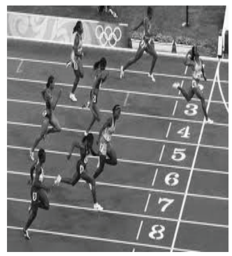
Chapter Two

MOTION


[The object, that we see around us either are stationery or in motion. What do we actually understand by the words ``rest'' and ``motion''. We need different quantities regarding motion to express the characteristics of motion of a moving object. In this chapter we will discuss different quantities regarding motion, their dimensions, units, the relations among them etc.]

By the end of this chapter we will be able to-

1. Explain the rest and motion

2. Find out the difference among different types of motion.

3. Explain the scalar and vector quantities

4. Analyze the relation among the quantities regarding motion

5. Explain the motion of freely falling bodies

6. Analyze the relations among the quantities regarding motion with the help of graph

7. Realize the effect of motion in our life

2.1 Rest and motion

Position : Where is your school ? In answer to this question we will know the position of your school. If you say your school is in Jheeltuli it is absolutely true but we cannot know the exact position of your school from this information. We can know the exact position only when you mention the position, direction and distance of your school with respect to a particulars place. At first we have to consider a known point or an object with respect to that the position of another point or object is to be determined. For example, if said your school is one kilometer apart in the east from the gate of your residence, its position can be told certainly. We have to consider a particular point to find out the position of our village or town, country or the world or the universe around us. This point is called reference point or origin and fixed object with respect to which we find out the position, rest and motion of another object is known as reference frame. Any point can be considered as reference point for our convenience. In the above example we could consider any other point as reference point.

Rest and motion : We see many object around us of them some are rest and some are in motion. What do we actually mean by rest and moving object.

Do by yourself : Hold a pen in your hand.

What is there around the pen ? Does the position of the pen get changed with respect to other objects around ? It does not. The pen in your has a particulars distance and direction with respect to the objects around you such as your chair, table, book, copy, house, door, window and to all other things. So the position of your pen is fixed with respect to other objects around you. The position of the pen is not changing with the change of time. We can say the pen is in rest to the surroundings. The act of remain rest of the pen is called rest. Therefore, a body is said to be static or at rest with respect to its surroundings when it does not change its position with time.

Ani is standing by the side of the road. He said that, houses, plants and trees, electric poles etc are standing at rest. Why does he say so ? According to Ani those objects are not changing their positions with respect to time.

Do by yourself : Keep the pen in your hand moving to and fro.

Does the position of the pen change with respect to the objects around, the position and direction of the pen is gradually changing with respects to each object of its surrounding. The position of the pen is changing with time. We say the pen is in motion with respect to the surroundings. A body is said to be in motion with respect to its surroundings when it changes its position with time. And this change of position with time is called motion.

We discussed earlier that to understand whether an object is in rest or in motion it is necessary to chose a reference object or reference frame. If the relative positions of this considered object and the reference object remain unchanged with time, the considered object is said to be in rest with respect to reference object. If the considered object and the reference object move along the same direction with same velocity even though the distance between the objects, remain unchanged despite the object, being in motion. If two friends remain seated face to face in a running train, then the relative position of one with respect to other does not change. So one is said to have in rest with respect to other. When a person observes these two friends standing by the side of the train line he will see their position is changing with respect to him. That is both the two friends are in motion with respect to the person standing by the side of the train line.

So we see that an object is actually in rest or not depends on the reference object. If the reference frame is actually in rest, object in rest will be : actually in rest with respect to that frame. This type of rest is called absolute rest. A body is said to be in absolutely rest when it is in rest with respect to an absolutely rest object.

Similarly absolute motion of a body is its motion with respect to a reference object absolutely at rest. But in this universe it is not possible to get a reference object which is at absolute rest. Since the earth is continuously moving round the sun, while the sun itself is moving along the galaxy with its planets and satellites. Thus when we say that a body is at rest or in motion, we mean it is to be so with respect to a body apparently at rest. So we can say that in this universe all rest and all motion are relative. No rest or no motion is absolute.

Mitu is waiting for a bus at the bus stand to go somewhere. She notices her friend Roni crossing her by rickshaw. She says that the rickshaw is in motion because it is changing its position continuously with respect to time.

The change of position of a body may take place in two ways.

Let us consider the following example :

a) Mou is standing under a tree and sees that her friend Awishi is running away from her. So the distance between Mou and Awishi is increasing with time.

b) A large circular tract is made in the school field of Raju for race of annual sports. He notices his friend Shihab practicing to running along that track standing at the centre of the trac (Fig 2.1 (b)). Raju says Shihab is in motion but the distance between them is not changing with time. How it can be said that Shihab is in motion with respect to Raju.

Fig-2.1(a)

Fig-2.1(b)

In the first example, the position of Awishi is changing with respect to Mou with the change of distance and time. In the second example, the position of Shihab is changing with respect to Raju with time but the distance is not changing. What is changing then ? The direction of position of Shihab is changing with respect to Raju. The position of a moving body with respect to an observer can be taken place either indirection or in distance or by both.

2.2 Types of motion

Linear motion : If a body is in motion along a straight line, that is, if the motion of a body is restricted on a straight line its motion is called linear motion. The motion of a car in a straight street is linear motion.

Rotational motion : When a body rotates around a particular point or an axis keeping the distance of the particles of the body unchanged is called rotational motion. For example, motion of an electric fan, motion of the heads of a clock.

Rectilinear motion : When a body moves along a straight line in such a way that each particle of the body travels the same distance at the same time in the same direction.

If a book is pushed to shift from one end to the other of a table without rotation, the motion will be rectilinear because all the particles of the book travel the equal distance, at equal time in the same direction.

Periodic motion : If the motion of a moving particle is such that it passes through a definite point along the path of its motion in the same direction in a definite interval of time, this type of motion is called periodic motion. This motion can be circular, elliptical or rectilinear. The motion of the hands of a clock, the motion of earth round the sun, the motion of piston in the cylinder of a steam or petrol engine etc.

The time interval at which a particle of periodic motion passes through a definite point from the same direction repeatedly is called its time period.

Vibratory motion : If a body executing periodic motion moves in a definite direction for one half of its time period and exactly for the other half in the opposite direction then this motion is called vibratory motion. Motion of a simple pendulum, motion of vibrating tuning fork and the motion of string of guitar.

2.3 Scalar and vector quantities :

Anything that can be measured in this physical world is called a physical quantity. When a physical quantity is measured, it has got a magnitude. We express this magnitude in terms of a number and a unit. For example, if we say that the height of the bench is 1.5 meter, we mean that the unit of length is meter and height of the bench is 1.5 times this unit. But all physical quantities cannot be completely expressed by its magnitude only. To express not only magnitude of some quantities is needed but also the direction.

For example, if we say that a car is running at the speed of 40 km per hour, it is understood that the car moves a distance 40 km in one hour, but the direction of motion of the car cannot be known from this statement. To know the actual position of the car, the direction of the motion should also be stated. So, we can see, to express some of the quantities completely direction is needed with the magnitude of the quantities. In consideration of direction all quantities of the world we can divide into two category. Such as

1. In-directional quantity or Scalar quantity
2. Directional quantity or Vector quantity

Scalar quantity : Physical quantities which can be fully expressed by magnitude only are called scalar quantities. Length, mass, speed, work, energy, time, temperature etc are the examples of scalar quantities.

Vector quantity : Physical quantity which need both magnitude and direction to be fully expressed are called vector quantities. Displacement, velocity, acceleration, force, electric intensity etc are the examples of vector quantities.

Table 2.1 Shows that vectors are expressed by magnitude and direction whereas scalars are expressed by magnitude only.

Table 2.1

Examples of scalar and vector quantities

Scalar Quantity			**Vector quantity**		
Distance	d	40m	Displacement	**s**	40m east direction
Speed	v	$30ms^{-1}$	Velocity	**v**	$30\ ms^{-1}$ north direction
Time	t	15s	Force	**F**	100N upward direction
Energy	E	2000j	Acceleration	**a**	$98ms^{-2}$ downward direction

Representation of a vector :

A vector quality is represented by an arrow over the symbol of the physical quantity. For example, $\vec{A}$ or $|\vec{A}|$, where $|\vec{A}|$ represents, the magnitude of the vector quantity $\vec{A}$. Sometimes bold **A** instead of $\vec{A}$ is used to represent a vector and an ordinary A to represent its magnitude. The vector quantities in the table 2.1 are represented by bold letter.

In figure, a vector quantity represented by an arrow headed straight line. The length of the straight line represents the magnitude and the arrow head indicates the direction of the vector. For example, in figure 2.2 displacement of 50km has been represented by 1cm. Hence the vector A in this figure, whose length is 3cm represents a displacement of 150km towards west. The vector B represents a displacement of 100km towards north at an angle of 30^0 with the east.

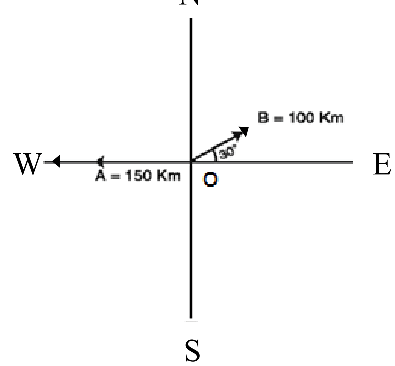


Fig-2.2

2.4 Different quantities related to motion

Distance and Displacement:

Suppose, Ovi ran 100m from his school gate. It is true that Ovi is 100m away from the gate, but it does not tell the exact position of Ovi. Because Ovi can be 100m away to the east, to the west, to the north, to the south or any other directions. To know exactly the change of position of Ovi, the direction towards which he moved 100m should also be known. If it is stated that Ovi ran 100m from the gate to the east then his exact position will be known definitely. If you go straight to the east from the gate you will find Ovi at a distance of 100m. The physical quantity which was first used to indicate the change of position of Ovi is distance. This is a scalar quantity. In the second case, direction has also been mentioned along with distance, this is called displacement. This is a vector quantity. Change of position or distance in a definite direction is displacement. So, the change of position of an object with respect to its surrounding in a definite direction is called displacement.

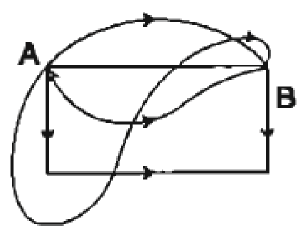


Fig-2.3

The minimum distance, that is, the linear distance between the initial and final position of a body is the magnitude of its displacement at its direction is towards final position from the initial position.

The displacement does not depend on the path of the object. An object can move from position A to position B following different paths. But its displacement will be from A towards B. The minimum distance between A and B, that is, in this case the linear distance AB is the magnitude of displacements. AB and its direction is towards B from A. Here, it is a vector quantity, since displacement has both magnitude and direction.

The dimension of displacement is the same as that of distance.

Therefore, $[\, s \,] = L$

The unit of displacement is the same as that of distance that is meter (m). The displacement of a body is 50m towards north means that the body has moved 50m from its initial position towards north direction.

Speed : Suppose in the previous example, Ovi takes 50 seconds, to travel 100m distance. If Mitu covers the same distance in 40 seconds, who goes faster ? Ovi or Mitu, definitely Mitu goes faster because she takes less time.

Suppose, Ovi travels 100m in 50 seconds, Mitu travels 75m in 30 seconds can we say Ovi goes slower than Mitu ? Does not Ovi travel more distance than Mitu ? The distance of a particular time Ovi and Mitu travels has to be compared to know who goes faster. Let the particular time be 1 second therefore,

In 1 second Ovi travels $\frac{100}{50}$ = 2 meter

In 1 second Mitu travels $\frac{75}{30}$ = 2.5 meter

So, Mitu goes faster than Ovi because in 1 second Mitu travels more distance than Ovi.

From the above discussion we can understand time and distance determines who goes faster.

The quantity by which we can measure how fast a body moves or distance traveled, is called speed. Speed expresses the rate of change position of a body. The rate of change of position of a body with time is called the speed.

Speed of a body is measured by the distance traveled per unit time. i.e

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

If a moving body travels a distance `d’ in time `t’ then the speed v is

$$v = \frac{d}{t}$$

The direction of rate of change of position of the body cannot be known by the speed. So it has no direction. Therefore, speed is a scalar quantity.

The dimension of speed is the dimension of = $\frac{\text{distance}}{\text{time}}$

$\therefore$ [V] = [$^{L} / _{T}$] = [LT^{-1}]

As speed is obtained by the division of distance and time, unit of speed is obtained, by the division of units of distance and time.

Since the unit of distance is meter (m) and unit of time is second (s), unit of speed is meter/second (ms^{-1}).

The speed of a body is $4ms^{-1}$ means that the body moves a distance of 4m in 1second.

Though the unit of speed is meter/second, for our convenience sometimes we consider the unit of speed is kilometer/hour where the unit of distance is kilometer and of time is hour. The speedometer of car measures the speed in kmh^{-1} .

Average Speed : If the magnitude of speed does not change during the motion of the body, that is if the body travels equal distance in equal interval of time, then the speed of the body is called uniform speed. And if the body does not travel equal distance in equal interval of time then the speed is called non uniform speed.

If a body does not move with uniform speed, then the speed obtained by dividing the total distance traveled by time is called average speed.

So, average speed = $\frac{\text{total distance}}{\text{time}}$

If a car runs 300 km in 6 hours since 7 in the morning on the way from Dhaka to Dinajpur, the average speed of the car is 300km/6h = $50kmh^{-1}$. Here, average speed $50kmh^{-1}$ does not mean the car travels 50km in every hour rather it might travel sometimes faster or sometimes slower than the average speed.

Instantaneous speed : If we want to know the instantaneous speed of any body at any instant, for example what was the speed of the car just the moment its 33miniutes travel is over, the speed of that moment will be the instantaneous speed. To find the instantaneous speed at any instant, the distance traveled at during a small interval, has to be known and then the distance has to be divided by the time interval.

If any one wants to the speed of the car at 10 : 32 : 43 am (10 hours 32 minute 43 second) or at the time of cross over a speed breaker on the highway beside any school, he has to see the reading of the speedometer at the moment. Similarly with the help of Rudder or Laser gun we can know whether a car is violating the highest limit on the highway or the speed every ball of Mashrafi Bin Murtaja, the fastest bowler of Bangladesh national team.

Velocity : Sometimes during usual conversation many people use the word velocity to mean speed. But in science the two words do not mean the same thing speed indicates only the rate of change of position with time, it does not indicate the direction of change of position. The velocity states the rate of change of position along with its direction that is, velocity means the rate of change of position in a definite direction or in other words the rate of change of displacement. Hence velocity of a body is its rate of change of displacement with time, that is the distance traveled by a moving body in unit time in a definite direction is called the velocity of the body.

If a body travels a distance *s* in a definite direction in time *t* the velocity is $v = \frac{3}{t}$

The dimension of velocity is the same as that of speed, i.e [LT^{-1}]

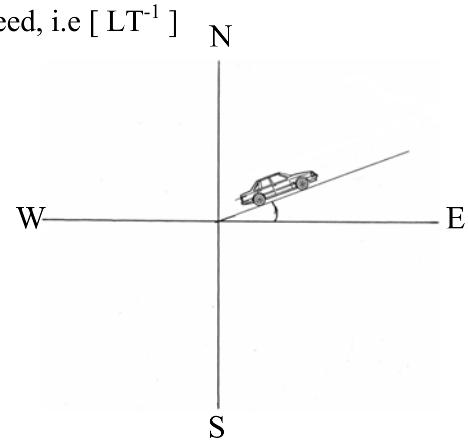


Fig-2.4

The unit of velocity is ms^{-1} the same as that of speed. Velocity has both magnitude and direction. So, velocity is a vector quantity. A road may be taken as an example at some place the road has made a 30^0 angle with east and has gone straight towards north (Fig 2.4). On this road, if a car moves with a uniform speed of $20kmh^{-1}$ then we will be able to state correctly that the velocity of the car is 20 kmh^{-1} towards north at an angle 30^0 with east. But if the same car moves in a circular road with uniform speed of $20kmh^{-1}$ than the direction of its motion will be continuously changed. So its velocity will also be changed continuously, although its speed will always remain the same. The magnitude of the velocity of a body is its speed. The specific directional speed is its velocity.

If the magnitude and direction of the velocity of a moving body remains unchanged, then the velocity of the body as called uniform or equal velocity. The velocity of sound is a good example of natural phenomenon of uniform velocity. Sound travels in a definite direction over equal distances in equal intervals of time and it is $332ms^{-1}$ in Air at 0^0c. Sound travels in a definite direction through a distance of 332m in the 1^{st} second, 332m in the 2^{nd} second and so on for every second. Here the magnitude and the direction of the velocity of sound remains the same. So the velocity of sound $332ms^{-1}$ is a uniform velocity.

If the magnitude or direction or both of the velocity of a moving body changes during its motion, then its velocity is called variable or uniform velocity. In other words if the body does not move through equal distance in equal intervals of time or changes its direction of motion while moving then its velocity will be variable. Usually we moving, car runs on the road etc. are the uniform velocity.

Acceleration and Retardation : If a body does not move with uniform velocity then the magnitude or direction or both of the velocity may change. We say that there is acceleration of a body if its velocity changes. Suppose a car is moving along a straight road. Mitu sitting in the car recorded the readings of speedometer of the car after every 8 seconds. The velocity of the car at different time in the units kmh^{-1} and ms^{-1} are shown in the following table.

Table 2.2

Velocity-Time table

Serial No	Time (s)	Velocity (kmh^{-1})	Velocity (ms^{-1})
1.	0	0	0
2.	8	14.4	4
3.	16	28.8	8
4.	24	43.2	12
5.	32	57.6	16
6.	40	72.0	20

From this table we can see that the velocity of the car increases from 0 to $4ms^{-1}$ in first 8 second. In the next 8 seconds the velocity of the car increases by $4ms^{-1}$. In the way the velocity of the car increases by $4ms^{-1}$ in every 8 seconds. In other words the change of velocity of the car is $0.5ms^{-1}$. So, the rate of change of velocity of the car with time is $0.5ms^{-1}$.

The rate of change of velocity with time that is the change of velocity in unit time is known as acceleration. The rate of increase of velocity with time of a body moving in a straight line is called positive acceleration and the rate of decrease of velocity of a body with time is called negative acceleration. Sometimes negative acceleration is called retardation or deceleration.

The rate of change of non-uniform velocity of a body with time is called its acceleration.

If the initial velocity of a body is u and its final velocity after time t is v.

then change of velocity in time $t = v - u$

Hence, change of velocity in unit time $= \frac{v-u}{t}$

$\therefore$ rate of change of velocity, i.e.

acceleration, a $= \frac{v-u}{t}$

Therefore, acceleration $= \frac{\text{change of velocity}}{\text{time}}$

Acceleration is a vector quantity. It has direction. Its direction is along the change of velocity. Since we are considering the motion along a straight line, change of direction of velocity will be either along the direction of velocity or opposite to the velocity. If the velocity increases than the change of velocity takes place along the velocity. In this case acceleration will be positive. If the velocity decreases then the change of velocity takes place opposite to the velocity. In this case acceleration will be negative and is called retardation or deceleration.

Dimension : The dimension of acceleration is the dimension of $^{\text{velocity}}/_{\text{time}}$

$$\text{That is, acceleration} = \frac{\text{velocity}}{\text{time}}$$

$$= \frac{\text{displacement}}{\text{time}} \times \frac{1}{\text{time}}$$

$$= \frac{\text{displacement}}{\text{time}^2}$$

$$\text{Therefore, } [\,a\,] = \frac{L}{T^2} = LT^{-2}$$

Unit : The unit of acceleration is the unit of $^{\text{velocity}}/_{\text{time}}$, that is, $^{ms^{-1}}/_{s} = ms^{-2}$

The acceleration of a body is $5ms^{-2}$ towards south means that the velocity of the body increases by $5ms^{-1}$ in 1 second towards south.

Uniform acceleration and non-uniform acceleration :

Acceleration may be two types. Such as- uniform acceleration and non-uniform acceleration. If the rate of increase of velocity of a moving body in a particular direction is maintained constant all the time, then the acceleration is said to be uniform. Conversely, if the rate of increase of velocity changes with time, the acceleration is said to be non-uniform or variable.

An example of uniform acceleration is the acceleration of a freely falling, body due to gravity the acceleration of a freely falling body is $9.8ms^{-2}$, that is, its velocity increases by $9.8ms^{-1}$ for each successive seconds. That is, generally we see these moving body-car, cycle, rickshaw, etc are the example of non-uniform acceleration.

Mathematical Example 2.1 : Velocity of a car increases uniformly at the rate of $5ms^{-1}$ and after 10s becomes $45ms^{-1}$. Find the acceleration of the car.

Solution :

We know,

$$a = \frac{v-u}{t}$$

$$\text{or, } a = \frac{45ms^{-1} - 5ms^{-1}}{5s}$$

$$= \frac{40ms^{-1}}{5s}$$

$$= 8ms^{-2}$$

Ans : $8ms^{-2}$

Here,

initial velocity $u = 5ms^{-1}$

final velocity $v = 45ms^{-1}$

time $t = 5s$

$\therefore$ acceleration $a = ?$

Mathematical Example 2.2 : The Velocity of a car decreases uniformly from $20ms^{-1}$ and after 4s it becomes $4ms^{-1}$. Find the acceleration of the car.

Solution :

We know,

$$a = \frac{v-u}{t}$$

$$\text{or, } a = \frac{4ms^{-1} - 20ms^{-1}}{4s}$$

$$= -16ms^{-1}$$

$$= 45$$

$$= - 4ms^{-2}$$

Ans : $- 4ms^{-2}$

Here,

initial velocity u = $20ms^{-1}$

final velocity v = $4ms^{-1}$

time t = 4s

$\therefore$ acceleration a = ?

2.5 Equations of motion :

We can solve the problems regarding motion of any moving bodies by using only four equations. These equations are called equation of motion. These equation are applicable when the object moves along straight line with uniform acceleration. Let a body with initial velocity u move with uniform acceleration a. Let the final velocity be v after traveling a distance s at time t.

Let the initial velocity of a body be u moving with uniform acceleration a. After traveling a distance s in time t its final velocity becomes v. We express the equations of motion by the following symbols. These symbols are :

u = initial velocity

a = uniform acceleration

t = traveled time

s = displacement i.e. distance traveled in time t

v = final velocity i.e. velocity after time t

There are five quantities ``Suvat'' are related in such a way that if we know the value of three, we can find the value of other two. So there are four equations and every equations has four quantities we can find the value of unknown quantities using the values known quantities by this equation.

In lesson 2.4 we see

Acceleration, $a = \frac{v-u}{t}$

$\therefore\ v = u + at$ (2.1)

We also find there

average speed = $\frac{\text{distance traveled}}{\text{time}}$

or, $\frac{u+v}{2} = \frac{s}{t}$

$$\therefore s = \frac{(u+v)t}{2} \tag{2.2}$$

Calculate : Put the value of v of eq (2.1) into equation (2.2)

$$\therefore s = ut + \frac{1}{2}at^2 \tag{2.3}$$

Calculate : Find the value of t from equation (2.1) and put it in eqn (2.2) and by cross multiplication arrange the terms.

$$\therefore v^2 = u^2 + 2as \tag{2.4}$$

If it is said in a problem the body starts its motion from rest, the initial velocity will be u = 0

Mathematical Example 2.3 : A car starting from rest moves with acceleration of $2ms^{-2}$ its velocity reach at $20ms^{-1}$. How long time does the car take part in acceleration activity?

Solution :

Here,

initial velocity u = 0
final velocity v = $20ms^{-1}$
acceleration a = $2ms^{-2}$
$\therefore$ time = ?

We know,

$v = u + at$

or, $at = v - u$

$t = \frac{v-u}{a}$

$= \frac{20ms^{-1} - 0}{2ms\text{-}2}$

10s

Ans : 10s

Mathematical Example 2.4 : A car is moving with a velocity, of $54kmh^{-1}$. It is accelerated by $4ms^{-2}$ for 5s. What is the final velocity of the car and how far will it travel during the period of acceleration ?

Solution :

We know,

$$v = u + at$$

$= 15ms^{-1} + 4ms^{-2} \times 5s$
$= 15ms^{-1} + 20ms^{-1}$
$= 35ms^{-1}$

Again,
We know

$$s = ut + \frac{1}{2} at^2$$

$= 15ms^{-1} \times 5s + \frac{1}{2} \times \frac{4ms^{-2}}{(5s)^2}$
$= 75m + 50m$
$= 125m$

Here,

initial velocity $u = 54kms^{-1}$

$= 54 \frac{km}{h} = \frac{54 \times 1000m}{3600s}$

$= 3 \times 5ms^{-1}$

$= 15ms^{-1}$

acceleration $a = 4ms^{-2}$
time, $s = 5s$
final velocity $v = ?$
traveled distance $s = ?$

Ans : Final velocity v = 35ms-1

Traveled distance s = 125m

Mathematical Example 2.5 : A car starting from rest in straight moves with uniform acceleration of $10ms^{-2}$. What will be the velocity while crossing a person at a distance 80m ?

Solution :
We know
$v^2 = u^2 + 2as$
$= 0 + 2 \times 10ms^{-2} \times 80m$
$= 1600m^2s^{-2}$
taking root both the sides,
$v = 40ms^{-1}$
$\therefore$ Ans : $40ms^{-1}$

Here,
Initial velocity $u = 0$
Acceleration $a = 10ms^{-2}$
Traveled distance $s = 80m$
Final velocity $v = ?$

2.6 Motion of falling bodies

Gravity : Every particle of this universe attracts towards each other. The force of attraction between any two bodies or particles in this universe is called ``Gravitation''. If earth is one of the two bodies, then the force of attractions is called gravity, that is, the attraction of the earth on any other body is called gravity. There is a law of Newton about this attraction between any two bodies of the universe is known as Newton's law of gravitation.

We know from the Newton's second law of motion that when a force acts on a body, it acts acceleration. So, acceleration of a body is produced due to the force of gravity as well. This acceleration is called acceleration due to gravity.

The rate of increase of velocity of a freely falling body on earth due to force of gravity is called the acceleration due to gravity. The acceleration due to gravity is represented by the letter g.

The quantities of magnitude of `g' any place on earth is

$$g = \frac{GM}{R^2}$$

Here, M = mass of the earth

G = a universal constant, which is called gravitational constant

R = Radius of the earth

As the earth is not perfectly round, the polar regions are a bit compressed, therefore the radius of the earth R is not constant. Hence the values of `g'' is not the same at all places on earth. The polar radius `R' is the shortest and so the value of `g' at the pole is the maximum. And the value of R is the longest at the equator. So the value of `g' at the equation is the minimum.

Since the value of `g' is different at different places on the surface of the earth, its value at sea level altitude 45° is accepted as the standard value. This standard value of `g' is $9.80665ms^{-2}$. For convenience the standard value of `g' is taken to be $9.8ms^{-2}$ or $9.81ms^{-2}$.

Falling Bodies : If a body is dropped from a certain height, it falls on earth due to the influence of gravity. If a heavy and a light object are dropped from the same height simultaneously, will they reach the ground at the same time ?

In fact, if a piece of stone and a piece of paper are dropped from the same height, it is seen that the stone reaches the ground first. Since the acceleration due to gravity does not dropped on the mass of the body, the acceleration of the stone and that of the paper would be the same. So they should reach at the same time on the earth, but due to the resistance of air two bodies reach at different time on the earth. If there is no resistance of the air, they would fall at the same time.

Laws of falling bodies :

Galilio discovered three laws relating to falling bodies : These are called laws of falling bodies. These laws are applicable only for bodies falling from rest without any resistance. At the time of falling, the body will ``fall from rest, it will have no initial velocity. The body will fall freely without any resistance, that is, no force other than the gravitational force will act on the body. For example, the resistance due to air will not act on it.

Laws of falling bodies are :

First Law : All bodies falling from rest and from the same height without any resistance traverse equal distance in equal time.

Second Law : The velocity *(v),* acquired by a freely falling body from rest in a given time *(t)* is directly proportional to time that is, $v \propto t$

Third Law : The distance *(h)* traversed by a freely falling body from rest in a given time *(t)* is directly proportional to the square of the time, that is, $h \propto t^2$.

Equation of falling Body : Let a body be falling freely due to gravity with initial velocity u. The body attains a velocity v after time t. If the body falls through a distance h in that time and distance s is replaced by h and acceleration a is replaced by accelerate on due to gravity g then the equations of falling body will be as following.

$$v = u+gt$$

$$h = \frac{(u+v)t}{2}$$

$$h = ut + \frac{1}{2}gt^2$$

$$v^2 = u^2 + 2gh$$

Mathematical Example : 2.6 : A body drops from the roof of a building 50m high. With what velocity will it strike the ground.

$g = 9.8 ms^{-2}$

We know, in case of falling bodies

$$\begin{aligned} v^2 &= u^2 + 2gh \\ \text{or } v^2 &= 0 + 2 \text{ x } 9.8 \text{ ms}^{-2} \text{ x } 50\text{m} \\ &= 980\text{m}^2\text{s}^{-2} \\ \therefore v &= 31.3\text{ms}^{-1} \end{aligned}$$

Ans : $31.3 ms^{-1}$

2.7 Motion and Graph

1. Distance-Time Graph : A moving object changes its position with the change of time. The distance traveled by the body depends on time. This relation can be represented graphically. In this case axis `X' in the graph represents time (t) and axis Y represent distance (s). This graph is called distance-time graph. We can find velocity easily by this graph. The methods of determining velocity from the distance-time graph for uniform and non-uniform velocities are discussed below. We will discuss the motion of an object moving only along straight line to avoid the complexities. So the velocity changes only for its magnitude.

(A) In case of uniform Velocity:

Suppose a pollution free CNG run auto-rickshaw is moving along plane straight road. The table below shows the distances traveled after every 12 minutes.

Distance – Time table

Time, *t* (min)	Distance *s* km
0	0
12	6
24	12
36	18
48	24
60	30

Table 2.3

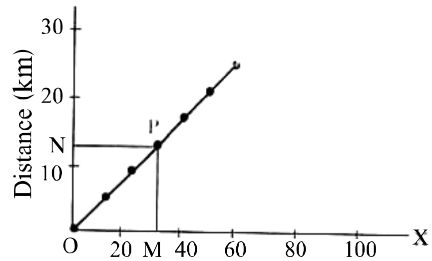


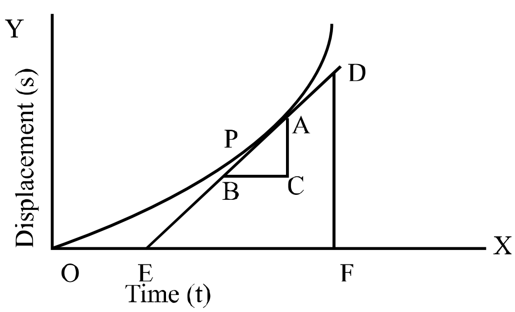
Figure 2.5

For above mentioned motion in the table a distance-time graph shown in fig 2.5. Suppose from the graph we have to find the traveled distance in 32 minute by the auto-rickshaw; we have to mark a point (M) to indicate time, 32 minute on X-axis. Then we have to draw a line parallel to Y-axis from that point on the graph. Let the line at point P. Now draw a perpendicular on Y-axis from P. This perpendicular meets at point N on Y-axis. Therefore, ON is the distance traveled in 32 minutes. The graph shows that the auto-rickshaw travels 16km in this time. Therefore, from graph we find any traveled distance S = PM for any time t = OM.

$\therefore$ Velocity $= \dfrac{\text{distance}}{\text{time}} = \dfrac{PM}{OM} = \dfrac{ON}{OM}$, Here, $\dfrac{PM}{OM}$ is the slope of the OP.

Do by yourself : Take a graph paper. Draw the distance-time graph on the graph paper using any convenient unit mentioned in the table above. Find the distance traveled and velocity of the auto-rickshaw in 32 minutes from the graph. What will be the distance traveled and velocity in 44 minutes.

(B) In case of Non-uniform velocity : Fig 2.6 represents a distance-time graph of a body moving with non-uniform velocity. In this case the body does not move over equal distance in equal intervals of time, so the graph will not be a straight line. It will be a curved line. Since, the body is not moving with uniform velocity, its velocity will not be the same at all instants during its motion. Suppose, the velocity of the body at a particular instant indicated by the point P in the curved line, is to be determined. To determine the velocity at the point P, we will have to consider a very small right angled triangle ABC. Its hypotenuse AB is so small



that it virtually consider with the curved line adjacent to point P. In other words we are considering a part of the curved line which is so small that it may be considered a straight line.

Then the velocity at the point P = $\frac{\text{distant represented by AC}}{\text{time interval represented by BC}}$

or v = $\frac{AC}{BC}$

But it is difficult to get correct result by measuring such a small triangle. So we draw a tangent ED at the point P and draw a greater triangle DEF similar to ABC.

Now from the triangles ABC and DEF We get, $\frac{AC}{BC} = \frac{DF}{EF}$

$\therefore\ v = \frac{DF}{EF}$

But, $\frac{DF}{EF}$ is the slope of ED

Therefore, the velocity at the point P is the slope or gradient of the tangent drawn at that point. Thus it may be said that the gradient of the tangent at any point on the distance-time graph represents the velocity at that point.

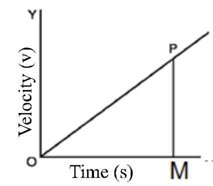
2. Velocity – time graph

The velocity of an object moving with non-uniform velocity depends on time. This relation can be expressed by a graph. In this case time (t) is plotted along X-axis and velocity (v) along Y-axis. This graph is called velocity-time graph. We can find velocity and acceleration i.e. the rate of change of velocity with time from the graph easily. The method of finding acceleration from velocity-time graph in case uniform acceleration is discussed below.

In case of uniform acceleration : When a body moves with uniform acceleration, its velocity increases equally for equal intervals of time. Hence the velocity-time graph will be a straight line (fig 2.7). Now let us take a point P on this graph and draw a normal PM on the X-axis from P. Then the change of velocity PM for any time interval of OM is obtained.

$\therefore$ Acceleration, $a = \dfrac{\text{change of velocity}}{\text{time interval}} = \dfrac{PM}{OM}$

But, $\dfrac{PM}{OM}$ is the slope or gradient of OP



So it is said that the slope of tangent drawn at any point on velocity-time graph represents the acceleration of that point.

Do by yourself : The velocity of a car after every five seconds is given in the table below.

Table : 2.4

Time (s)	Velocity (kmh^{-1})	Velocity (ms^{-1})
0	0	0
5	9	2.5
10	18	5.0
15	27	7.5
20	36	10.0
25	45	12.5
30	54	15.0

Take a graph paper. Draw the velocity-time graph on the graph paper using any convenient unit mentioned in the table above. Find the velocity and acceleration of the car in 12 seconds from the graph.

Investigation: 2.1

Determination of the average speed of a marble rolling over slanting plank.

Objective : To determine the average speed in every case finding time of equal distance traveled in different acceleration.

Apparatus : Plank, meter scale, marble, stopwatch.

Working Procedure :

1. Take a plank long as possible
2. Place brick or book under one end to make it high. So the plank will be inclined with the horizontal
3. Hold a marble at the upper end of the plank and then start the stopwatch the moment you release the marble. Stop the stopwatch the moment it strikes the ground
4. Find the average speed dividing the distance i.e. the length of the plank the marble travels by this time
5. Place more bricks or books at the upper end to make it higher i.e. to make it more sloppy
6. Again find the average speed measuring the time the marble requires to strike the ground.
7. Similarly measure the average speed for different slope of the plank.

Table of observation

Reading	Traveled distance i.e. length of the plank	Time (s)	Average speed $= \frac{\text{distance}}{\text{time}}$ (ms^{-1})
1			
2			
3			
4			
5			
6			
7			

8. Discuss the causes of change of average speed

Investigation:2.2

Demonstration of models of different kinds of motion through different activities.

Objective : To demonstrate the models of different types of motion and observe their differences by the role play of the students.

Apparatus: Long rope, chalk powder or lime.

Working Procedure :

1. Mark a long straight line by chalk powder or lime in your school field or any play ground nearby or stretch out a long rope straightly
2. Now run to the other end along the rope
3. Put a mark at any place of the field and let one stand on the mark. Then let another one hold the right hand of other straightly by his left hand. Third one holds the right hand of second by his left hand. Stand by holding hands successively in this way. It will be a long straight chain like form.
4. If any one outside the chain produces sound all the members start to run slowly centering the first one holding their hands so that the chain does not break or disorder.
5. Stretch a few meter (Suppose 10 meter) long straight rope at one side of the field. Two of you stand at the two ends of the rope and one of you at the middle of it. Now starting from the first one walk towards second and return to first one just touching him without stopping your walk. Again touching first one go to the second one . Repeat it for several times.
6. Note down the characteristics of the motion mentioned in procedure 2 in your copy.
7. Write down the characteristics of motion in your copy mentioned in procedure 4. In this case the motion of all participants are circular and periodic. Example the causes why these motions are circular and periodic breaking the chain.

8. Note down the characteristics of the motion mentioned in procedure 5. In this case motion of all participants are periodic and vibratory. Explain why this motion is periodic and vibratory
9. By this observation compare various kinds of motion and write down their differences.

Investigation: 2.3

Determination of speed of 100 meter race and its graphical analysis

Objectives : To determine the average speed by the traveled distance in different times, draw distance-time graph determine instantaneous speed at any time and average acceleration.

Apparatus : Meter scale, stopwatch, rope or measuring tape

Working procedure :

1. Stretch out a rope straightly at one end of the school play ground (Use any other field if there is no field in the school)
2. Stretch another four ropes each 25 meter distance. So the final rope will be at 100 meter distance.
3. Stand near the first rope and let your four friends stands by the four ropes with stopwatch.
4. Start running with the whistle of your teacher and every one standing will start their stopwatch.
5. When the runner will just cross the rope the respective person will stop his stopwatch. You will find the amount of time from the stopwatch.
6. Find average speed by dividing the distance by time for that time interval.
7. Draw a graph by plotting time (t) along X-axis and distance (d) along Y-axis.
8. Determine the distance traveled at any time, average speed of that time interval and instantaneous speed of that moment from the graph.
9. Draw the graph again and find the instantaneous speed of two separate time and find the average acceleration by dividing the difference of speed.
10. Repeat this experiment walking and running at different speed.
11. Every student will do the experiment in the same way.

Table

Reading	Traveled distance (m)	Time (s)	Average speed = $^{\text{distance}}/_{\text{time}}$
1			
2			
3			
4			
5			
6			
7			

Exercise

A. Multiple choice questions

Put the tick (√) mark on the correct answer

1. What is the unit of acceleration ?

   a) ms^{-1} b) ms^{-2}

   c) NS d) kgs^{-2}

2. What type of motion does the hands of a clock have ?

   a) Linear motion b) Elliptical motion

   c) Periodic motion d) Vibratory motion

3. The distance traveled in a given time by a freely falling body from rest will be

   a) Proportional of the time

   b) Proportional to the square of that time

   c) Inversely proportional to that time

   d) Inversely proportional to the square of that time

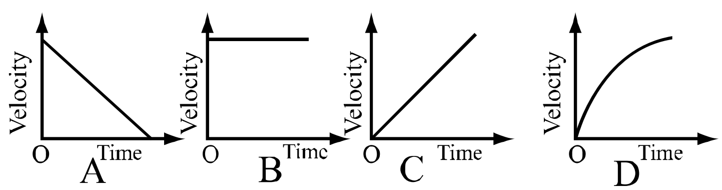
4. A body moves with a uniform acceleration a starting from rest. What will be the traveled distance of the body at a given time ?

   (i) $s = \frac{(u+v)t}{2}$ (ii) $\therefore\ s = ut + \frac{1}{2}at^2$ (iii) $s^2 = u^2 + 2at$

Which one of the following is the correct

   (a) i (b) ii (c) ii & iii (d) i, ii & iii

5. Which one of the velocity-time graph below does represent the graph of freely falling body ?



   (a) A (b) B (c) C (d) D

6. Creative question

Rajib with his family members started for visiting Jaflong in Sylhet by microbus.He recorded the magnitude velocity i.e. speed of the car from the speedometer after every 5min throughout the journey. The magnitude of velocity he got per hour was 18, 36, 54, 45, 54, 36, and 18 kilometer.

   a) What is instantaneous speed ?

   b) Explain the acceleration of an object moving with uniform velocity.

   c) Find the distance traveled by the car in first 5min.

   d) Draw and explain the velocity-time graph by the collected data.