Chapter 5: Force and Motion-I

- ✓ **Force**
- ✓ **Basic Laws of Motion (Newton's Laws)**
- ✓ **Applying Newton's Laws**

Chapter 5: Force and Motion-I

Session 10:

- ✓ **Applying Newton's Laws**

Basic Laws of Motion

1) Newton's First Law (Law of Inertia):

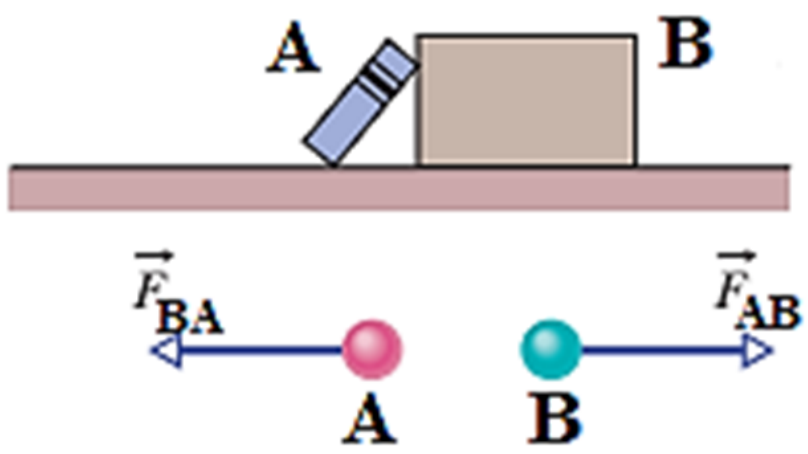
if $\vec{\mathbf{F}}_{net} = 0 \Rightarrow \boxed{\vec{\mathbf{a}} = 0 \quad ; \quad v = \textbf{constant}}$

2) Newton's Second Law:

$$\boxed{\vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}}} \Rightarrow \begin{cases} \mathbf{F}_{net,x} = \mathrm{m}\mathrm{a}_x \\ \mathbf{F}_{net,y} = \mathrm{m}\mathrm{a}_y \\ \mathbf{F}_{net,z} = \mathrm{m}\mathrm{a}_z \end{cases}$$

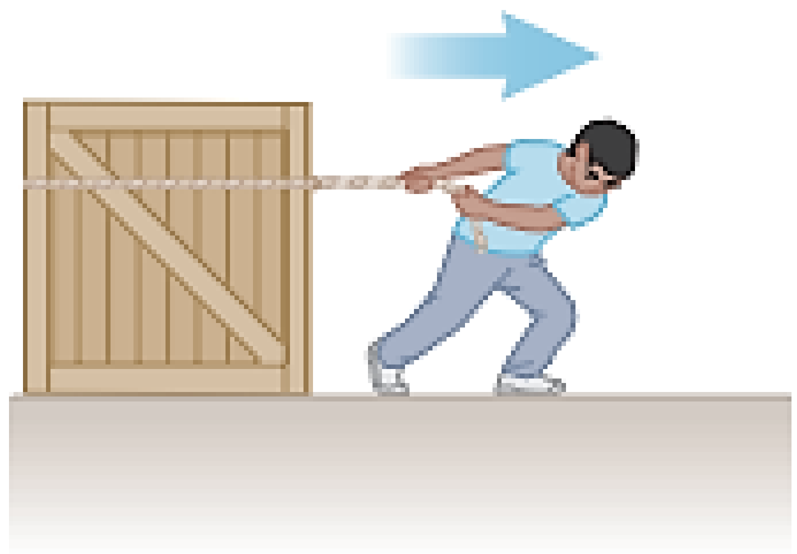
3) Newton's Third Law:

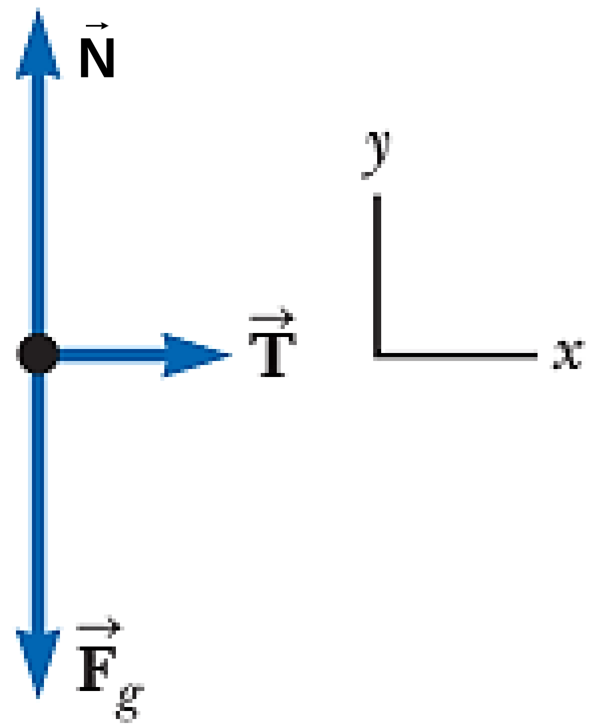
$$\boxed{\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}}$$



Applying Newton's Laws

Analysis Model: The Particle Under a Net Force





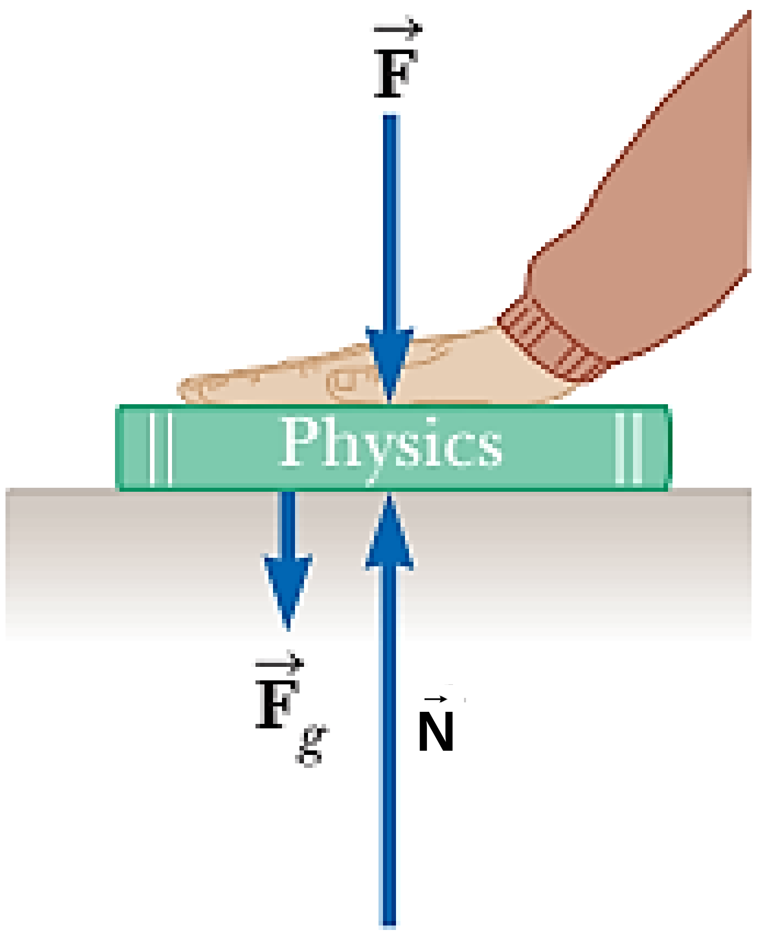
$$\vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}} \Rightarrow \begin{cases} \mathbf{F}_{net,x} = \mathrm{m}\,\mathrm{a}_x \\ \mathbf{F}_{net,y} = \mathrm{m}\,\mathrm{a}_y \end{cases}$$

$$\boxed{T = \mathrm{m}\,\mathrm{a}_x \;\Rightarrow\; \mathrm{a}_x = \frac{T}{m}}$$

$$\boxed{N - F_g = 0 \;\Rightarrow\; N = F_g}$$

Applying Newton's Laws

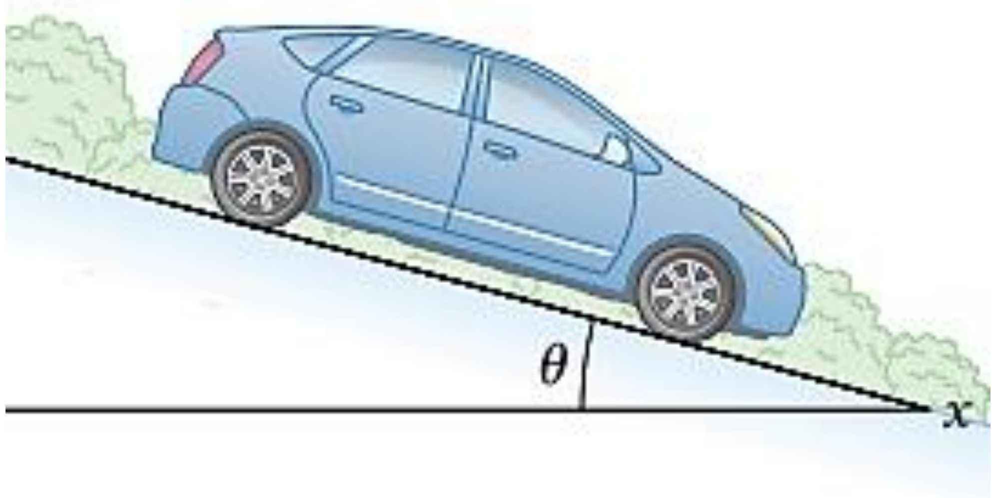
Note About the Normal Force:

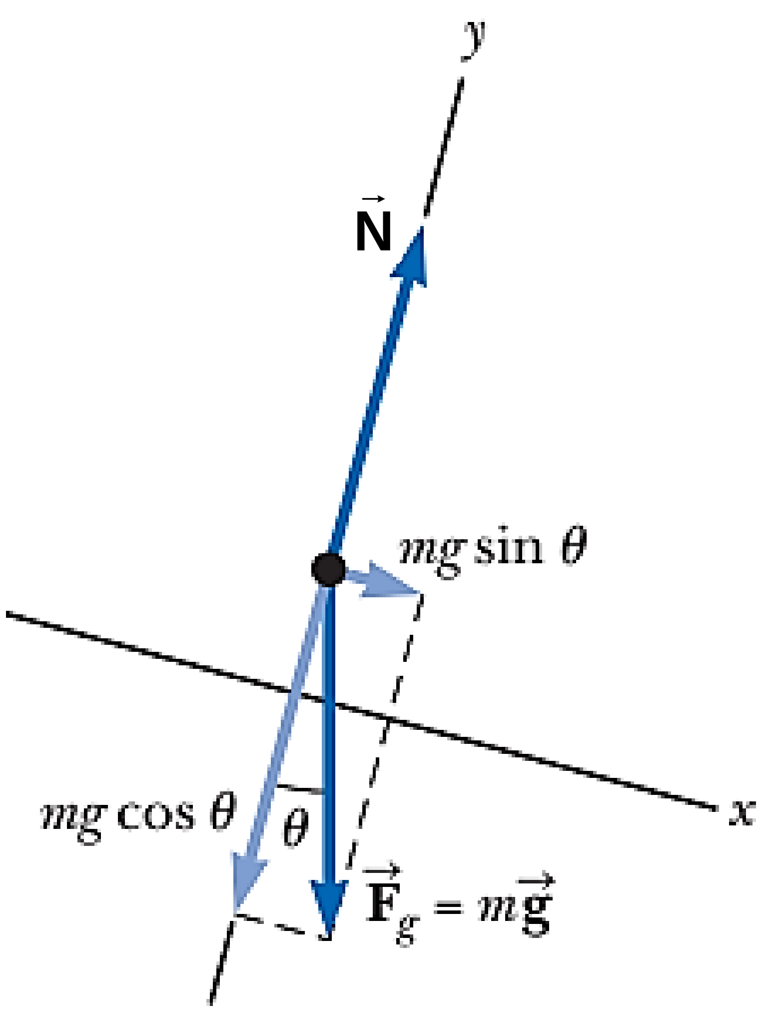


$$\mathbf{F}_{net,y} = \mathrm{m}\,\mathrm{a}_y$$

$$N - F_g - F = 0$$

$$\boxed{N = F_g + F = mg + F}$$





$$\mathbf{F}_{net,y} = \mathrm{m}\,\mathrm{a}_y \Rightarrow N - mg\cos\theta = 0$$

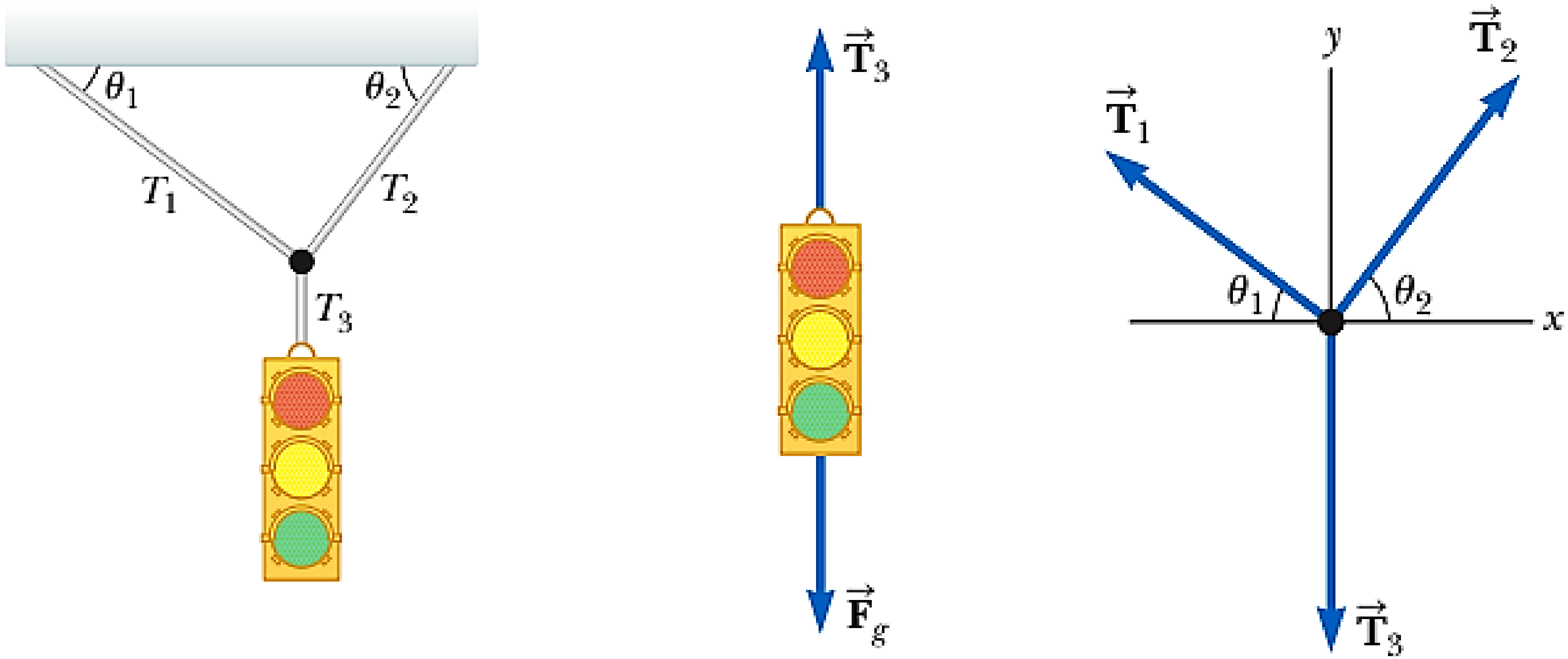
$$\boxed{N = mg\cos\theta}$$

$$\mathbf{F}_{net,x} = \mathrm{m}\,\mathrm{a}_x \Rightarrow mg\sin\theta = ma_x$$

$$\boxed{\mathrm{a}_x = g\sin\theta}$$

Applying Newton's Laws

Equilibrium:



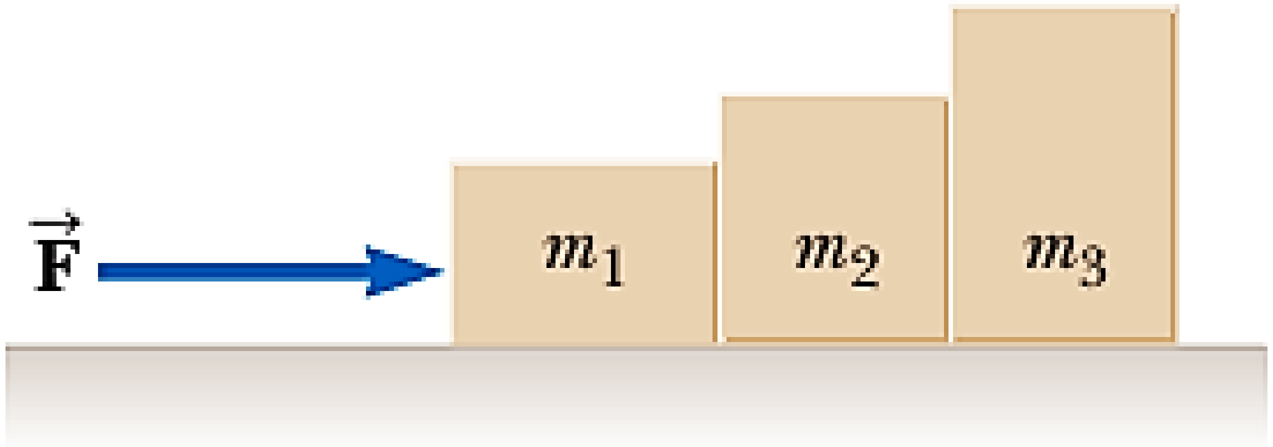
$$\mathbf{F}_{net,y} = 0 \Rightarrow T_3 - F_g = 0 \Rightarrow \boxed{T_3 = F_g}$$

$$\begin{cases} \mathbf{F}_{net,x} = 0 \\ \mathbf{F}_{net,y} = 0 \end{cases} \Rightarrow \begin{cases} -T_1 \cos\theta_1 + T_2 \cos\theta_2 = 0 \Rightarrow T_1 \cos\theta_1 = T_2 \cos\theta_2 \\ T_1 \sin\theta_1 + T_2 \sin\theta_2 - T_3 = 0 \Rightarrow T_1 \sin\theta_1 + T_2 \sin\theta_2 = T_3 = F_g \end{cases}$$

Applying Newton's Laws

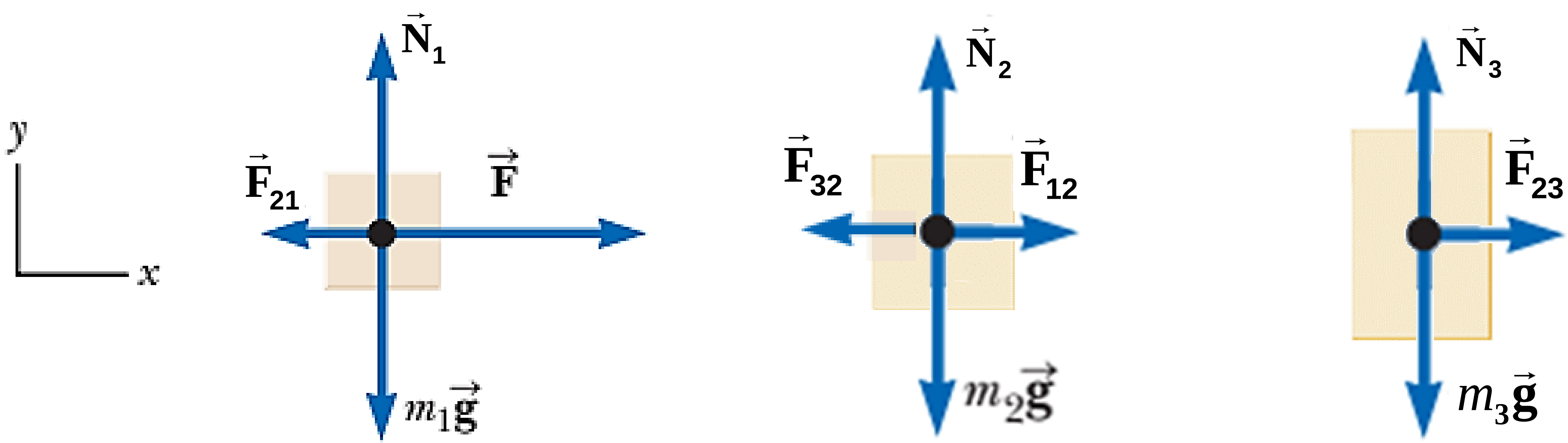
Ex 1: Three blocks of masses **m_1= 1 kg**, **m_2= 2 kg** and **m_3= 3 kg** are placed in contact with each other on a frictionless, horizontal surface. A constant horizontal force **F= 6 N** is applied to m_1 as shown. (a) Find the magnitude of the **acceleration of the system**. (b) Determine the magnitude of the **contact forces between the blocks**.

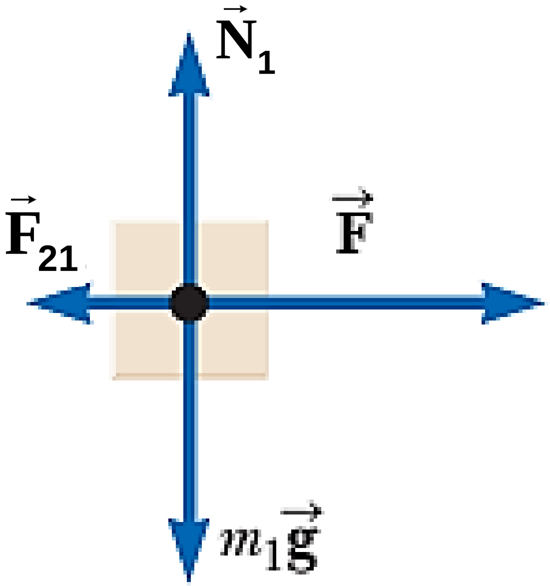
$$\begin{cases} \mathbf{F}_{net,x} = ma_x \\ \mathbf{F}_{net,y} = ma_y \end{cases}$$



$$F = (m_1 + m_2 + m_3)a$$

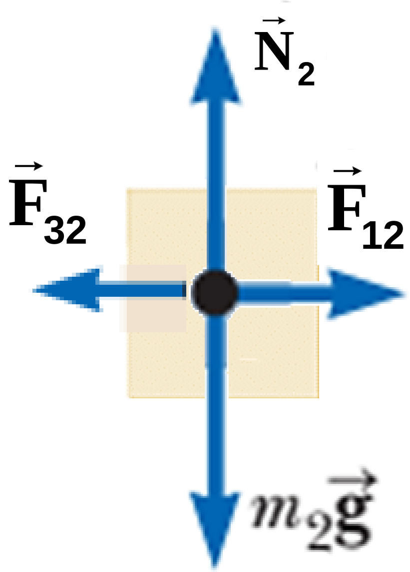
$$\boxed{a = \frac{F}{m_1 + m_2 + m_3} = \frac{6}{6} = 1 \ \ (m/s^2)}$$





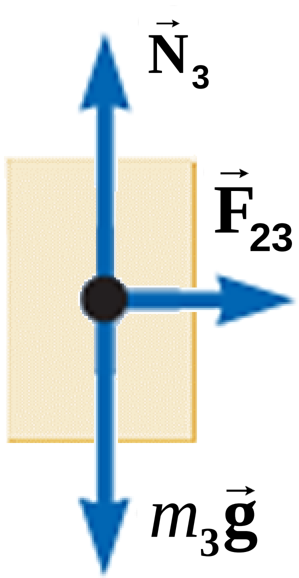
$$F - F_{21} = m_1 a \Rightarrow \boxed{F_{21} = F - m_1 a = 6 - 1(1) = 5\ N}$$

$$\boxed{F_{12} = F_{21} = 5\ N}$$



$$F_{12} - F_{32} = m_2 a \Rightarrow \boxed{F_{32} = F_{12} - m_2 a = 5 - 2(1) = 3\ N}$$

$$\boxed{F_{23} = F_{32} = 3\ N}$$

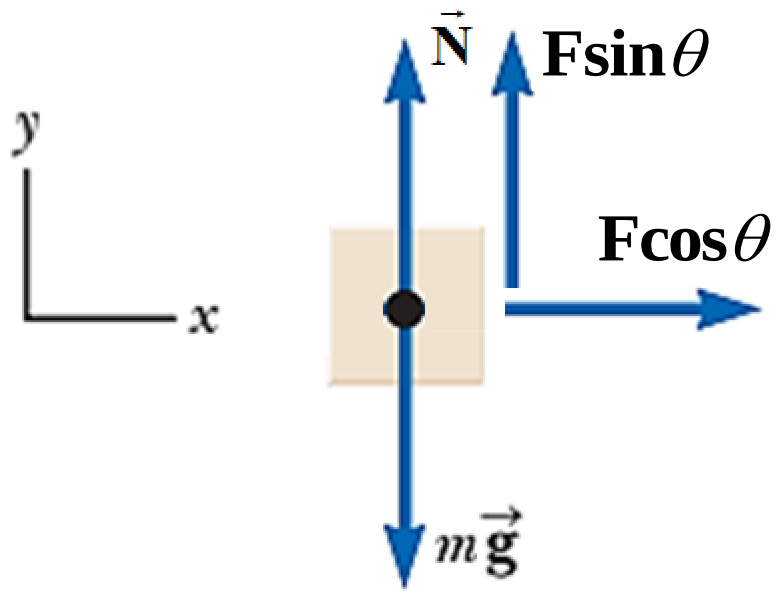


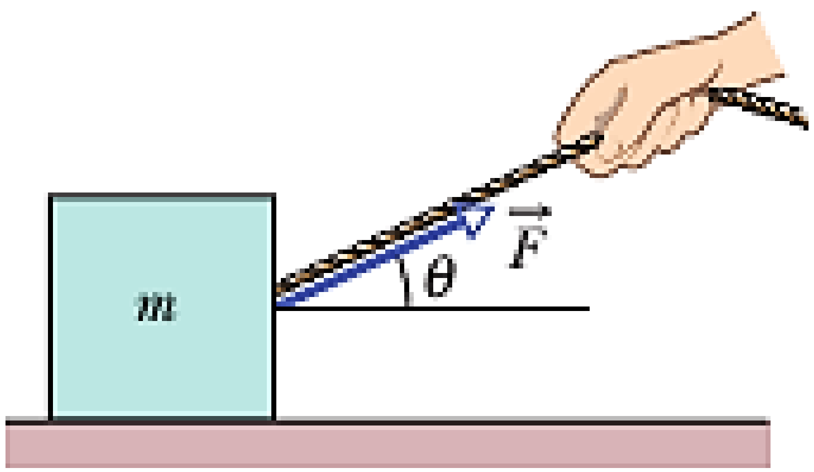
$$F_{23} = m_3 a \Rightarrow \boxed{F_{23} = 3(1) = 3\ N}$$

$$\boxed{a = \frac{F}{m_1 + m_2 + m_3} = \frac{F_{12}}{m_2 + m_3} = \frac{F_{23}}{m_3}}$$

Ex 2: (Problem 5.49 Halliday)

A block of mass **m = 5 kg** is pulled along a horizontal frictionless floor by a cord that exerts a force of magnitude **F= 12 N** at an angle **θ= 25.** (a) What is the magnitude of the block's acceleration? (b) The force magnitude **F** is slowly increased. What is its value just before the block is lifted (completely) off the floor? (c) What is the magnitude of the block's acceleration just before it is lifted (completely) off the floor?





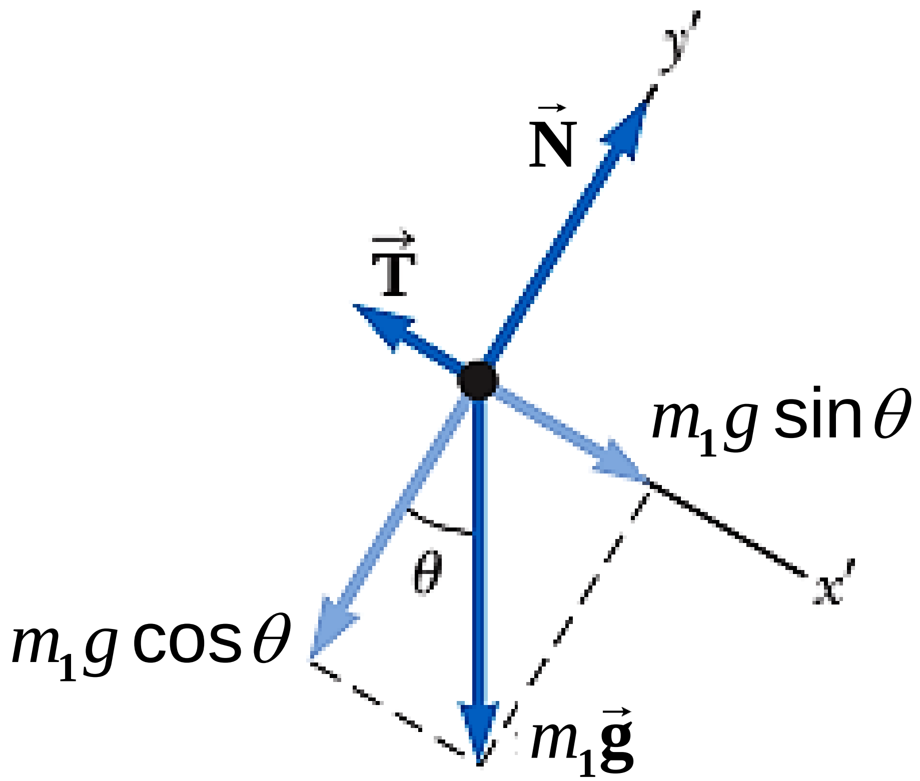
$$\begin{cases} F_{net,x} = m a_x \\ F_{net,y} = m a_y \end{cases} \Rightarrow \begin{cases} F\cos\theta = m a_x \\ N + F\sin\theta - mg = m a_y \end{cases} \Rightarrow \boxed{a_x = \frac{F\cos\theta}{m} = 2.16\ m/s^2}$$

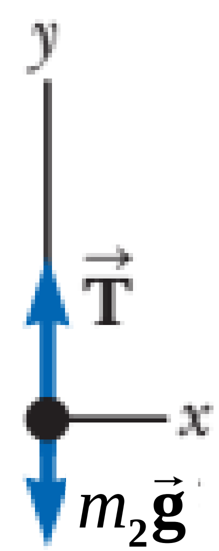
$$(mg = 49) > (F\sin\theta = 5.04) \Rightarrow \text{block is on the floor};\ a_y = 0 \Rightarrow \boxed{N = mg - F\sin\theta = 43.96\ N}$$

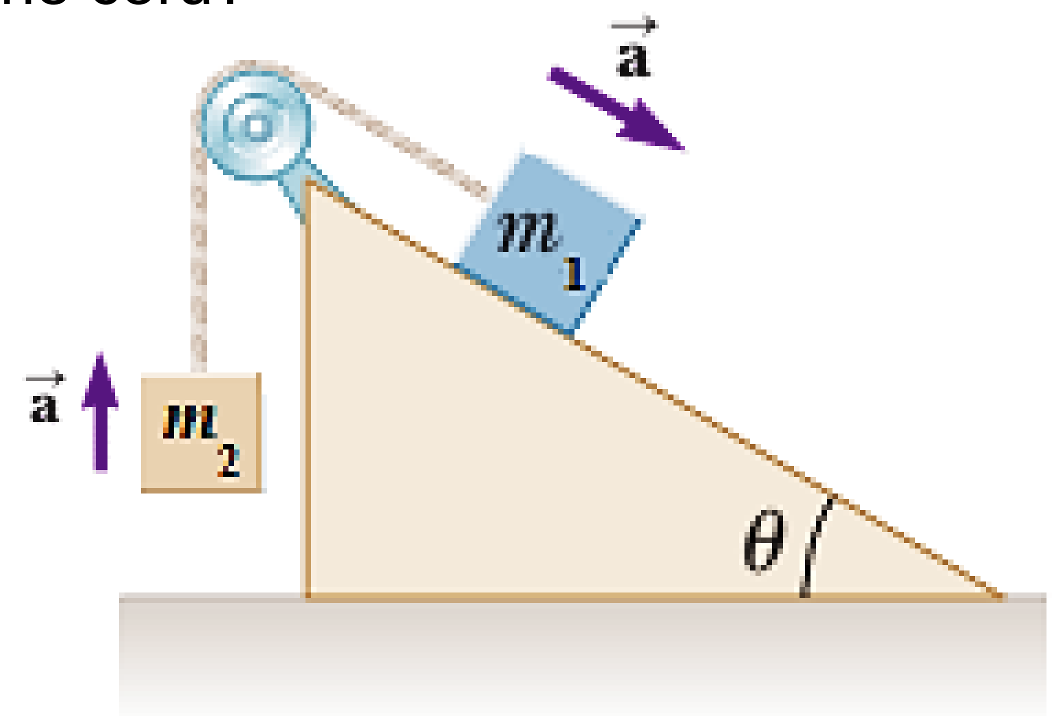
$$\text{lifted off the floor};\ N = 0 \Rightarrow \boxed{F\sin\theta = mg \Rightarrow F = 116.6\,N} \Rightarrow \boxed{a_x = 21\ m/s^2}$$

Ex 3: (Problem 5.57 Halliday)

A block of mass **m_1= 3.7 kg** on a frictionless incline of angle **θ= 30** is connected by a lightweight cord over a massless, frictionless pulley to a second block of mass **m_2= 2.3 kg**. 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?







$$\mathbf{F}_{net,y} = m_2 a_y \;\Rightarrow\; \boxed{T - m_2 g = m_2 a}$$

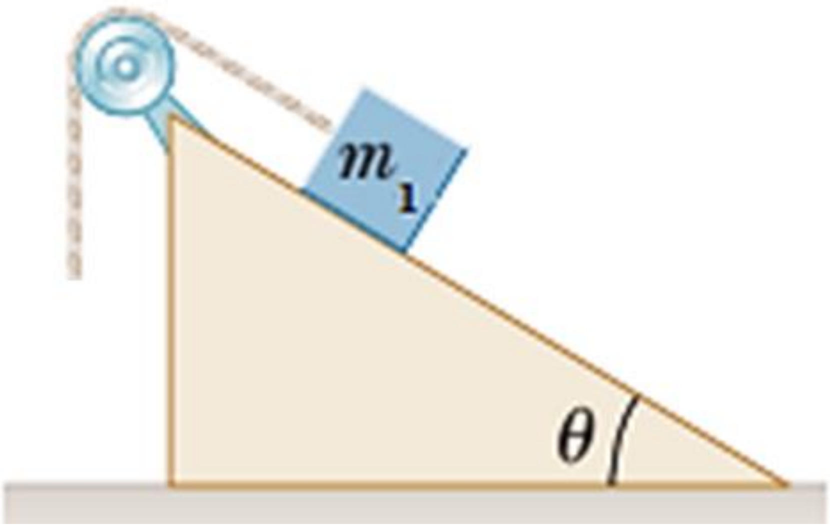
$$a = \frac{m_1 g \sin\theta - m_2 g}{m_1 + m_2} = -0.74\ m/s^2$$

$$\begin{cases} \mathbf{F}_{net,x'} = m_1 a_{x'} \\ \mathbf{F}_{net,y'} = m_1 a_{y'} \end{cases} \;\Rightarrow\; \begin{array}{l} \boxed{m_1 g \sin\theta - T = m_1 a} \\ \boxed{N - m_1 g \cos\theta = 0} \end{array}$$

$$T = \frac{m_1 m_2 g (1 + \sin\theta)}{m_1 + m_2} = 20.84\,N$$

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

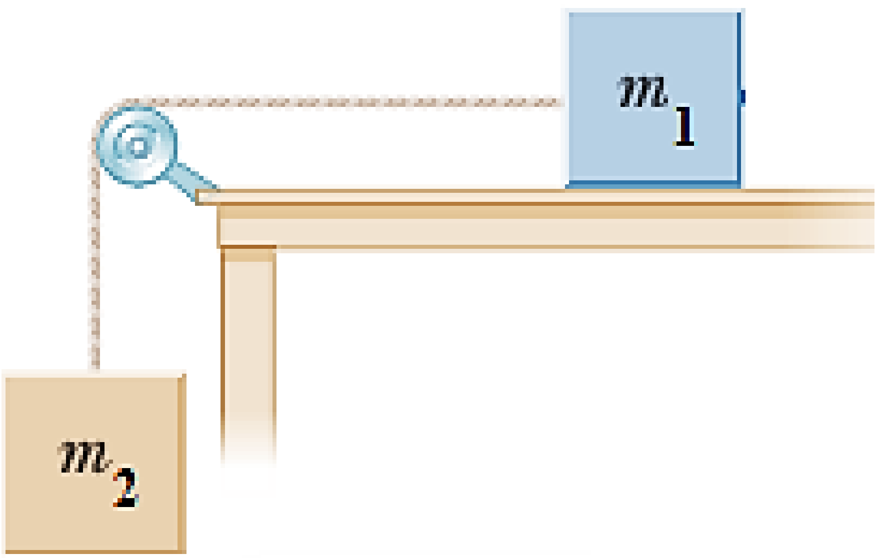
$$T = \frac{m_1 m_2 g(1 + \sin\theta)}{m_1 + m_2}$$



Special cases:

$$\boxed{\text{if } \; m_2 = 0}$$

$$a = g\sin\theta \qquad T = 0$$



$$\boxed{\text{if } \; \theta = 0}$$

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

$$\boxed{\text{if } \; \theta = \frac{\pi}{2}}$$

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