Chapter 3

Newton’s Law of Motion

3.1 Newton’s First Law

If there is no net force acting on a body, then the body will preserve its state of motion, i. e. if the body is at rest then it remains at rest; if the body moves with a velocity, it will keep on moving with that constant velocity.

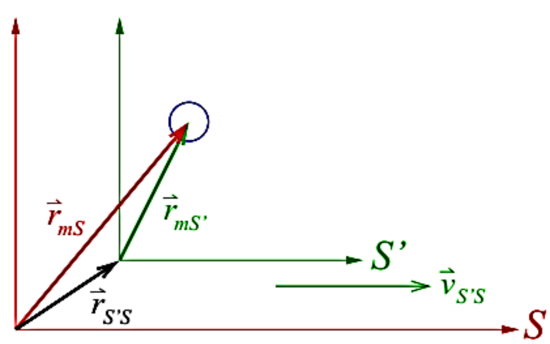
What is ’force’?
In physics, there are four different kinds of forces:

- Electromagnetic force,
- Gravitational force,
- Strong force,
- Weak force.

experienced in our daily lifes!

3.2 Reference frame and relative motion

Reference frame: Where do we observe the motion of an object?



S : Earth’s frame

S' : Car’s frame moving with $\vec{v}_{S'S}$ with respect to S

where $\vec{r}_{S'S}$ - Position vector of the car observed from the earth,
$\vec{r}_{mS}$ - Position vector of the object observed from the earth,
$\vec{r}_{mS'}$ - Position vector of the object observed from the moving car.

Notice that: $\dfrac{d\vec{r}_{S'S}}{dt} = \vec{v}_{S'S}$

From the vector diagram:

$$\begin{aligned} \vec{r}_{mS} &= \vec{r}_{S'S} + \vec{r}_{mS'} \\ \Rightarrow \frac{d\vec{r}_{mS}}{dt} &= \frac{d\vec{r}_{S'S}}{dt} + \frac{d\vec{r}_{mS'}}{dt} \\ \text{or } \vec{v}_{mS} &= \vec{v}_{S'S} + \vec{v}_{mS'} \end{aligned}$$

where $\vec{v}_{S'S}$ - velocity of the car observed from the earth,
$\vec{v}_{mS}$ - velocity of the object measured from the earth,
$\vec{v}_{mS'}$ - velocity of the object measured from the moving car.

N. B. In this chapter, we are still only considering laws for which the observation is made on the earth.

3.3 Newton's Second Law

If there is a net force $\vec{F}$ acting on an object m, then the force will be equal to the rate of change of the object momentum.

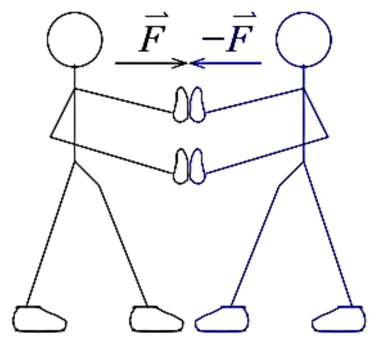
OR in a simplier statement: if the mass of the object is constant, $\vec{F} = m\vec{a}$ where $\vec{a}$ is the object acceleration.

Unit of force: Newton = $[\mathrm{MLT}^{-2}]$

One Newton of force is the force acts on a 1 kg object that will accelerate the object with acceleration of 1 ms^{-2}.

3.4 Newton's Third Law

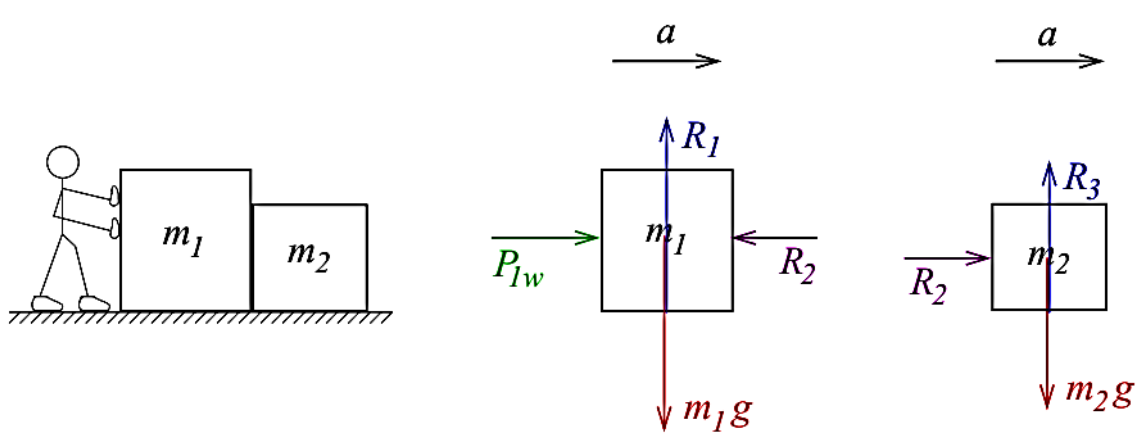
As a body exerts a force on another body, the second body also exerts a force on the first. The two forces are equal in magnitude but opposite in direction.



3.5 Application of Newton's Law in One Dimensional Cases

3.5.1 Pushing a Packing Crate

A worker w is pushing a packing crate of mass $m_1 = 4.2$kg. In front of the crate is a second crate of mass $m_2 = 1.4$kg. Both crates slide across the floor without friction. The worker pushes on crate 1 with a force $P_{1w} = 3.0$N. Find the accelerations of the crafts and the force exerted by crate 1 on crate 2.



where R_1 - reaction from the ground on m_1,

R_2 - action reaction pair between m_1 and m_2,

R_3 - reaction from the ground on m_2.

Note that $R_1 = m_1 g$, $R_3 = m_2 g$ and no vertical motion (i. e. $a = 0$).

Taking right side as positive. Using Newton's 2$^{\text{nd}}$ law, we find the equation of motions:

$$P_{1w} - R_2 = m_1 a \tag{3.1}$$

$$R_2 = m_2 a \tag{3.2}$$

Substitute (3.2) into (3.1), we get:

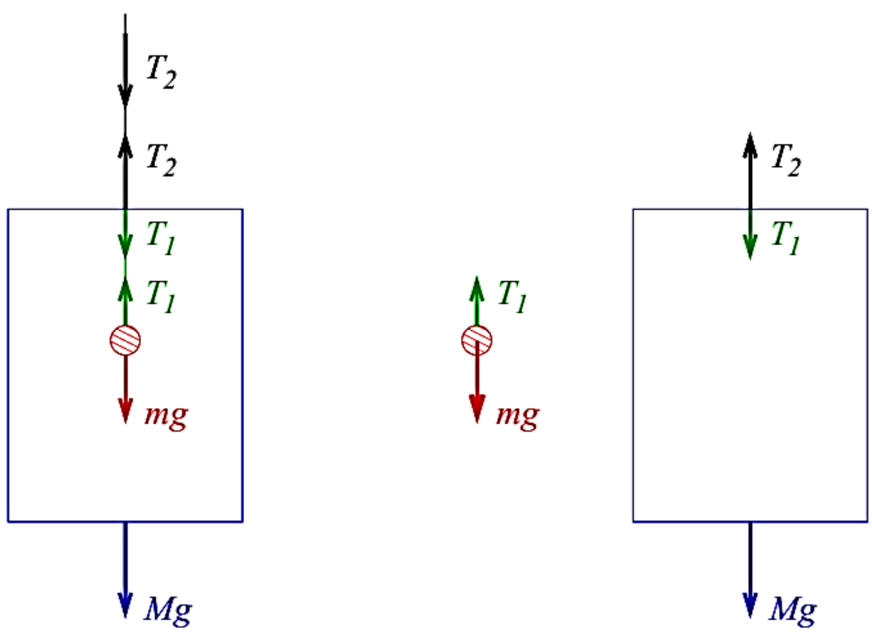
$$P_{1w} - m_2 a = m_1 a$$
$$\Rightarrow \ a = \frac{P_{1w}}{m_1 + m_2}$$
$$\therefore \ R_2 = m_2 a = \frac{m_2 P_{1w}}{m_1 + m_2}$$

Remark: It is interesting to compare the reaction force when the two crates are interchanged.

3.5.2 Mass Hanging in a Lift

Consider a mass m hanging by a massless string attached to the ceiling of a lift which the mass of lift $= M$.

Case 1: Lift has no acceleration but moves upward with constant speed v (see figure below).



Taking upward as positive. Since $a = 0$, the equation of motions are given by:

$$T_1 - mg = 0 \quad \Rightarrow \ T_1 = mg$$
$$T_2 - T_1 - Mg = 0 \quad \Rightarrow \ T_2 = (m + M)g$$

N. B. Results are the same for cases:

1) $a = 0$ and $v < 0$,

2) $a = 0$ and $v = 0$

Case 2: Lift accelerates upward with acceleration a.

Note that a must be positive for this case. Therefore, the equation of motions are now given by:

$$T_1 - mg = ma \quad \Rightarrow \quad T_1 = m(g+a)$$

$$T_2 - T_1 - Mg = Ma \quad \Rightarrow \quad T_2 = (m+M)(g+a)$$

Note that T_1 in this case is larger than that in the previous case ($a = 0$).

As this lift is accelerating upward, we feel as if there is a 'force' pressing us down toward the lift floor when we are riding on the lift. This is NOT a real force but a pseudo force.

Example

Compute the least acceleration with which a 45-kg woman can slide down a rope if the rope can withstand a tension of only 300 N.

Solution

According to Newton's second law,

$$\sum_i \vec{F}_i = m\vec{a}.$$

Therefore, taking *down* as positive direction, the tension of the rope T and the acceleration of the woman a are thus related by:

$$mg - T = ma$$

where m is the mass of the woman.

Now it is given that the maximum tension of the rope is $T_{\max} = 300$ N. Hence, the minimum acceleration of the woman $a_{\min}$ is given by:

$$a_{\min} = \frac{mg - T_{\max}}{m} = \frac{[(45 \text{ kg})(9.8 \text{ ms}^{-2}) - 300 \text{ N}]}{45 \text{ kg}} = 3.13 \text{ ms}^{-2}$$