Course: PGPathshala-Biophysics
Paper 1:Foundations of Bio-Physics
Module 22: Kinematics, kinetics, dynamics, inertia

Kinematics is a branch of classical mechanics in physics in which one learns about the properties of motion such as position, velocity, acceleration, etc. of bodies or particles without considering the causes or the driving forces behindthem. Since in kinematics, we are interested in study of pure motion only, we generally ignore the dimensions, shapes or sizes of objects under study and hence treat them like point objects. On the other hand, kinetics deals with physics of the states of the system, causes of motion or the driving forces and reactions of the system. In a particular state, namely, the equilibrium state of the system under study, the systems can either be at rest or moving with a time-dependent velocity. The kinetics of the prior, i.e., of a system at rest is studied in statics. Similarly, the kinetics of the later, i.e., of a body moving with a velocity is called dynamics.

Introduction

Classical mechanics describes the area of physics most familiar to us that of the motion of macroscopic objects, from football to planets and car race to falling from space. NASCAR engineers are great fanatics of this branch of physics because they have to determine performance of cars before races. Geologists use kinematics, a subarea of classical mechanics, to study 'tectonic-plate' motion. Even medical researchers require this physics to map the blood flow through a patient when diagnosing partially closed artery. And so on. These are just a few of the examples which are more than enough to tell us about the importance of the science of motion. In this module, we will discuss the basic components of kinematics such as position, velocity and acceleration and the rules governing them. Following this, we will learn about fundamental rules of motion which govern the state of the system. Learning of the concepts has been attempted through appropriate examples at various stages in the discussion.

Objectives

In this chapter, we aim to learn the following subjects:

- Motion
- Components of kinematics
- Equations of motion
- Relative motion
- Kinetics
- Laws of motion
- Learning through given illustrations

1. What is motion?

The basic question to be asked is that 'what exactly is motion?' and 'how do we measure it?' Well, in the simplest words, 'motion can be defined as the change in position of an object with reference to a fixed point or object with which we attach our coordinate system and measure quantities relative to it. In the broadest sense, motion is divided into two categories, the translational motion, and the rotational motion

2. Components of motion

Now, before proceeding further, let's recall some basic definitions and terms related to motion. The physical quantities can be 'scalar' or 'vector'. Scalar quantities are those which have only magnitude, for example, energy, length, mass, speed, temperature and time are all scalar quantities. On the other hand, vector quantities need both the magnitude and direction to represent them. So to simplify things we use special language of vectors. In one dimensional motion, a particle can move in two directions only, i.e., along positive and negative axis. However, while studying two and three dimensional motion, this convention becomes less effective. Here vectors come in handy. Some of the commonly used physical quantities that are vector quantities are displacement, velocity, acceleration, force, momentum, etc. To deal with such quantities, we use vector algebra.

2.1 Position

To define the position of any object, we consider a reference coordinate system, in most of the cases it's the Cartesian co-ordinates xyz-system in three dimensions. Obviously, for one dimensional motion, the position can be defined either using x-axis or y-axis or z-axis depending on the choice of the person. Similarly, for motion in a two dimensional plane, the choice can be either xy-plane or yz-plan or xz-plane.

A vector is denoted by some alphabet with an arrow over it, e.g., $\vec{A}$. But for keeping the notations simpler in this text, we will use bold letters to represent the vector quantities, i.e., the same vector A will be written as $\boldsymbol{A}$. The direction of the vector is usually denoted by some unit vector (or with respect to some reference axis). Here, unit vector is a vector which has magnitude one but points in a particular direction. For instance, unit vectors $\hat{i}$, $\hat{j}$ and $\hat{k}$ point along the direction of positive x-axis, y-axis and z-axis, respectively of the xyz-reference frame.

Illustration 1: Using a given xyz Cartesian coordinate system, the position of two objects on a plane can be represented as $(x_1,y_1) = (4,11) = 4\hat{i} + 11\hat{j}$ and $(x_2,y_2) = (11,4) = 11\hat{i} + 4\hat{j}$ as shown here in the figure below.

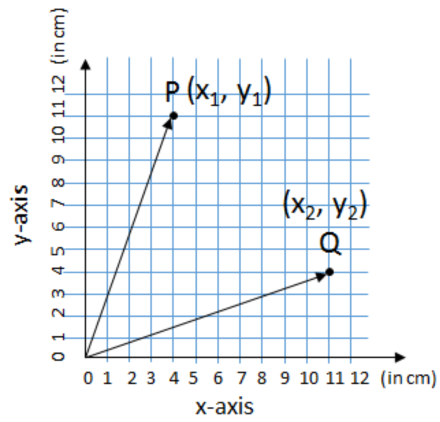


Figure 1: Illustration for representing the positions of objects by points in a Cartesian coordinate system.

2.2 Distance and displacement

One should not confuse distance with displacement as the two quantities have different meaning. Distance is a scalar quantity and it is the total length of the path traversed by a moving body or object. Whereas displacementis a vector quantity and defined as the shortest distance between the initial and final position of a body. The difference between the two quantities will become clear in the following illustrations.

Illustration 2: Suppose an object moves from point P to point Q, then the displacement can be represented by a vector pointing from P to Q. The displacement vector **PQ** (as well as other displacement vectors) represent only the overall effect of the motion. For instance, all the three paths connecting P and Q, as shown in the figure below correspond to the same displacement vector, i.e., vector **PQ**.

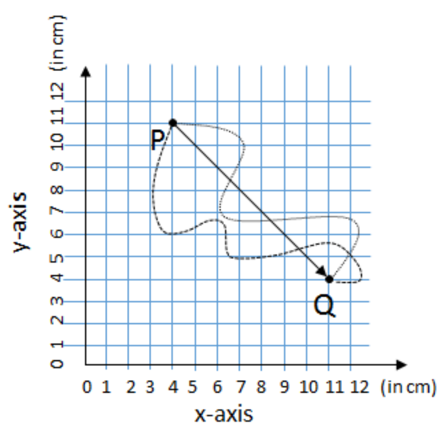
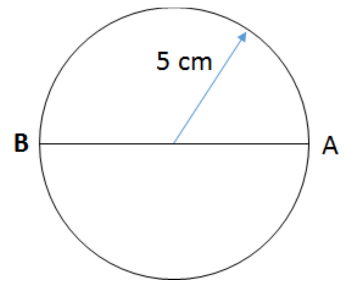


Illustration 3: A particle starts from point A and stops at point B, both of which are diametrically opposite to each other while covering the semi-circular part. If radius of the circular path is 5m then find:

(a) Distance covered by the particle, and
(b) Displacement of the particle.



Solution: (a) Distance covered = ½ × (circumference of the circle) = π × radius of the circle = π × 5 = 15.7 m

(b) Displacement of the particle = distance between points A and B = length of circles diameter = 2 × radius = 10 m. Note that a vector quantity has a specific direction. So the displacement in this example is vector **AB**. Again, the other vector, i.e., vector **BA** should not be confused with vector AB. Though the two vectors have the same magnitude but they have different directions, i.e., vector AB has direction from A to B whereas vector BA has direction from B to A. Therefore, when the particle moved from point A to B, we are to calculate displacement vector **AB**.

2.3 Velocity

While studying kinematics, the most common terms we come across are 'speed' and 'velocity'. Often these two quantities are considered to be the same in general. But doing so while studying kinematics would be a 'blunder' as these two are 'very different quantities'. Let's have a look at their properties.

Speed	Velocity
1. It is the distance covered per unit time. 2. It can never be zero or negative. 3. It is a scalar quantity, i.e., it has only the magnitude but no direction associated with it.	1. It is the displacement per unit time. 2. It can be zero or negative. 3. It is a 'vector' quantity, i.e., it has both the direction and magnitude associated with it.

To get a better understanding of the two quantities above, i.e., speed and velocity, let's once again take a look at Illustration 2. Suppose that the particle takes 5 second (sec) to cover the total distance from P to Q, then the speed = distance/time = 15.7/5 = 3.14 m/sec. And velocity = displacement/time = 10/5 = 2 m/sec. Clearly, speed and velocity have different values for the same case.

Now, several quantities are related with the motion of a particle describing 'how fast' or 'how slow' it is moving. Two of them, i.e., speed and velocity have already been discussed. Technically, the terms speed and velocity are known as 'average speed' and 'average velocity'. However, 'instantaneous velocity' and 'instantaneous speed' are also used to define motion. The basic difference between these two is that average velocity tells us about 'how fast an object or a body is moving in a given 'interval of time'. However, as the name itself suggest instantaneous velocity and instantaneous speed tell us about motion at a particular instant of time, e.g., at time t = 5 sec, or t = 6 sec, etc. Instantaneous velocity is also defined as 'the rate of change of displacement with time' and its value can be found by differentiating the displacement with respect to time, i.e., if x is the displacement of a body at t = 5 sec then the instantaneous velocity is = dx/dt. Here and below, whenever we are describing through numerical examples or equations, the magnitudes of the vector quantities have been used.

Illustration 3: The magnitude of the displacement '***x***' of a particle (given in m) at any time 't' is given by the equation $x = 5t^2 - 2t$. Find the velocity at t = 3 sec.

Solution: Note that we are required to find velocity at a particular instant of time, i.e., at t = 3 sec. so, we differentiate the given equation so that

$$\begin{aligned}\frac{dx}{dt} &= 5\times\frac{d}{dt}\left(t^2\right) - 2\times\frac{d}{dt}\left(t\right)\\ &= 5\times(2t) - 2\pm(1)\\ &= 10t - 2\end{aligned}$$

Or the magnitude ofvelocity $v = 10t - 2$.

We have obtained a general equation of velocity at any time t. So at a particular time t = 3 sec, the magnitude of velocity is calculated to be $v = 10\times 3 - 2 = 28$ m/sec.

2.4 Acceleration

Suppose a particle's velocity is changing with time. In that case the particle is said to be accelerated. For motion along any axis, the average acceleration of the particle can be defined as,

$$a = \frac{v_2 - v_1}{t_2 - t_1},$$

where v_1 and v_2 are velocities at times t_1 and t_2.

The instantaneous acceleration (or simply acceleration) is given as the time derivative of the velocity,

$$a = \frac{dv}{dt}.$$

In general, acceleration at any instant is the rate at which its velocity changes with time. Mathematically, we obtain this by differentiating velocity with respect to time. A common unit of acceleration is meter per second^2 (m/sec^2). Just like the velocity, its algebraic sign indicates its direction along a given axis, i.e., positive for motion along positive direction of the reference axis and negative for the motion along negative direction of the reference axis. Large accelerations are sometimes expressed in terms of units of the gravitational acceleration g, the value of which is = 9.8 m/sec^2. As we shall discuss in dynamics, g is the magnitude of the acceleration with which a body falls towards the surface of earth.

Illustration 3: A particle's position is related to time as $x = 2t^3 + 4t^2 - 6$. Find the particle's velocity and acceleration at time t.

Solution: Acceleration is the time-derivative of velocity which itself is the time-derivative of displacement. So first we differentiate the given equation with respect to t to find the velocity v, i.e.,

$$\begin{aligned} v &= 2\times\frac{d}{dt}\left(t^3\right)+4\times\frac{d}{dt}\left(t^2\right)-\frac{d}{dt}(0) \\ &= 2\times(3t^2)+4\times(2t)-0 \\ &= 6t^2+8t \end{aligned}$$

Now differentiating this equation again with respect to t will give us the acceleration, i.e.,

$$\begin{aligned} a &= 6\times\frac{d}{dt}\left(t^2\right)+8\times\frac{d}{dt}(t) \\ &= 6\times(2t)+8\times(1) \\ &= 12t+8 \end{aligned}$$

It's not that acceleration is bound to change with time. A body can have varying acceleration also. For example, for $t = 1$ to $t = 2$ sec, it can have $a = 5$ m/sec^2 and for next 2 sec, it can have a = -4 m/sec^2 (negative sign means motion in the opposite direction). Similarly, acceleration can also be constant, i.e., the body can be uniformly speeding up. It should be noted that for moving objects which are slowing down, the rate of change of their velocity is called deceleration. Deceleration also has a negative sign.

3. Relative motion

Suppose you spot your friend and somehow measure his speed which comes out to be, say, 4 km/hr. Now if you try to move along with your friend in the same direction and with the same speed then you will observe that your friend seems to be stationary with respect to you. However, other people nearby you will see you two moving with the same speed. So it is clear that our observation of motion of objects depends on our point of view or on our frame of reference. Hence, no motion can be called absolute because something at rest for you may be moving for others and vice versa. So every motion is 'relative' and depends on factors such as frame of reference and state of motion of the observer.

So to deal with such discrepancies in our observations, the concept of relative motion was introduced. If two bodies A and B are moving with velocities v_A and v_B then velocity of B relative to A or velocity of B as observed by A will be given by

$$v_{BA} = v_B - v_A$$

This is a basic formula used to solve problems of relative motion. Similarly, acceleration of B as observed by A will be

$$a_{BA} = a_B - a_A$$

4. Equations of motion

In kinematics, constant acceleration is given special place. The three basic equations of motion (discussed below) are applicable only when acceleration is constant (for the time-period within which we are studying motion).

4.1 Motion in one dimension

Let's consider motion of a particle or a body along the x-axis for which the position at a time t is given by x. Then for this systems, the general forms of the three equations of motion are given as

(1) $v = v_0 + at$

(2) $x - x_0 = v_0 t + \frac{1}{2} a t^2$

(3) $v^2 = {v_0}^2 + 2a(x - x_0)$

In the above equations, v is the final velocity, $v_0$is initial velocity, $a$isacceleration, x is final position after time t, and x_0 is initial position. These equations can be used to find an unknown quantity when rest of the quantities are known. The following illustration depicts use of one of these equations.

Illustration 4: A body moving with a speed of 50 m/sec undergoes a retardation (acceleration with opposite motion of the body, i.e., acceleration in the direction opposite to the body's velocity) of 10 m/sec^2. Find the body's final velocity after 2 sec.

Solution: Note that here acceleration is opposing the motion so it will have a negative sign. Using the first equation of motion, i.e., $v = v_0 + at$, we can find the final velocity. Here $v_0 = 50$ m/sec, $a = -10$ m/sec^2 and $t = 2$ sec. Therefore, final velocity will be $v = 50 – 10 \times 2 = 30$ m/sec

4.2 Acceleration during free fall

When a body is tossed up or down then earth's gravitational pull attracts it towards the ground. Hence the object accelerates downward at a certain constant rate. This rate is called free fall acceleration. It is denoted by g and has a value of 9.8 m/sec^2. However, it should be noted that g changes with altitude (height). Also, various factors such as air resistance affect its value. But for the sake of our convenience, we neglect the air resistance and take the value of g = 9.8 m/sec^2.

Also, a negative sign always accompanies g because it is always directed in the downward direction. So for every case we will take gravitational acceleration = - g.

It is interesting to note that g is constant for body of any size and mass. But due to air resistance and several other factors, heavy objects experience slightly greater acceleration. If however, a feather and a hammer are dropped from the same height in perfect vacuum (i.e., in absence of air) then both will reach the ground at the same time, thus showing that g is independent of mass, shape and size. The velocity, however, changes during the ascent of flight of an object because it is being opposed by g.

Illustration 5: suppose you toss a coin with initial velocity of 10 m/sec along y-axis. Then find,

(a) How long does the coin take to reach its maximum height?
(b) What is the maximum height reached by the coin from the initial point?

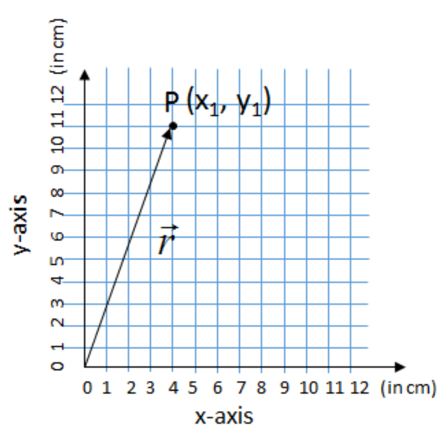
Solution: (a) Here initial velocity v_0 = 10 m/sec, $a = -g$ = -9.8 m/sec^2. Hence, after throwing the coin, it goes to a maximum height where its' velocity becomes zero and then due to g it starts falling down. Let t be the time taken to reach maximum where $v = 0$, then using the first equation of motion, $v = v_0 + at$, we have the time taken $t = (v - v_0)/a = (0 - 10)/(-9.8) = 1.02$ sec.

(b) Let $x = h$ be the maximum height attained by the object then by using third equation of motion, i.e., $v^2 = v_0^2 + 2ah$, we get

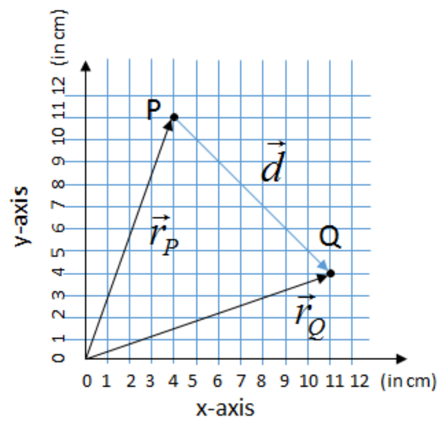
$$h = (v^2 - v_0^2)/2a$$
$$= (0 - 10^2)/(-2 \times 9.8) = 18.7 \text{ m}$$

4.3 Motion in higher dimensional space

The equations of motion as described above are valid in two or three dimensions as well. The only changes in the equations will be that x is replaced by r, a general position coordinate in the Cartesian coordinate system which, for example in three dimensions means r = (x,y,z). Therefore, the magnitude of r should be used in the above equations for motion along r or any other direction.



Any particle in free space can be located by using a vector starting from origin to the particles position which is termed as position vector. For example, below in the figure, the point P is located in the xy-coordinate space by a vector $\vec{r}$.



The displacement vector for the particle can then be defined using position vectors of initial and final positions of the particle. For example, suppose the particle starts from point P and stops at point Q then its total displacement will be given by $\vec{d}$ or $\Delta\vec{r}$, i.e., $\vec{d}$ is directed from the initial position vector $\vec{r}_P$ towards the final position vector $\vec{r}_Q$. In the language of vector algebra, $\vec{d}$ can be calculated as the vector difference between the final position vector and the initial position vector, i.e.,

$$\vec{d} = \vec{r}_Q - \vec{r}_P .$$

Using unit vector notations, we can write $\vec{d}$ as

$$\vec{d} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} ,$$

Where $x_1\hat{i} + y_1\hat{j}$ and $x_2\hat{i} + y_2\hat{j}$ are the x and y component of vectors $\vec{r}_A$ and $\vec{r}_B$, respectively.

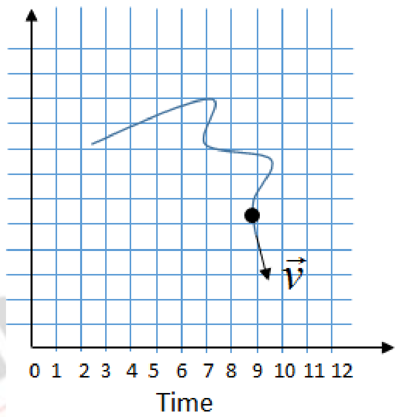
Illustration 6: The coordinates of a man's position along x-axis and y-axis at any time t are given as $x = -0.25t^2 + 1.9t$, $y = 3.5t^2 - 0.7t - 300$. At $t = 15$ sec, what is the man's position vector $\vec{r}$ in unit vector notation.

Solution: At $t = 15$ sec, displacement along x-axis will be $x = -0.25 \times 15^2 + 1.9 \times 15 = = -27.75$ m. Similarly, the displacement along the y-axis will be $y = 3.5 \times 15^2 - 0.7 \times 15 - 300 = 477$ m. Therefore, the net displacement in m will be $\vec{r} = (-27.75)\hat{i} - (477)\hat{j}$

Just like the displacement, velocity too is a vector quantity. If a particle's initial and final position vectors in time t are r1 and r2, then, its average velocity vector will be

$$v_{avg} = (r_2 - r_1)/(t_2 - t_1) = \Delta r/\Delta t.$$

Here Δ simply denotes the change in the quantities. Δr thus becomes the displacement vector. For instance if a particle moves through displacement (5m)i + (10m)j in 3 sec. then its average velocity vector will be given by $v_{avg}= \Delta r/\Delta t$ = (12m)i + (30m)j. However, when we speak of velocity of a particle, we usually refer to its 'instantaneous velocity' v at some instant. The instantaneous velocity is given by v = dr/dt, i.e., first derivative of the displacement with respect to time. Note that direction of average velocity vector is along the direction of displacement vector. However, direction of instantaneous velocity at any point of time is along a tangent to that point, e.g., if the displacement is represented in the form of a graph as follows then the instantaneous velocity at 5 = 5 sec will be as shown in the figure.



If a particle's velocity changes from v_1 to v_2 in a time interval Δt, its average acceleration a_{avg} during Δt is $\underline{a}_{avg}$ = change in velocity/time interval = $(v_2 - v_1)/\Delta t = \Delta v/\Delta t$. Similarly, instantaneous acceleration is given by a = dv/dt, i.e., the first derivative of velocity vector with respect to time. Note that if the velocity changes even in direction, then too, the particle must have an acceleration.

5. Kinetics

As we have said in the beginning that in kinetics one has to deal not only with the kinematics but also the state of the motion, causes of the motion or the driving forces and the reactions of the system to applied forces. The kinetics under balanced forces is studied in statics and that under unbalanced forces or the object being in motion is a subject studied within dynamics. In this section, we will elaborate on these points and explain through examples.

In the most basic terms, a force can be defined as a 'push' or 'pull' which makes a body to change its velocity, i.e., makes it accelerate. Thus, whenever a body experiences some force, it always undergoes acceleration. In dynamic, we perform systematic study of forces and their resulting accelerations (or motion in general). If we look around ourselves, we find that there are various forces acting in our surroundings, for example, every falling object experiences a 'gravitational force' of earth which makes it accelerate in the downward direction. Every object that is moving on a surface experiences an opposite force due to friction. If a car strikes a wall then the wall applies a force back onto the car as a reaction bringing the car to rest. There are similar innumerable examples of activities from our daily lives which involve some kind of force. In fact our entire world would face lot of chaos if these forces were absent.

5.1 Laws of motion

Isaac Newton, in the seventeenth century, was the first scientist who studied kinetics of physical objects in detail and laid out three fundamental laws which are now popularly known as Newton's laws of motion or some people prefer to call it the Newtonian mechanics. It should be underlined that these laws of motion hold true for nonrelativistic cases only, i.e., the speed of the object is much smaller than a universal constant called the speed of light in vacuum, and for classical objects only, i.e., the size of the objects is not too small on the scale of atomic structure.

Newton's first law of motion or the law of 'Inertia'

An object will remain at rest or continue in motion with a constant velocity, unless acted upon by an external force. In simple words, physical objects like to remain in their state of equilibrium. Thus, we can say that every object opposes a change in its state of motion.

"The resistance towards any external perturbation that can change their current state is called inertia."

If there was no friction or air resistance, then a body moving at 5 m/sec would carry on indefinitely with the same speed. Obviously, this doesn't happen in real life due to the air resistance and frictional forces always acting on them.

Illustration 1: Suppose you are riding in a car and you step on the brakes suddenly. Inertia keeps you moving forward at the same speed as the car was moving. You will keep moving until something stops you. This might be the car's steering wheel, dashboard, or windshield. You might be hurt if you hit these parts of the car, unless you are wearing a seat belt. A seat belt keeps you from moving forward when the car stops suddenly.

Furthermore, Newton's laws of motion are not true for all reference frames. The special frames in which Newton's laws are application are called inertial reference frames. For instance, for an accelerating observer, the force applied by him on a body would be somewhat different from what would be seen by a stationary observer. Hence in general, Newton's laws are not valid when there is a relative motion between the observer and the body on which force is acting.

(a) Newton's second law of motion or the law of acceleration

The second law states that the net force on a body is the product of body's mass and its acceleration. Mathematically, for a body of mass m which is acted upon using an external force F, then according to the second law of motion

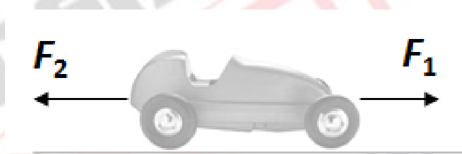
$$F = ma,$$

where$a$ is the acceleration produced by the force F in the body.

Every force acting on a body produces some related acceleration. Therefore to assign the unit of force, we shall relate it with the acceleration it produces on a standard reference body. If we push or pull a body of mass 1 kilogram on a frictionless surface such that the acceleration of 1 m/sec^2 is produced in it then we say that a force of one Newton (1 N) is acting on the body. So in general, a force is measured by the acceleration it produces and since acceleration is a vector quantity, so is the force. Its direction is along the direction of acceleration. Hence, forces combine according to rules of vector algebra.

It makes sense from the above equation that if something has a greater mass, it would take a larger force to give it the same acceleration as something with less mass. Now this equation seems to be quite simple but it should be used very cautiously. Firstly, we must identify the body which we want to study. Secondly, we must consider all the forces acting on the body. Adding them vector ally would give us the net force. However, while doing so we should neglect other bodies in the systems. For example, suppose you and your friend push each other and you want to measure the force acting on yourself, then you should neglect the force applied by you on your friend.

Illustration 5: Consider a toy car experiencing forces F_1=6 N and F_2=4 N in opposite directions. Assuming the surface to be frictionless, calculate the acceleration produced in the body if mass of the toy car is 1.5 kg.



Solution: Since force is a vector quantity, multiple forces acting on a body are added accordingly. Let's assume that F_1 is along positive x-axis then we can write the two forces as

$\boldsymbol{F}_1 = (6\text{ N})\hat{i}$ and $\boldsymbol{F}_2 = -(4\text{ N})\hat{i}$.

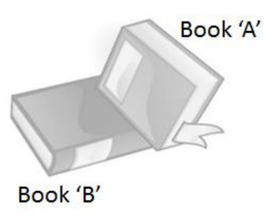
So the net force acting on the car will be given by

$\boldsymbol{F}_{\text{net}} = \boldsymbol{F}_1 + \boldsymbol{F}_2 = (6\text{ N})\hat{i} - (4\text{ N})\hat{i} = (2\text{ N})\hat{i}$

So the net force will act in the positive x-direction, so will be the direction of the acceleration $\boldsymbol{a}$. Magnitude of the acceleration $\boldsymbol{a} = F_{\text{net}}/\text{m} = 1.66$ m/sec^2.

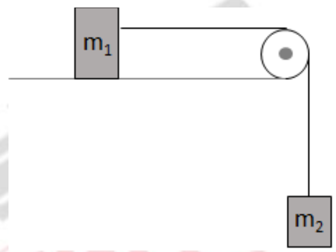
(b) Newton's third law of motion or the law of action reaction

According to the third law of motion, whenever a body applies a force on a second body then the second body also applies the same force on the first body. Which means that if you push against a wall, it pushes you back, which is a good thing really because otherwise you'd go straight through!

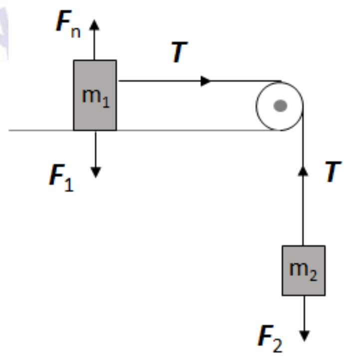


Consider two books kept against each other as shown in the figure below. Although both the books look stationary but they are exerting equal and opposite force on each other. These forces are termed as action-reaction pair of forces. Consider another example where a book is kept on a table, then there are two forces acting on the book, i.e., the gravitational force due to earth and the normal force due to the table these two forces may seem to be action-reaction pair of forces but actually they are not because both these forces are acting on the same body, i.e., the book. However, action-reaction pair of forces always act on two different bodies. So Newton's third law is stated as 'for every action force, there is an equal and opposite reaction force'.

Illustration 3: consider two blocks of different masses m_1 and m_2 connected to each other as shown in the figure. Take m_1 = 3 kg and m_2 = 2 kg. The rope as negligible mass and is inextensible. Also, there is no friction on the surface and the pulley. Find acceleration of both the blocks.



Solution: First of all, let's redraw the picture as shown below with all the forces acting on the systems in proper directions. There are gravitational forces acting on both the masses, i.e., $\mathbf{F}_1 = m_1\mathbf{g}$ on the first block with mass m_1 and $F_2 = m_2 g$ on the block with mass m_2, reaction force $\mathbf{F}_n$acting on the mass m_1, tensile force $\mathbf{T}$ in the string which is same for both the blocks because only one string is involved.



Now, since the block m_1 is moving only along the horizontal axis, so the normal force on this block must be balanced, i.e., $\mathbf{F}_1 = \mathbf{F}_n$. Suppose this block is moving with acceleration $\boldsymbol{a}_1$ than along the horizontal axis, the tensile force T will produce this acceleration as there is no other force acting on it along the horizontal axis. This means,

$$\mathbf{T} = m_1\boldsymbol{a}_1 = 3\boldsymbol{a}_1$$

Similarly, for block m_2, the movement is along the vertically downward direction only. If $\boldsymbol{a}_2$ is the net acceleration of block m_2 then the force producing this acceleration should be a resultant of $\boldsymbol{T}$ and $\boldsymbol{F}_2$. Therefore,

$$\boldsymbol{F}_2 - \boldsymbol{T} = m_2\boldsymbol{a}_2 = 2\boldsymbol{a}_2$$

$$\text{or} \quad 2\boldsymbol{g} - \boldsymbol{T} = 2\boldsymbol{a}_2$$

Replacing T from the above equation into this equation, we get

$$2\boldsymbol{g} - 3\boldsymbol{a}_1 = 2\boldsymbol{a}_2$$

Since, the two blocks are connected, the magnitude of the acceleration in both of them should be the same, i.e., $a_1 = a_2 = a$. This results into the solution as

$$5a = 2g$$

$$\text{or} \quad a = (2 \times 9.8)/5 = 3.9 \text{ m/sec}^2$$

Therefore, both the blocks will move with acceleration 3.9 m/sec^2. This means the horizontal force acting on the block with mass m_1 is $F_1 = (3 \times 3.9) = 11.7$ N and the vertical force acting on the block with mass m_2 is $F_2 = (2 \times 3.9) = 7.8$ N.

Summary

1. We learned about the motion of classical objects. The differences between kinematics and kinetics should be kept in mind which have been explained here through simple examples.
2. Various quantities that we study in kinematics, such a position, displacement, velocity, acceleration are vector quantities.
3. Kinetics deals with not only kinematics of moving objects but also the forces causing their motion.
4. There are three equations of motion in kinematics which govern the motion of moving objects
5. There are three laws of motion which involve the concepts of force, inertia and action-reaction. These laws are called Newton's laws of motion and hold true only in inertial frame of references.