ch. 3

# Newton's Laws of Motion

- Force: any influence that causes the object to accelerate

- Newton's first law: An object at rest will remain at rest and an object in motion with constant velocity in a straight line will maintain that motion unless it experience a net external force.

- Newton's second law: the acceleration of an object is directly proportional to the resultant force acting on it and inversely proportional to its mass.

$$\sum \vec{F} = m\vec{a}$$

- Newton's Third law: To every action there is always an equal and opposite reaction

$$\vec{F}_{12} = -\vec{F}_{21}$$

- Equilibrium: An object is at equilibrium if the resulting forces on it are zero.

$$\sum \vec{F} = 0$$

- Weight: the Force exerted by the earth on a body

$$W = mg, \quad g = 9.8\ m/s^2$$

- unit of force: Newton (N), $1N = 1\ kg \cdot m/s^2$

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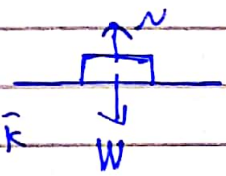
Example: A woman has a mass of 60 kg, she is standing on a floor and remains at rest. Find the normal force exerted on her by the floor

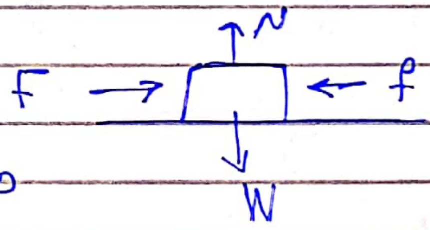



equilibrium: $\vec{N} + \vec{W} = 0$ , $\vec{N} = N\hat{k}$, $\vec{W} = -W\hat{k}$

$N = W = mg$

$N = 60(9.8) = 588\ N$

Example: An ice cream vendor (بيّاع) exerts a force of 40 N to overcome friction and push his cart at a constant velocity, the car has a mass of 150 kg. Find the forces acting on the cart.




The net forces are zero

$$\sum_{i=1}^{4} \vec{F_i} = \vec{F} + \vec{N} + \vec{f} + \vec{W} = 0$$

$F = f = 40\ N$ , $N = W = mg = 150(9.8) = 1470\ N$

Example: A child pushes a sled (زلاجة) across a frozen pond with a horizontal force of 20 N. Assume friction is nengligible.

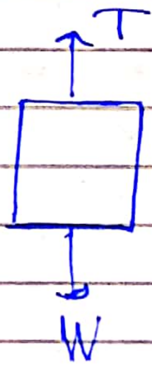
a) if the sled accelerates at $0.5\ m/s^2$, what is its mass?

b) Another child with a mass of 60 kg sits on the sled, what acceleration will the same force produce now?

a) $F = ma \Rightarrow m = \frac{F}{a} = \frac{20}{0.5} = 40\ kg$

b) $a = \frac{F}{m_1 + m_2} = \frac{20}{40+60} = 0.2\ m/s^2$

Example: An elevator has a mass of 1000 kg.
a) it accelerates upward at $3\ m/s^2$, what is the force $T$ exerts by the cable on the elevator?
b) what is the force $T$ if the acceleration is $3\ m/s^2$ downward?




a) $T - mg = ma$

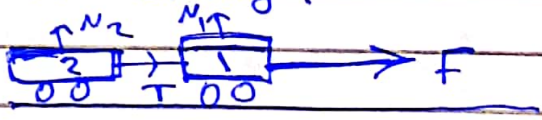
$T = mg + ma = m(g + a)$

$= 1000(9.8 + 3) = 12800\ N$

b) $T - mg = -ma$

$T = m(g - a) = 1000(9.8 - 3) = 6800\ N$

Example: A child pulls a train of two cars with a horizontal force of 10 N, if we neglect the mass of the string and friction
a) find the normal forces exerted on each car by the floor
b) What is the acceleration of the train?
c) What is the tension in the string?




a) $N_1 = m_1 g = 3(9.8) = 29.4\ N$

$N_2 = m_2 g = 1(9.8) = 9.8\ N$

$m_1 = 3\ kg$

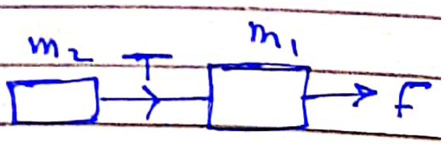
$m_2 = 1\ kg$

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

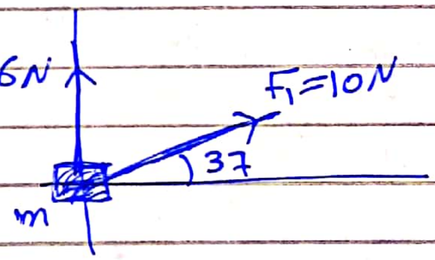
$$a = \frac{F}{m_1 + m_2} = \frac{10}{3+1} = \frac{10}{4} = 2.5\ m/s^2$$

c) $T = m_2 a = 1(2.5)$

$= 2.5\ N$



Example: Two Forces $F_1$ and $F_2$ acting on an object of mass 2 kg in the directions shown in the figure. a) Find the acceleration of the object.




$$\sum \vec{F} = m\vec{a}$$

$$\sum F_x = m a_x$$

$$F_1 \cos 37 + F_2 \cos 90 = m a_x$$

$$10\,(0.8) + 0 = 2a_x \Rightarrow a_x = 4 \; m/s^2$$

$$\sum F_y = m a_y$$

$$F_1 \sin 37 + F_2 \sin 90 = m a_y$$

$$10\,(0.6) + 6(1) = 2a_y \Rightarrow a_y = 6 \; m/s^2$$

$$a = \sqrt{a_x^2 + a_y^2} = \sqrt{16+36} = 7.2 \; m/s^2$$

$$\theta = \tan^{-1} \frac{a_y}{a_x} = \tan^{-1} \frac{6}{4} = 56.3^\circ$$

b) Find the third force that causes the object to be in equilibrium

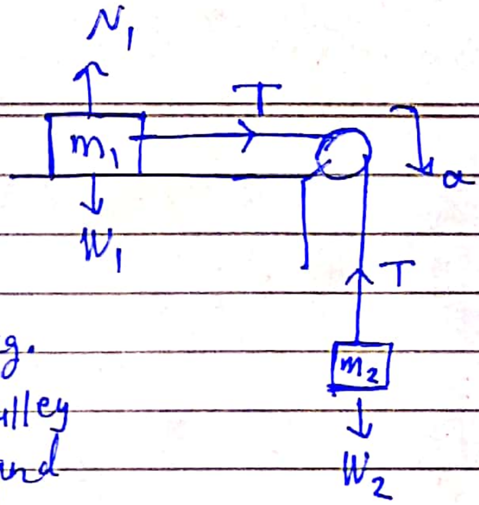
$$\vec{F_3} = -(\vec{F_1} + \vec{F_2})$$

but $\vec{F_1} + \vec{F_2} = m\vec{a} = 2(4\hat{i} + 6\hat{j}) = 8\hat{x} + 12\hat{y}$

$$\therefore \; \vec{F_3} = -8\hat{x} - 12\hat{y}$$

$$|\vec{F_3}| = \sqrt{(-8)^2 + (-12)^2} = 14.4 \; N$$

Example: A block of mass $m_1 = 20$ kg is free to move on a horizontal surface. A rope, which passes over a pulley, attaches it to a hanging block of mass $m_2 = 10$ kg. Assuming for simplicity that the pulley and rope masses are negligible and that there is no friction. Find
a) the forces on the blocks
b) their acceleration
c) if the system is initially at rest, how far has it moved after 2 s.




a) $N_1 = m_1 g = 20(9.8) = 196\ N$

$W_1 = N_1 = 196\ N$

b) $T = m_1 a$ ——(1)

$T - W_2 = -m_2 a$ ——(2)

$(1) - (2) \Rightarrow W_2 = (m_1 + m_2)a \Rightarrow a = \frac{W_2}{m_1 + m_2}$

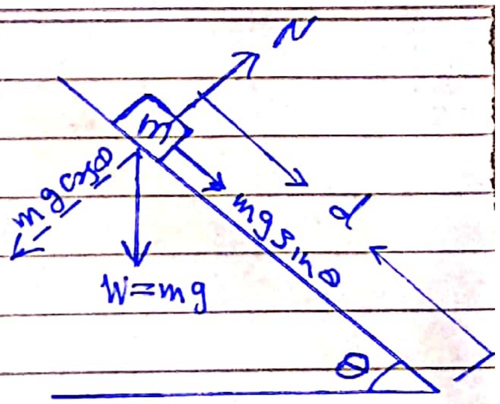
$$a = \frac{m_2 g}{m_1 + m_2} = \frac{10(9.8)}{20+10} = 3.27\ m/s^2$$

c) $\Delta x = v_0 t + \frac{1}{2} a t^2$

$= 0 + \frac{1}{2}(3.27)(2)^2 = 6.54\ m$

Example:

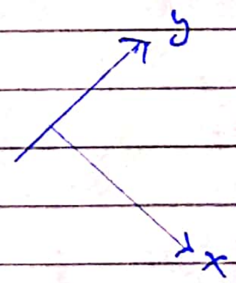
A block of mass m is placed on a smooth inclined plane of angle $\theta$ and length d




a) determine the acceleration of the block after it is released

b) how long does it take the block to reach the bottom?

c) What is the speed as it gets their ?




a) $\sum F_x = m a_x$

$mg\sin\theta = m a_x \Rightarrow a_x = g\sin\theta$

$\sum F_y = 0$

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

b) $\Delta x = d = v_{0x} t + \frac{1}{2} a_x t^2$

$d = 0 + \frac{1}{2} g\sin\theta \, t^2 \Rightarrow t = \sqrt{\frac{2d}{g\sin\theta}}$

c) $v^2 = v_0^2 + 2 a_x \Delta x$

$= 0 + 2 g\sin\theta \, d$

$v = \sqrt{2dg\sin\theta}$