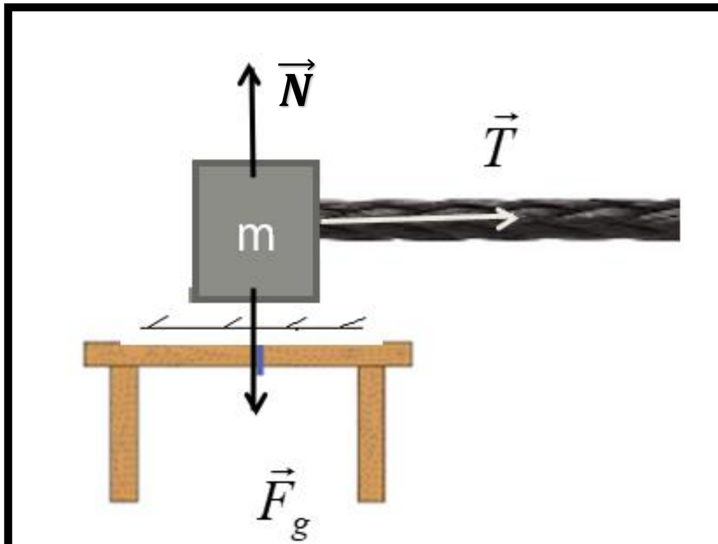
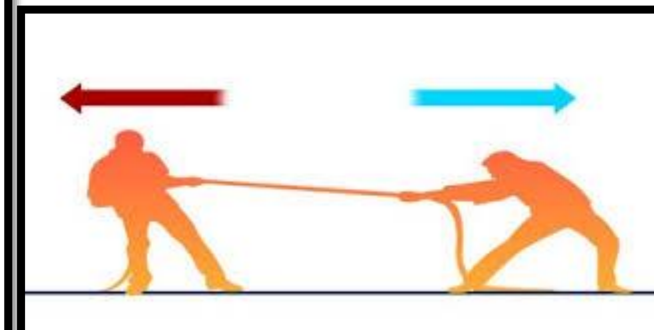
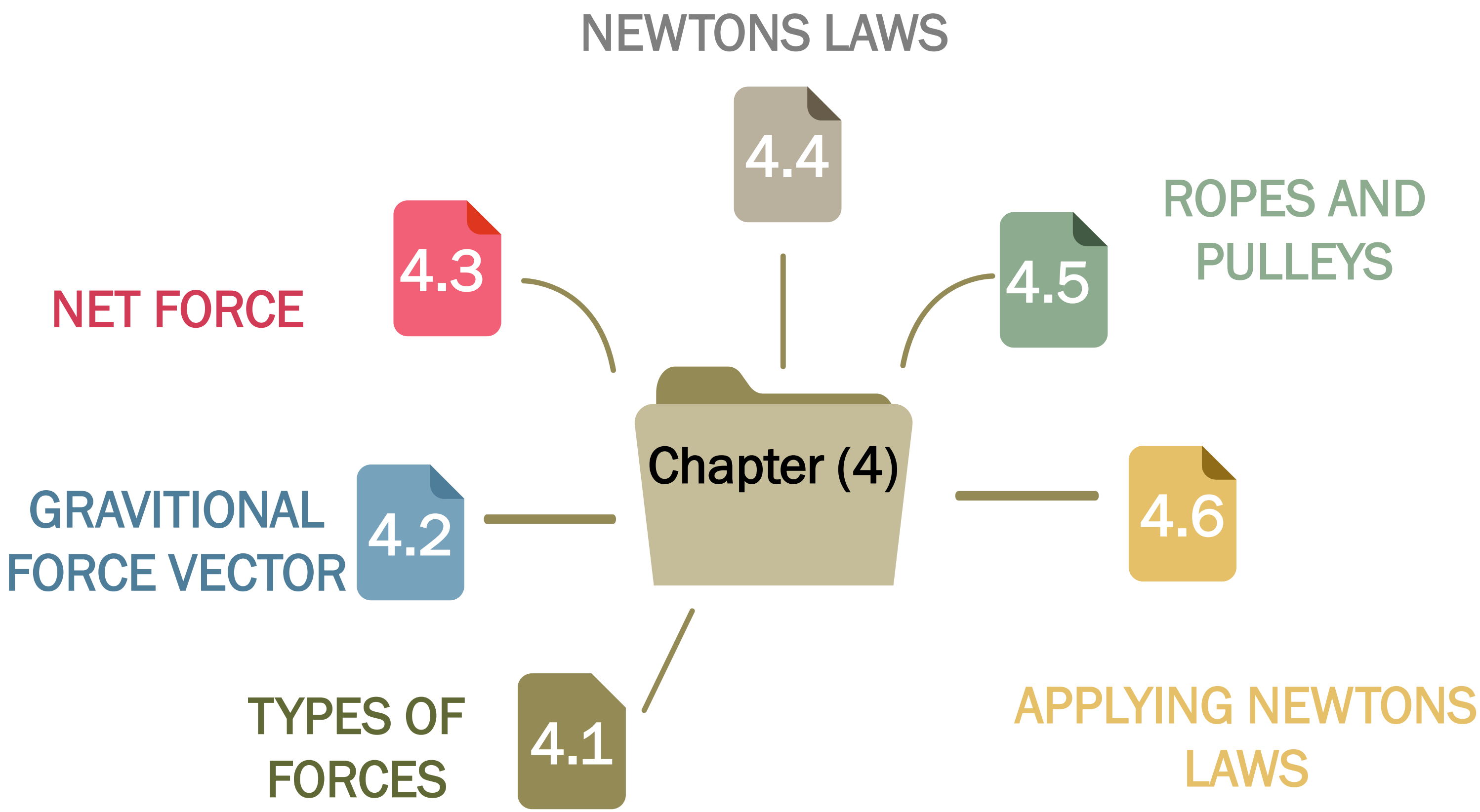
Chapter 4 Force





Outline



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Learning outcomes

After studying this chapter, you will be able to:

- Identify that a force is a vector quantity and thus has both magnitude and direction and also components.
- Differentiate between forces types.
- Determine the magnitude and direction of the gravitational force
- Identify the weight of a body.
- Determine the magnitude and direction of the normal force on an object.
- Identify the tension force.
- Calculate the net force.
- understand Newton's first, second and third laws.
- Sketch a free-body diagram for an object
- Applying Newton’s Law for a system of a single particle or a system of particles.

4.1 Types of Forces

Force

Contact force

The object has to be in contact with another to exert a force on it

- **Friction**
  force that opposes the motion
- **Tension**
  Force exerted by a rope or cable attached to an object
- **Normal Force**
  Force exerted by a surface on an object when it presses against the surface

Non-contact force (fundamental force)

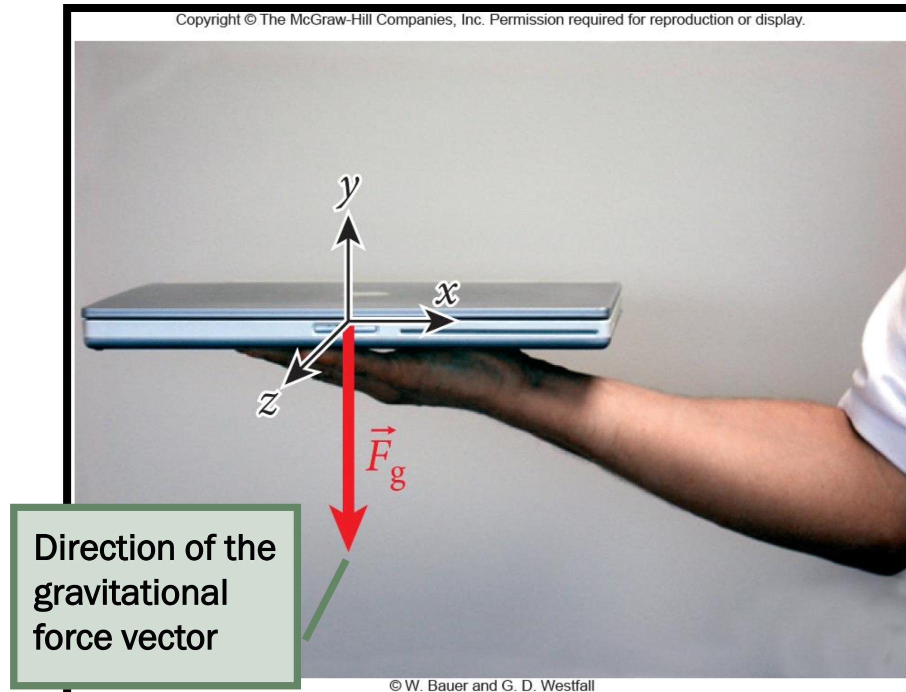
Can acts at a distance

- **Gravitational force**
  Force that Earth exerts on an object
- **Electrostatic force**
  It's the attractive or repulsive force between two electrically charged objects

4.2 Gravitational Force Vector, weight, and mass

- ❑Force has a direction.
- ❑The unit of force is Newton **(N)**
- ❑The gravitational Force: is the force that the Earth exerts on any object .It is directed toward the center of the Earth
- ❑If you hold a laptop in your hand, you can tell that the gravitational force always points downward (-*y* direction)
- ❑The force vector of the gravitational force acting on the laptop is:

$$\vec{F}_g = -F_g \hat{y}$$



4.2 Gravitational Force Vector, weight, and mass

- Magnitude of gravitational force on an object = weight

$$\boxed{\text{Weight} = \left|\vec{F}_g\right| = mg} \qquad g = 9.81\ \text{m/s}^2$$

- Gravitational force on an object, F_g, is always proportional to its mass.

Example:

Object with mass m = 5.00 kg

The magnitude of gravitational force

$$\left|\vec{F}_g\right| = mg = (5.00\ \text{kg})(9.81\ \text{m/s}^2) = 49.05\ \text{kg m/s}^2$$

4.2 Gravitational Force Vector, weight, and mass

Force Unit:

From $|F_g|$=mg

1 N= 1 kg m/s^2

Named after British physicist Sir Isaac Newton (1642-1727), Who made a key contribution to the analysis of forces

Mass Unit:

- Mass (m)
- Is constant
- Is measured in units of **kg**

Weight Unit:

- The weight (w) is the magnitude of the gravitational force.
- It Is variable
- It depends on **g**
- It is measured in units of **N**.

<u>Mass and weight of an object are related</u>

Weight (w) =$|\vec{F_g}|$= mg

For example: if your mass is 70kg, then your weight is 687N

4.3 Net Force

❑ **Net force:** is the vector sum of all forces acting on a given object.

$$\vec{F}_{\text{net}} = \sum_{i=1}^{n} \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \ldots + \vec{F}_n$$

❑ Cartesian components of net force are given by:

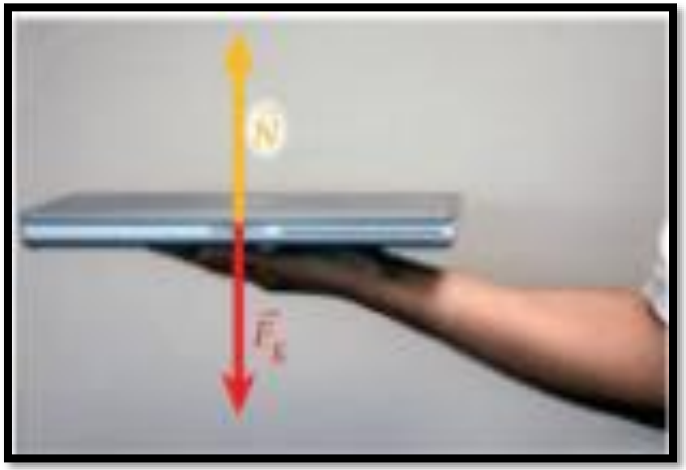
$$F_{\text{net},x} = \sum_{i=1}^{n} F_{i,x} = F_{1,x} + F_{2,x} + \ldots + F_{n,x}$$

$$F_{\text{net},y} = \sum_{i=1}^{n} F_{i,y} = F_{1,y} + F_{2,y} + \ldots + F_{n,y}$$

$$F_{\text{net},z} = \sum_{i=1}^{n} F_{i,z} = F_{1,z} + F_{2,z} + \ldots + F_{n,z}$$

4.3 Normal Force

- ❑Hand exerts a force on computer ➔ (Normal force, $\vec{N}$)
- ❑Normal force is always directed perpendicular to the plane of the contact surface
- ❑When a body presses against a surface, the surface pushes on the body with a normal force perpendicular to the contact surface



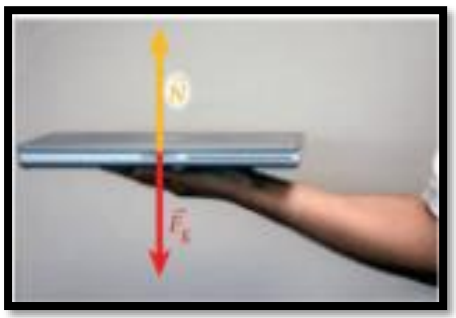
4.3 Free-Body Diagram

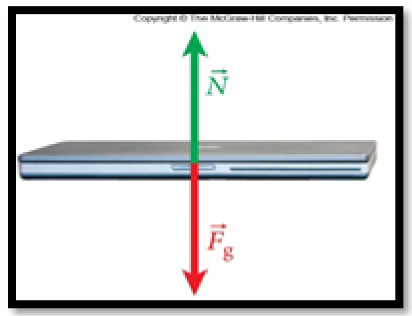
❑**First observation**:

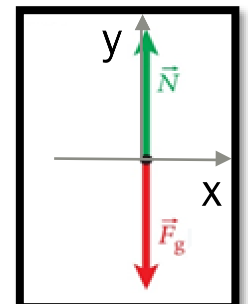
No need for the hand in the picture➔ It's entire effect is represented by the normal force arrow

❑**Second observation**:

No need for an exact representation of the notebook computer ➔A point is sufficient.





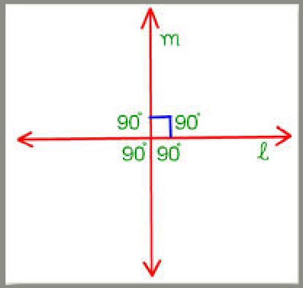
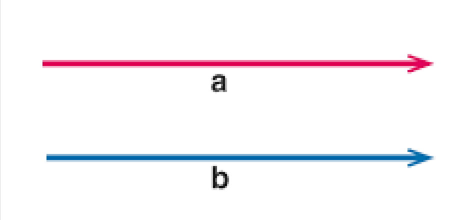
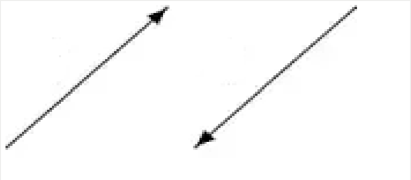


Free-body diagram!

1. Draw x and y coordinates.
2. The body is represented by a dot at the origin.
3. Each Force on the body is drawn as a vector arrow with its tail on the body.

4.3 Free-Body Diagram

Force direction

Perpendicular (ϴ =90°)	
Parallel (ϴ =0°)	
Anti-parallel (ϴ =180°)	

4.4 Newtons Laws

Newton's First Law

An object at rest will remain at rest and an object in motion will remain in motion, with the same speed and in the same direction. So long as the net force acting on the object is zero.

$$\overrightarrow{\boldsymbol{F}_{net}} = \mathbf{0}$$

Newton's First Law is sometimes called the ***law of inertia***

Newton's Second Law

If a net external force, $\overrightarrow{F_{net}}$, acts on an object with mass m, the force will cause an acceleration, $\vec{a}$, in the same direction as the force

$$\overrightarrow{\boldsymbol{F}_{net}} = \boldsymbol{m}\vec{\boldsymbol{a}}$$

Newton's Third Law

The forces that two interacting objects exert on each other are always exactly equal in magnitude and opposite direction

$$\overrightarrow{\boldsymbol{F}_{1\rightarrow 2}} = -\overrightarrow{\boldsymbol{F}_{2\rightarrow 1}}$$

4.4 Newton's First Law

States that: "if the net force on an object is equal to zero, An object at rest will remain at rest and an object in motion will remain in motion, with the same speed and in the same direction"

There are two possible states for an object with no net force ($\overrightarrow{\boldsymbol{F}_{net}} = \mathbf{0}$)

Static equilibrium

(At rest)

Dynamic equilibrium

(Moving with constant velocity)

Consider a car at rest

The weight of the car is balanced by the normal force.

4.4 Newton's Second Law

- The second law relates acceleration to force.

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

- The magnitude of the acceleration of an object is proportional to the magnitude of the net external force acting on it

- For a given external force, more massive objects are harder to accelerate than less massive ones:

- Newton's Second Law hold for each component:

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

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

The acceleration vector is in the same direction as the net external force vector that is acting on the object to cause this acceleration

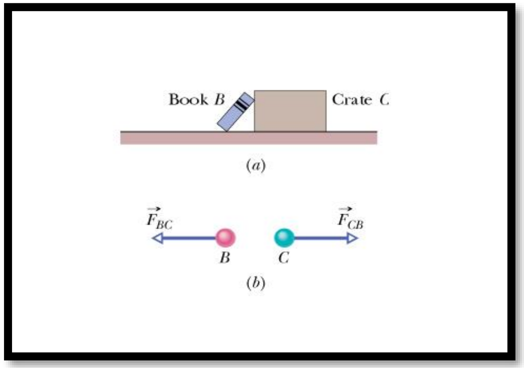
The acceleration component along a given axis is caused *only by* the sum of the force components along that *same* axis, and not by force components along any other axis.

4.4 Newton's Third Law

When two bodies interact by exerting forces on each other, the forces are equal in magnitude and opposite in direction.

The force on the book from the crate denoted by $\vec{F}_{BC}$

The force on the crate from the book denoted by $\vec{F}_{CB}$



$$\vec{F}_{BC} = -\vec{F}_{CB} \text{(equal magnitude and opposite direction)}$$

$$F_{BC} = F_{CB} \text{(equal magnitude)}$$

Why the action and reaction force do not cancel each other?

Action and reaction are called third-law force pair

CONCEPT CHECK

When a bus makes a sudden stop, passengers tend to fall in forward.

Which of Newton's laws can explain this?

A. Newton's First Law

B. Newton's Second Law

C. Newton's Third Law

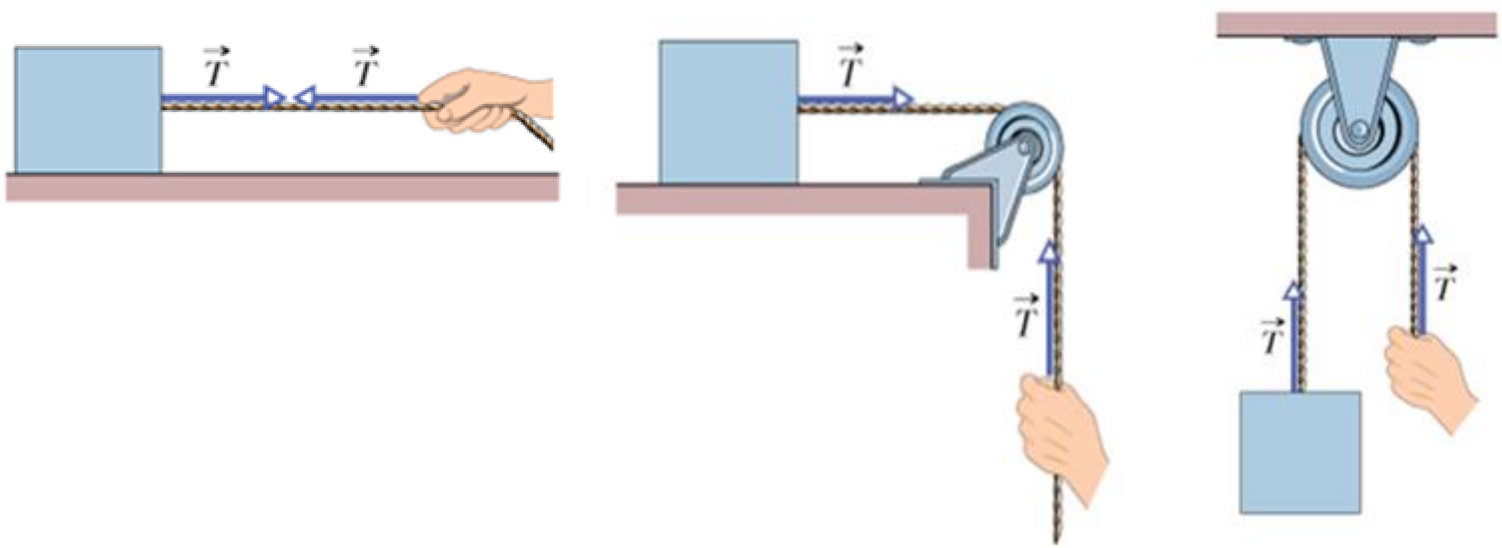
D. It cannot be explained by Newton's laws.

The instant before braking, the passenger is moving with respect to the static road surface. And that passenger will at first continue to travel in the same direction and at the same speed, until something acts on them to change this.

4.5 Ropes and Pulleys

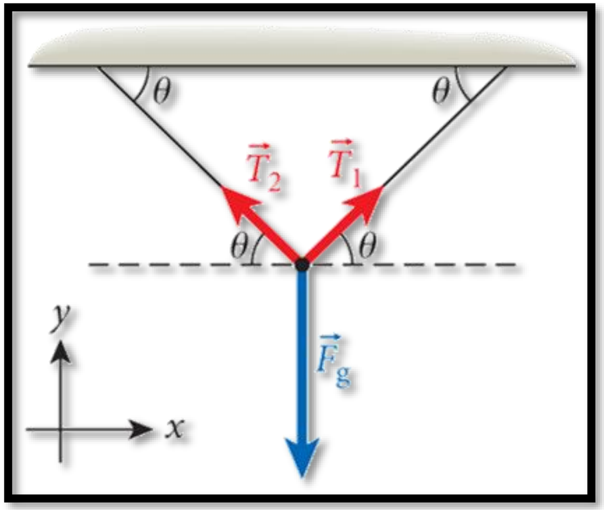
Tension has the following characteristics:

1. It is always directed along the rope.
2. It is always pulling the object.
3. It has the same value along the rope.
4. If a rope is guided over a pulley, the direction of the tension force is changed but the magnitude is still the same everywhere



Example (4.1) P86

Gymnast of mass 55 kg hangs from the ceiling with a rope in each hand where the rope makes an angle $\theta = 45°$ relative to the ceiling as shown in the figure. What is the tension in each rope?



Example (4.1) P86

Solution:

$$\sum_i F_{x,i} = 0 \ , \qquad \sum_i F_{y,i} = 0$$

In the *x*-direction:

$$\sum_i F_{x,i} = T_1 \cos\theta - T_2 \cos\theta = 0 \ \Rightarrow \boxed{T_1 = T_2 = T}$$

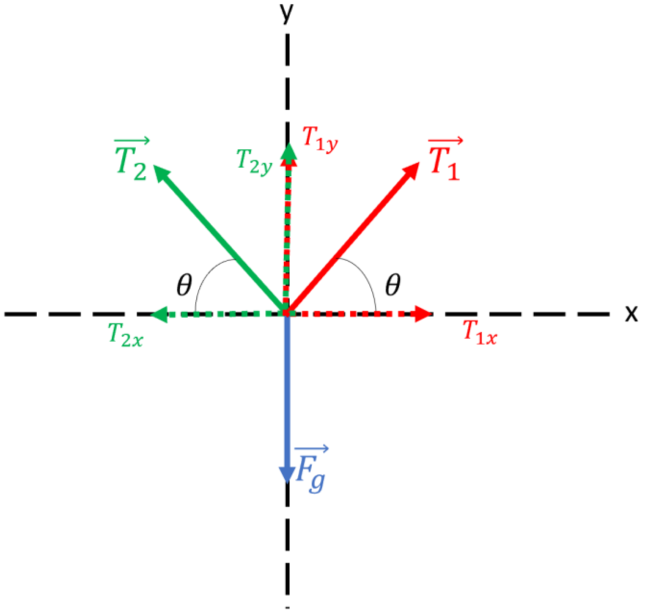
In the *y*-direction:

$$\sum_i F_{y,i} = T_1 \sin\theta + T_2 \sin\theta - mg = 0$$

Combining these two equations gives us:

$$T \sin\theta + T \sin\theta - mg = 0$$

$$2T \sin\theta - mg = 0 \Rightarrow T = \frac{mg}{2\sin\theta} = \frac{(55\ \mathrm{kg})(9.81\ \mathrm{m/s^2})}{2\sin 45^\circ} = 380\ \mathrm{N}$$



4.6 Applying Newton’s Laws

How to apply Newton’s Laws for a single particle?

1. Identify all the forces that act on the system. Label them on the diagram and the direction of motion of the object if it is moving.
2. Draw a free-body diagram for the object.
3. Check if there is any force needs to be resolved.
4. Write Newton's second law.
5. Decide how many equations do you need, if its 1D, need one equation, 2D, you need two equations.
6. If the object is stationary (At rest) or moving with constant velocity, then the acceleration is zero along that axis, otherwise it has a value.
7. Add all the components of the forces along the axis.
8. Solve the equation to find the unknown.

4.6 Applying Newton's Laws

How to apply Newton's Laws for a system of particles?

1. Identify all the forces that act on the system. Label them on the diagram and the direction of motion of each object if they are moving.

2. Remember that the system of two objects moves with the **same acceleration.**

3. Choose one object to start with and follow the steps below:

a) Draw a free-body diagram for the object.

b) Check if there is any force need to be resolved.

c) Write Newton second law.

d) decide how many equations do you need, if its one-dimension, need one equation, two-dimension ,you need two equations.

e) If the object at rest or moving with constant velocity, then (a=0) the acceleration is zero along that axis, otherwise it has a value.

f) simplify the equation you get and label it (1)

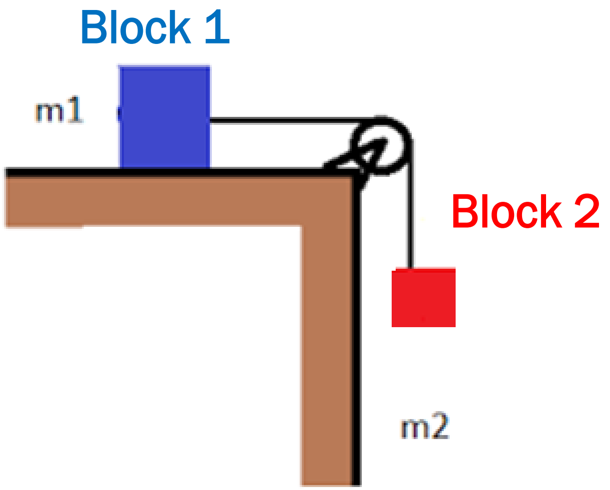
4. Now Apply step(3) to the other object till you get another equation and label (2).

5. Solve the two Equations to find the unknown.

Example (4.2)

A hanging mass generates an acceleration for a second mass on a horizontal surface. One **block 1**, of mass m_1 **=3.00 kg**, lies on a frictionless horizontal surface and is connected via a massless rope over a massless pulley to another **block 2**, with **mass** m_2 **= 1.30 kg**, hanging from the rope.

What is the acceleration of block m_1 and block m_2 ?



Sample Problem 4.2

Solution:

- Block 1 (m_1)

$\overrightarrow{F_{net}} = m\overrightarrow{a_{net}}$

In x-direction

$F_{net,x} = m_1 a_x$

$T = m_1 a_x \ (equ - 1)$

In y-direction

$F_{net,y} = m_1 a_y$ (a_y =0 no motion)

$N_1 - F_{g1} = 0$

$N_1 - m_1 g = 0 \ (equ - 2)$

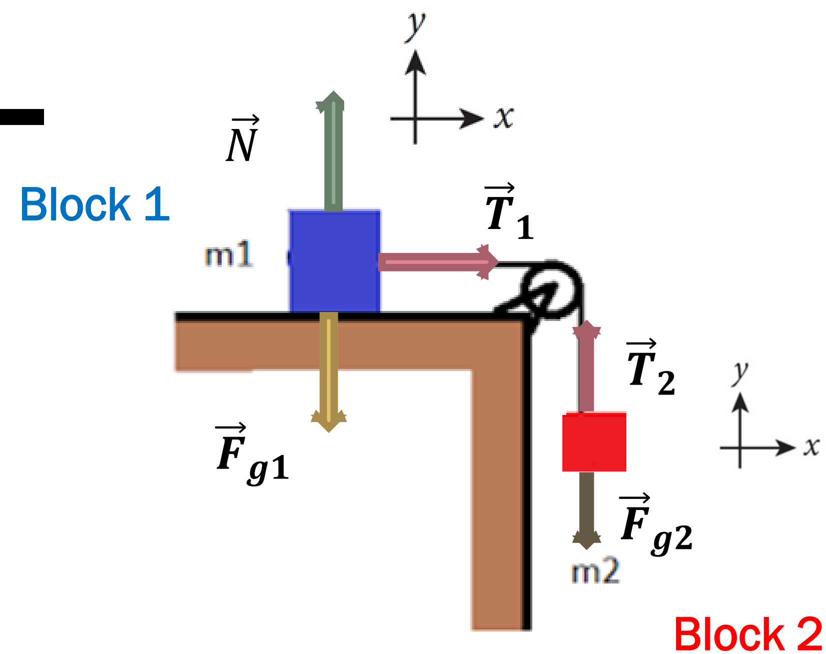
- Block 2 (m_2)

In y-direction

$F_{net,y} = m_2 a_y$

$T - F_{g2} = T - m_2 g = -m_2 a_y$

$T = m_2 g - m_2 a_y \ (equ - 3)$



Note that : $a = a_y (equ - 2) = a_x (equ\text{-}1)$

all Blocks move with the same acceleration

Simplify

Take our two results for T and equate them:

$$m_1 a = m_2 g - m_2 a \quad \Rightarrow \quad m_1 a + m_2 a = m_2 g$$

$$a(m_1 + m_2) = m_2 g \quad \Rightarrow \quad a = g\frac{m_2}{m_1 + m_2}$$

$$a = g\frac{m_2}{m_1 + m_2} = \left(9.81 \text{ m/s}^2\right)\frac{1.30 \text{ kg}}{3.00 \text{ kg} + 1.30 \text{ kg}} = 2.96581 \text{ m/s}^2$$

Example 4.2

A snowboarder (mass 72.9 kg, height 1.79 m) glides down a slope with an angle 22° with respect to the horizontal. If we can neglect friction, what is his acceleration?

Solution:

$\overrightarrow{F_{net}} = m\overrightarrow{a_{net}}$

In x-direction

$F_{net,x} = ma_x$

$F_{gx} = ma_x$

$mgsin\Theta = ma_x$

$a_x \dfrac{mgsin\Theta}{m} = gsin\Theta = (9.81)(sin22)$

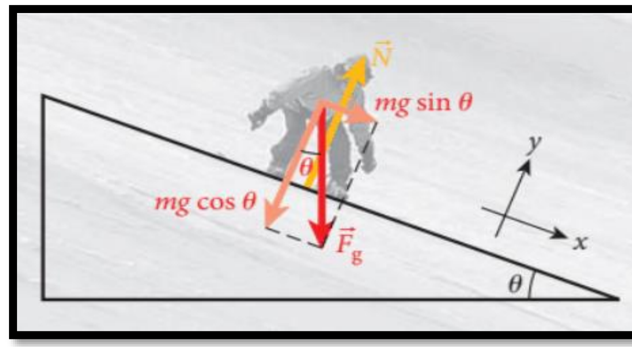
$= 3.7\, m/s^2$

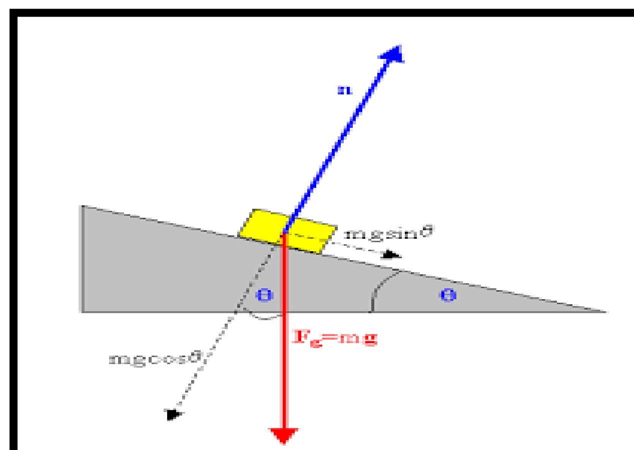
In y-direction

$F_{net,y} = m_1 a_y$

$N - F_{gy} = 0$

$N - mgcos\Theta = 0$





Equation summary

(1) **Gravitational Force Vector**

$$\vec{F}_g = -F_g \hat{y}$$

$$|\vec{F}_g| = mg$$

(2) Weight=magnitude of gravitational force

$$(w) = |\vec{F_g}| = mg$$

(3) **The Net Force**

$$\vec{F}_{net} = \sum_{i=1}^{n} \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \ldots + \vec{F}_n$$

(4) **Newton's Second Law**

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

(5) **Newton's Third Law**

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

The END OF CHAPTER (4)