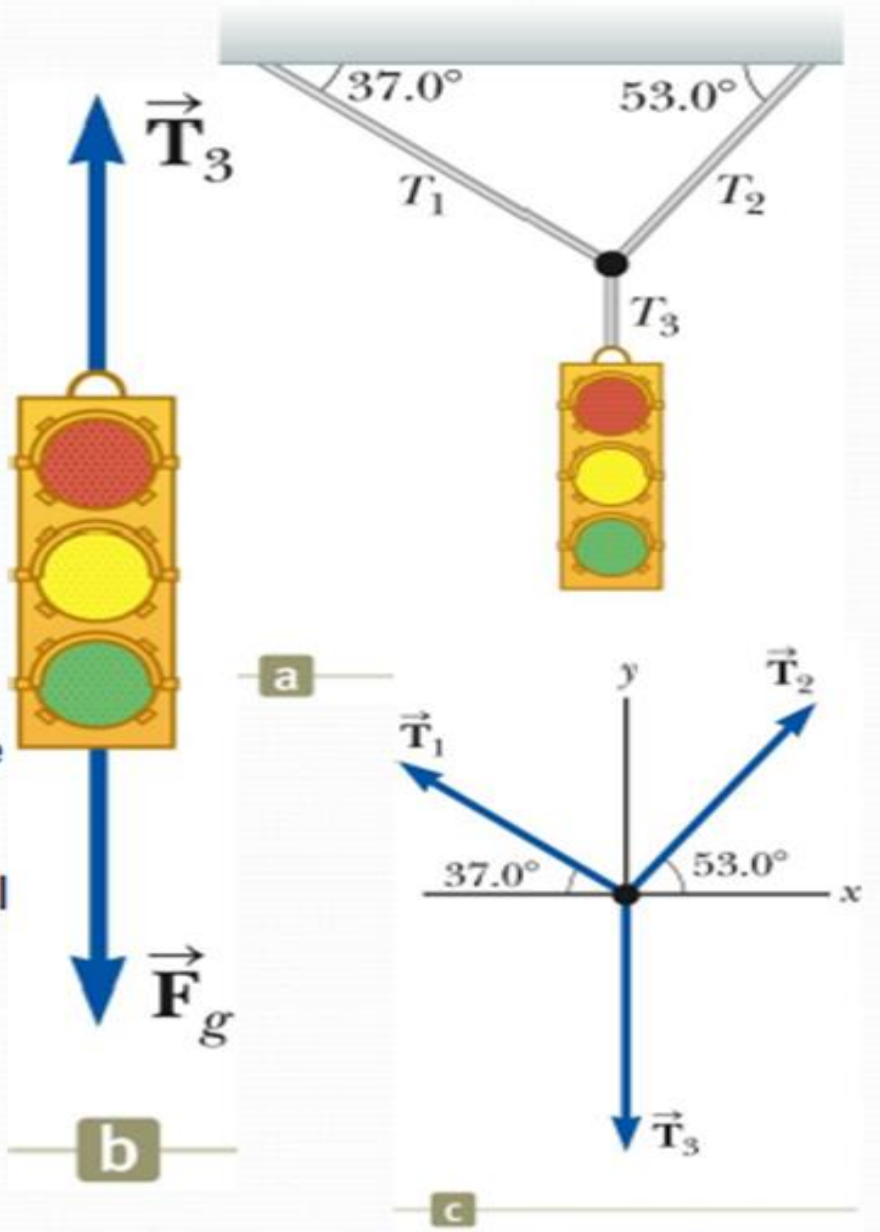
- Assume cables don't break
- Nothing is moving

Categorize as an equilibrium problem

- No movement, so acceleration is zero

Analyze

- Construct a diagram for the forces acting on the light
- Construct a free body diagram for the knot where the three cables are joined
- The knot is a convenient point to choose since all the forces of interest act along lines passing through the knot.
- Apply equilibrium equations to the knot
- Find T_1 , T_2 and T_3 from applying equilibrium in the x- and y-directions to the knot



Example

- Think about different situations and see if the results are reasonable.
- Knowing that the knot is in equilibrium (a = 0) allows us to write

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	-122 N

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

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

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

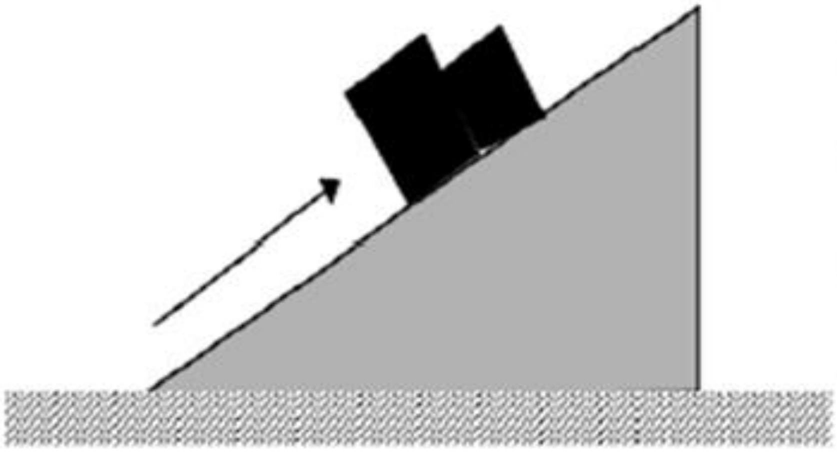
$$T_1 \sin 37.0° + (1.33 T_1)(\sin 53.0°) - 122 \text{ N} = 0$$

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

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

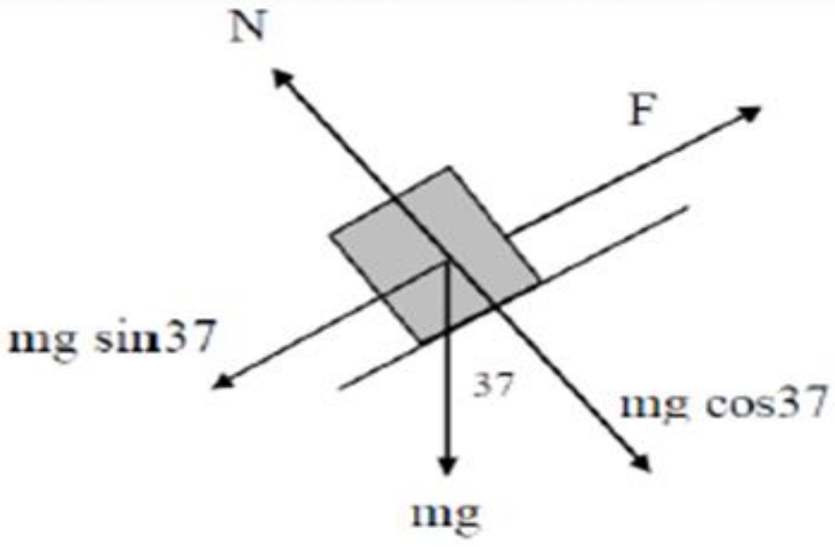
Inclined Planes, Example

Two blocks having masses of 2 kg and 3 kg are in contact on a fixed smooth inclined plane as in Figure. Treating the two blocks as a composite system, calculate the force *F* that will accelerate the blocks up the incline with acceleration of 2m/s2,



Solution

We can replace the two blocks by an equivalent 5 kg block as shown in Figure. Letting the *x* axis be along the incline, the resultant force on the system (the two blocks) in the *x* direction gives



$$\sum F_x = F - W \sin(37^\circ) = m\, a_x$$

$$F - 5\,(0.6) = 5(2)$$

$$F = 39.4\ \text{N}$$

Multiple Objects, Example – Atwood's Machine

Forces acting on the objects:

- Tension (same for both objects, one string)
- Gravitational force

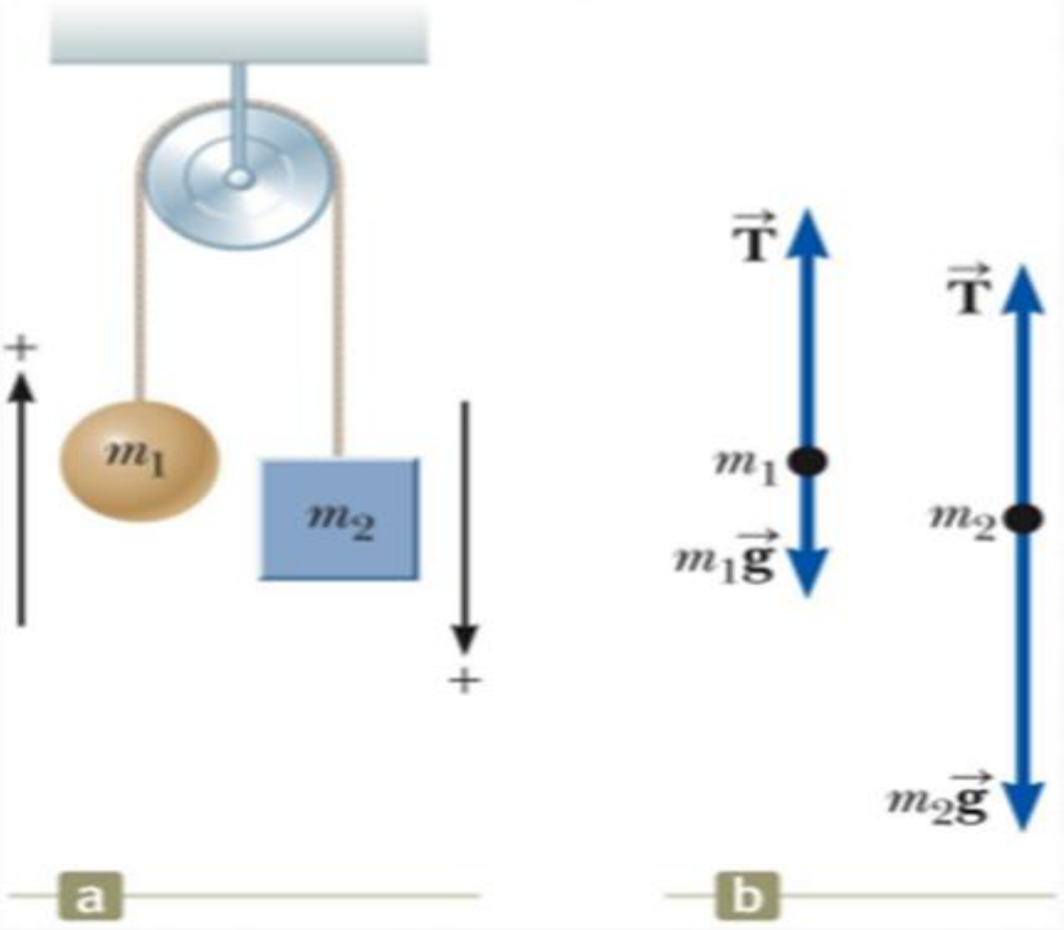
Each object has the same acceleration since they are connected.

Draw the free-body diagrams

Apply Newton's Laws

Solve for the unknown(s)

- Note the acceleration is the same for both objects
- The tension is the same on both sides of the pulley as long as you assume a massless, frictionless pulley.



- Example
- Two masses of 3 kg and 5 kg are connected by a light string that passes over a smooth pulley as shown in the Figure. Determine (a) the tension in the string, (b) the acceleration of each mass, and (c) the distance each mass moves in the first second of motion if they start from rest.

(a)

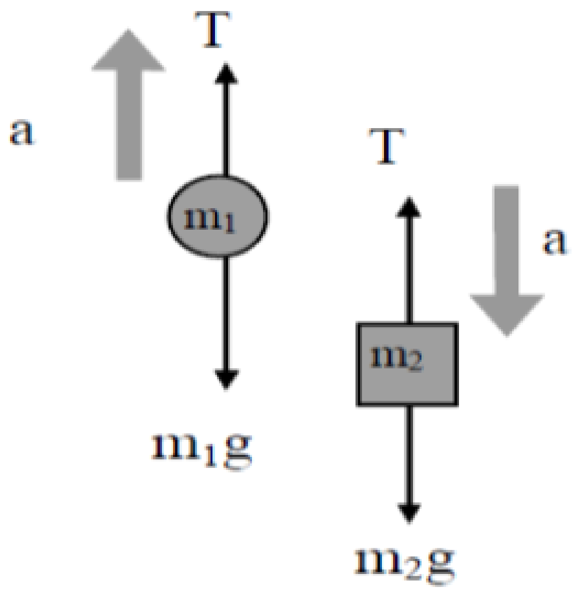
$$m_1 a = T - m_1 g \qquad (1)$$

$$m_2 a = m_2 g - T \qquad (2)$$

Add (1) and (2)

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

$$a = \frac{m_2 - m_1}{(m_2 + m_1)g} = \frac{5-3}{(5+3)(9.8)} = 2.45\text{m/s}^2$$



(b)

$$T = m_2\,(g - a) = 5(9.80 - 2.45) = 36.6\ \text{N}$$

(c) Substitute a into (1)

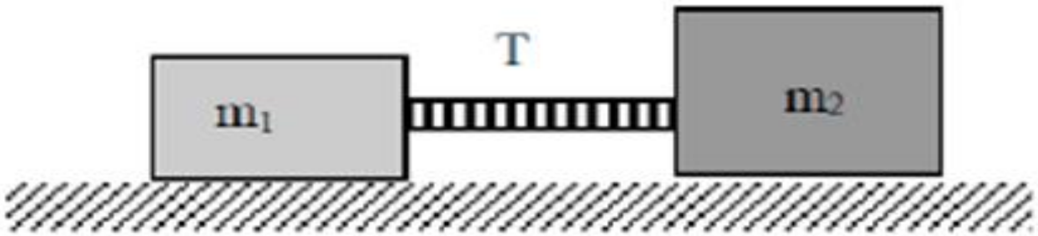
$$T = m_1\,(a + g) = \frac{2m_1 m_2 g}{m_1 + m_2}$$

$$s = \frac{at^2}{2} \quad (v_o = 0),$$

At $t = 1\text{s}$, $$s = \frac{(2.45)(1^2)}{2} = 1.23\text{m}$$

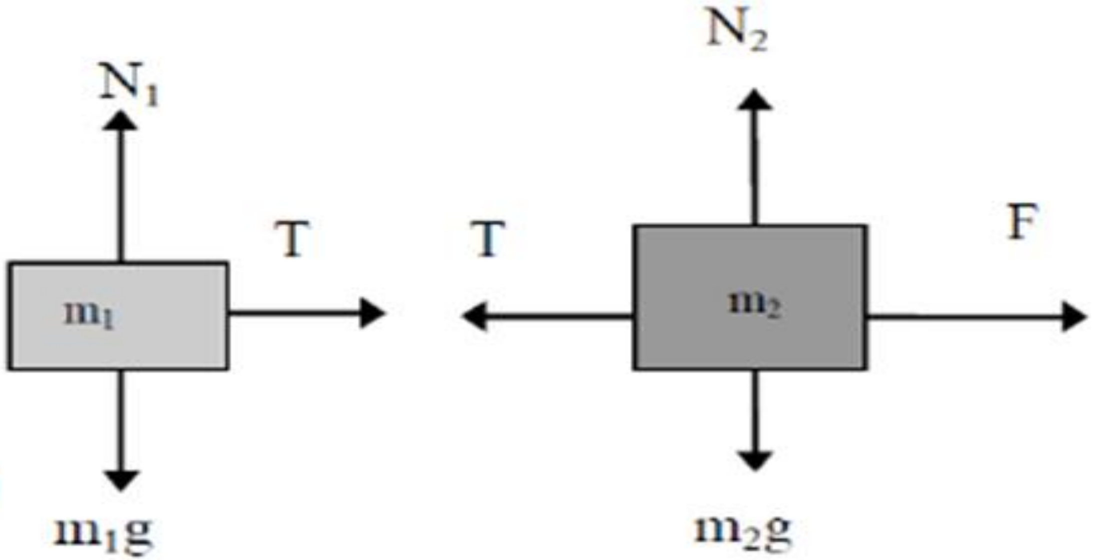
Multiple Objects, Example 2

Two blocks connected by a light rope are being dragged by a horizontal force *F* as shown in the Figure 3.5. Suppose that *F* = 50 N, m_1 = 10 kg, m_2 = 20 kg,



(a) Draw a free-body diagram for each block.

(b) Determine the tension, *T*, and the acceleration of the system.



Solution

$\sum Fx(m1) = T = m1\ a$ $\sum Fx(m2) = 50 - T = m2\ a$

$\sum Fy(m1) = N1 - m1g = 0$ $\sum Fy(m2) = N2 - m2g = 0$

$T = 10\ a$, $50 - T = 20\ a$

Adding the expression above gives

$50 = 30\ a$,

$a = 1.66$ m/s2

$T = 16.6$N

Friction: A force that resists the motion of one object sliding past another.

Static friction

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

$f_{s,max}$ = maximum static friction
μ_s = coefficient of static friction
F_N = normal force

Frictional Force

Friction and energy loss due to friction appear every day in our life.

The maximum force of friction F is

F = μ N

Where **N** is a Normal force.

μ Is the coefficient between the two surfaces.

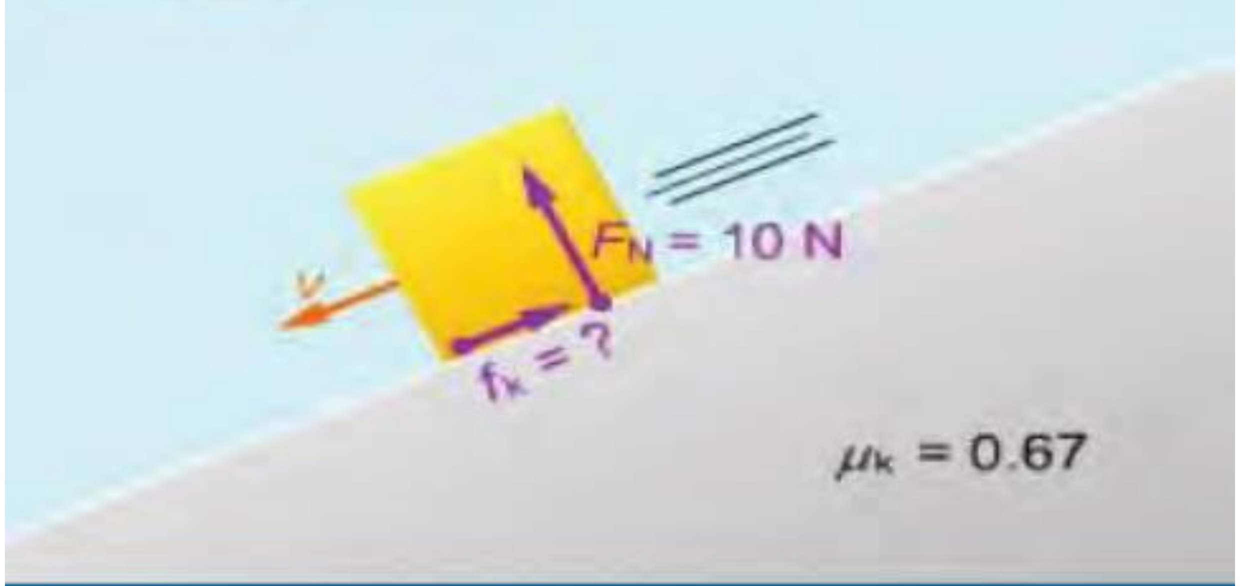
The value of μ depends upon the two materials in contact , and it is essentially independent of the surface area , as shown in Table 1.

TABLE 5.1 *Coefficients of Friction*

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

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

example 1



What is the force of friction?

$$f_k = \mu_k F_N$$

$$f_k = (0.67)(10\ \text{N})$$

f_k = 6.7 N (pointing up the ramp)

- **Friction Example, 2**
- A 3 kg block starts from rest at the top of 30 o incline and slides with a = 1.78 m/s 2. Find
- (a) the coefficient of kinetic friction between the block and the plane
- (b) the friction force acting on the block

Solution

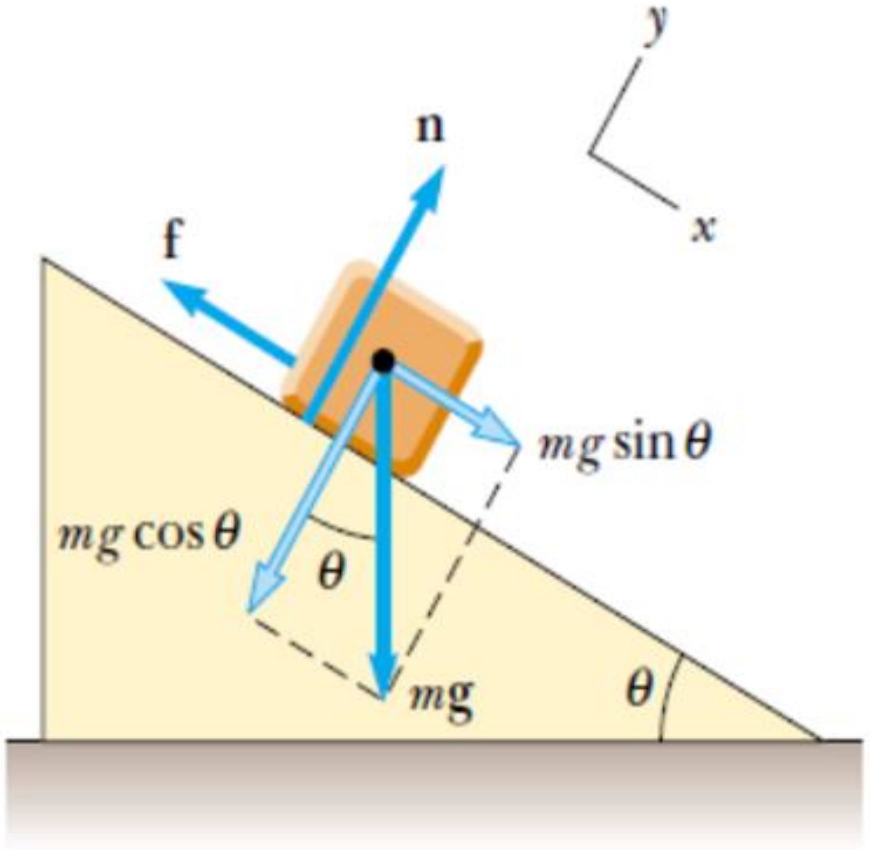
Given $m = 3\text{kg}$, $\theta = 30_\circ$

$mg \sin 30 - f = ma \Rightarrow f = m(g \sin 30 - a) \Rightarrow f =$ 9.37N

$N - mg \cos 30 = 0 \Rightarrow N = mg \cos 30$

$f = 9.37\text{N}$

$\mu_k = N/f = 0.368$



- **Friction, Example 3**
- Draw the free body diagram, including the force of kinetic friction. Continue with the solution as with any Newton s Law problem. This example gives information about the motion which can be used to find the acceleration to use in Newton s Laws.

Solution:

We apply Newton’s second law in component form to the puck and obtain

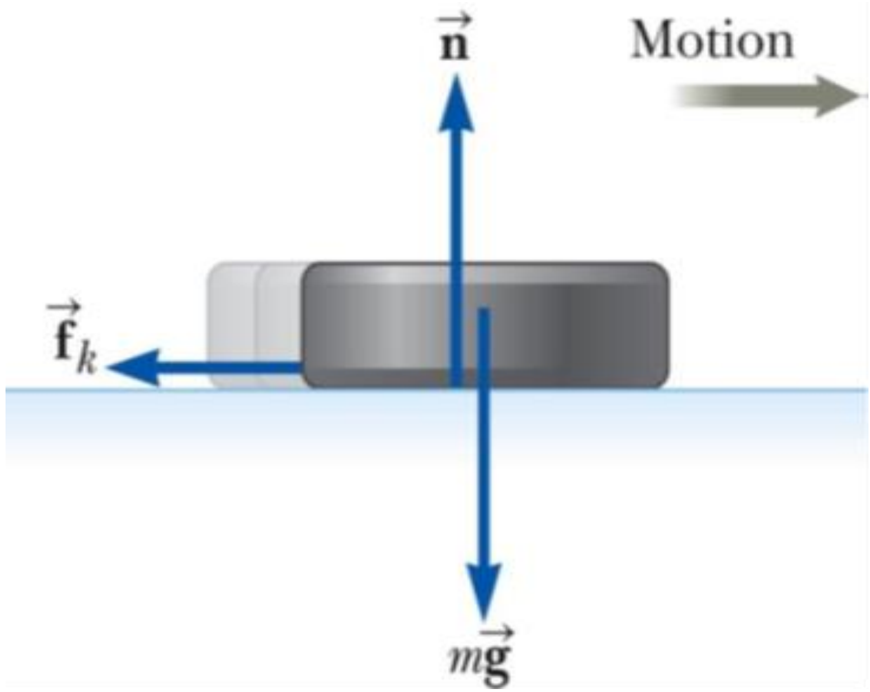
(1) $\sum F_x = -f_k = ma_x$

(2) $\sum F_y = n - mg = 0 \quad (a_y = 0)$

But $f_k = \mu_k n$, and from (2) we see that $n = mg$. Therefore, (1) becomes

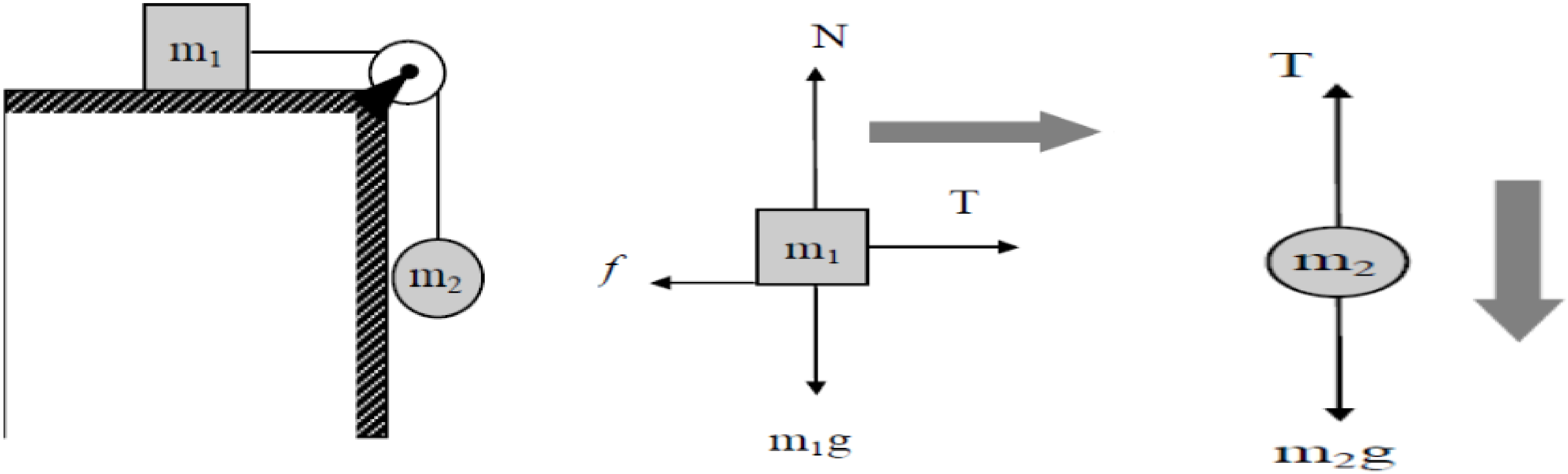
$$-\mu_k n = -\mu_k mg = ma_x$$

$$a_x = -\mu_k g$$



Friction, Example 4

Two blocks are connected by a light string over a frictionless pulley as shown in Figure. The coefficient of sliding friction between m 1 and the surface is m. Find the acceleration of the two blocks and the tension in the string.



Solution

Friction acts only on the object in contact. Draw the free body diagrams. Apply Newton s Laws as in any other multiple object system problem.

Consider the motion of $m1$. Since its motion to the right, then $T>f$. If T were less than f, the blocks would remain stationary.

$$\sum F_x \text{ (on } m_1) = T - f = m_1 a$$

$$\sum F_y \text{ (on } m_1) = N - m_1 g = 0$$

since $f = \mu N = m_1 g$, then

$$T = m_1(a+\mu g)$$

For $m2$, the motion is downward, therefore $m2g>T$. The equation of motion for $m2$ is: $\sum F_y \text{ (on } m_2) = T - m_2 g = - m_2 a \quad \Rightarrow \quad T = m_2(g-a)$

Solving the above equation $m_2(a+\mu g) - m_2(g-a) = 0$

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

The tension T is $T = m_2 \left(1 - \frac{m_2 - \mu m_1}{m_1 + m_2}\right) g = \frac{m_1 m_2 (1+\mu) g}{m_1 + m_2}$