1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 01 (Physics - Part 1, Class XI)
Module Name/Title	Unit 2, Module 3, **Speed and Velocity** Chapter 3, Motion in a Straight Line
Module Id	Keph_10303_eContent
Pre-requisites	Rest and motion frame of reference , graph , basic secondary school mathematics and science course
Objectives	**After going through this module, the learners will be able to** • Recognize the meaning of rate of change of position • Distinguish between speed and velocity • Appreciate zero, negative and positive velocity • Derive the unit of velocity • Explain uniform and non-uniform motion • Understand the need to describe average speed • Justify the term instantaneous velocity • Draw and use velocity time graphs • Relate position time and velocity time graphs
Keywords	Velocity speed average speed instantaneous velocity position time graph, velocity time graphs ,unit of velocity

2. Development Team

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1. UNIT SYLLABUS

Chapter 3: Motion in a straight line

Frame of reference, motion, position –time graph Speed and velocity
Elementary concepts of differentiation and integration for describing motion, uniform and non-uniform motion, average speed and instantaneous velocity, uniformly accelerated motion, velocity –time and position time graphs relations for uniformly accelerated motion - equations of motion (graphical method).

Chapter 4: Motion in a plane

Scalar and vector quantities, position and displacement vectors, general vectors and their notations, multiplication of vectors by a real number , addition and subtraction of vectors, relative velocity, unit vector, resolution of a vector in a plane, rectangular components ,scalar and vector product of vectors

Motion in a plane, cases of uniform velocity and uniform acceleration projectile motion uniform circular motion.

2. **MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 10 Modules**

3. **The above unit is divided into 10 modules for better understanding**.

Module 1	• Introduction to moving objects • Frame of reference, • limitations of our study • treating bodies as point objects
Module 2	• Motion as change of position with time • Distance travelled unit of measurement • Displacement negative, zero and positive • Difference between distance travelled and displacement • Describing motion by position time and displacement time graphs
Module 3	• Rate of change of position • Speed • Velocity • Zero , negative and positive velocity • Unit of velocity • Uniform and non-uniform motion • Average speed • Instantaneous velocity • Velocity time graphs • Relating position time and velocity time graphs
Module 4	• Accelerated motion • Rate of change of speed, velocity • Derivation of Equations of motion
Module 5	• Application of equations of motion • Graphical representation of motion • Numerical

Module 6	• Vectors • Vectors and physical quantities • Vector algebra • Relative velocity • Problems
Module 7	• Motion in a plane • Using vectors to understand motion in 2 dimensions' projectiles • Projectiles as special case of 2 D motion • Constant acceleration due to gravity in the vertical direction zero acceleration in the horizontal direction • Derivation of equations relating horizontal range vertical range velocity of projection angle of projection
Module 8	• Circular motion • Uniform circular motion • Constant speed yet accelerating • Derivation of $a = \frac{v^2}{r} or\ \omega^2 r$ • direction of acceleration • If the speed is not constant? • Net acceleration
Module 9	• Numerical problems on motion in two dimensions • Projectile problems
Module 10	• Differentiation and integration • Using logarithm tables

MODULE 3

4. WORDS YOU MUST KNOW

Let us remember the words we have been using in our study of this physics course

- Rigid body: An object for which individual particles continue to be at the same separation over a period of time.

- Point object: If the position of an object changes by distances much larger than the dimensions of the body the body may be treated as a point object.
- Frame of reference: Any reference frame the coordinates (x, y, z), which indicate the change in position of object with time.

- Inertial frame: It is a stationary frame of reference or one moving with constant speed.

- Observer: Someone who is observing objects.

- Rest: A body is said to be at rest if it does not change its position with surroundings.

- Motion: A body is said to be in motion if it changes its position with respect to its surroundings.

- Time elapsed: Time interval between any two observations of an object.

- Motion in one dimension: When the position of an object can be shown by change in any one coordinate out of the three (x, y, z), also called motion in a straight line.

- Motion in two dimension: When the position of an object can be shown by changes any two coordinate out of the three (x, y, z), also called motion in a plane.

- Motion in three dimension: When the position of an object can be shown by changes in all three coordinate out of the three (x, y, z).

- Distance travelled: The distance an object has moved from its starting position SI unit m, this can be zero, or positive.

- Displacement: The distance an object has moved from its starting position moves in a particular direction.SI unit: m, this can be zero, positive or negative.
- Path length: Actual distance is called the path length.

- Position time, distance time, displacement time graph: These graphs are used for showing at a glance the position, distance travelled or displacement versus time elapsed.

5. INTRODUCTION

In **our previous modules,** we considered rigid bodies changing their position as time elapsed. We are dealing with motion along a straight line (also called rectilinear motion) or motion in one dimension. In one-dimensional motion, there are only three directions back and forth along x- x' y- y' z-z' in which an object can move. We considered notation x(t) to describe the position of particle at instant t.

So z (t) would mean position of the particle along z – z' direction at instant t, this is useful when we have two or more objects moving along x- x' and y- y' simultaneously occupying different positions at the same instant.

https://www.youtube.com/watch?v=iGNPGCPMDhA

Video shows traffic on the road fast and slow movement of vehicles

Think about this do all objects change their position in time at the same pace , the idea of fast and slow is comparative but comes from this basic concept distance covered in a specific time

https://www.youtube.com/watch?v=Vl7dpVeP5Ww

Athletes run 100m race, same distance but each athlete takes different time to cover it

In order to understand how fast or slow we need to find the rate of change of position

https://www.youtube.com/watch?v=MdMtAtSWKIo

Fish in aquarium.

We can assign (x (t), y (t), z (t) as position coordinates for each of the fish in the picture as they move.

In this module we will focus our attention to rate of change of position of an object

6. RATE OF CHANGE OF POSITION

Rate of change of position is speed.

Rate of change of position in a particular direction is velocity.

Both have the same unit m/s.

Mathematically

$$\text{speed} = \frac{\text{distance travelled}}{\text{time}}$$

$$= \frac{X_2 - X_1}{t_2 - t_1}$$

or

$$= \frac{X(t) - X(0)}{t - 0}$$

Unit m/s

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

$$= \frac{X_2 - X_1}{t_2 - t_1}$$

or

$$= \frac{X(t) - X(0)}{t - 0}$$

Unit m/s

Velocity should be reported with direction so we represent velocity with vector, the dimensional formula is the same as speed **M^0LT^{-1}.**

7. ZERO, NEGATIVE AND POSITIVE VELOCITY

The **concept of assigning a positive or negative sign to the velocity of a particle, is needed, and used, for a particle having a one –dimensional motion**.

In general, it can also be used for the component of velocity along any one axis.

By component, you will understand, means **effective in another direction**.

The convention followed, for this purpose, is the standard co-ordinate geometry convention.

The velocity of a particle (or the component of its velocity), along anyone axis of coordinates, will be regarded as

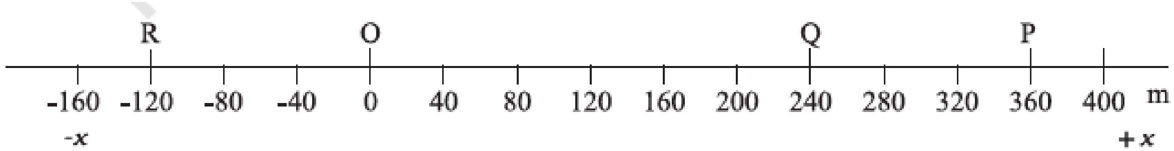
1. **Positive if, (that) coordinate of its position increases with time**
2. **negative if, (that) coordinate of its position decrease with time**
3. **zero if, (that) coordinate of its position does not change with time**

We can also represent speed and velocity graphically.

We have studied distance- time, position -time or displacement- time graphs and we have learnt interdependent functions can be plotted on a graph and the nature of motion can be viewed at a glance.

EXAMPLE

Calculate the speed and velocity in the following cases



a) a car moves from R to Q in 5 h
b) a car moves from O to Q in 3 h
c) a car moves from Q to O in 3h

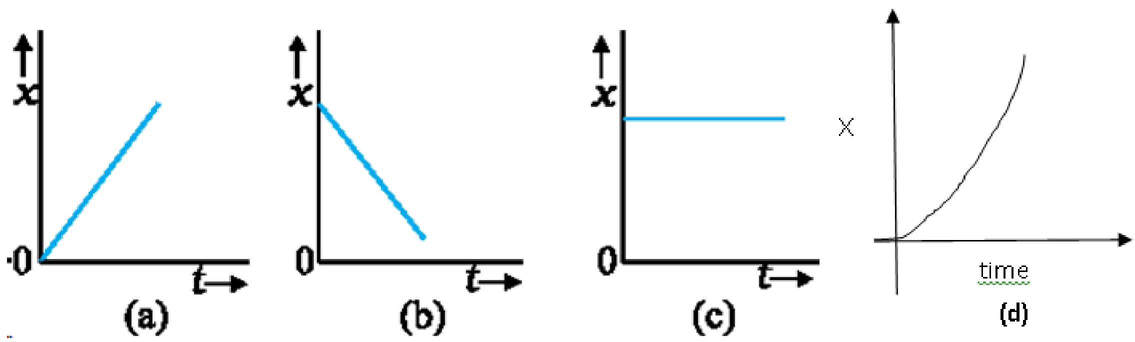
SOLUTION

a) total distance moved by the car =120 +240=360 units so speed $=\frac{360}{5} = 72\ units/h$ velocity 72 units /h towards +x direction

b) speed =240units/3 h=80units/h, velocity +80units/h towards +x direction

c) speed =240units/3 h=80units/h, velocity - 80units/h towards -x direction

TRY YOURSELF



EXAMPLE

Study the position time graphs and answer the questions that follow

a) **Which graph shows the body at rest and why?**

b) Which graph shows the body moving with constant speed?

c) Which graph shows the body moving with NOT constant speed?

EXAMPLE

Use the following tables to plot a graph

Time(s)	Position(m)
0	0
1	2
2	4
3	6
4	8
5	8
6	8
7	6
8	5
9	3

10	2
11	0

From the graph identify the positions/sections

a) **Where the object is moving same distance in same intervals of time**

b) **Where the object is not moving same distance in same intervals of time**

https://www.youtube.com/watch?v=0nvTrySqqVE

In a game of football, each player moves with different speeds and notice most of the time their velocities are very different. This is because the direction in which each player moves is also different

7. UNIFORM AND NON-UNIFORM MOTION

If a body covers equal distances in equal time intervals then it is said to move with uniform speed and its motion is called uniform motion

If the body covers unequal distance in equal time interval then it is said to move with non-uniform speed and its motion is called non-uniform motion.

If the body covers **unequal displacement** in **equal time interval** then it is said to move with **non-uniform velocity** and its motion is called non- uniform motion.

Unequal displacement could be due to

- **magnitude of actual distance travelled**
- **change in the direction in which the object is moving**
  OR
- **due to changes in both of the above**

8. AVERAGE SPEED AND AVERAGE VELOCITY

Objects moving in uniform motion cover equal distance in equal intervals of time, but in non - uniform motion this is not the case. In the latter case we need to define average speed and average velocity

Average speed is the total path length divided by total time interval. This value may or may not be the value of speed at different points during the journey.

$$\text{average speed} = \frac{\text{total path length}}{\text{total time interval}}$$

$$\text{average velocity} = \frac{\text{displacement}}{\text{total time}}$$

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1}$$

$$\bar{v} = \frac{\Delta x}{\Delta t}$$

As magnitude of displacement may be different from the actual path length, the average velocity may be different from average speed

FOR EXAMPLE

Someone who takes 40 minutes to drive 20 km north and then 20 km south (to end up at the same place), has an average speed of 40 km divided by 40 minutes, or 1 km per minute . Average velocity, however, involves total displacement, instead of distance. It is calculated by dividing the total displacement by the time interval. In this example, the driver's displacement is zero, which makes the average velocity zero km/min

EXAMPLE:

A drunkard walking in a narrow lane takes 5 steps forward and 3 steps backward, followed again by 5 steps forward and 3 steps backward, and so on. Each step is 1m long and requires 1 s. Plot the *x-t* graph of his motion. Determine graphically and otherwise how long the drunkard takes to fall in a pit 13 m away from the start

SOLUTION

Use geo geobra app to view the graph

Solution: Click on the geogebra app, you need to download it, its free

Go to view, click, choose spread sheet

Fill the data keeping in mind the position of the man at the end of the time interval example at the end of 5s +3 s the man is at a distance of 5m - 3m = 2m

Select data right click choose create, polyline

The graph generated may be zoomed in or out for better visibility

	A	B	C
1	time	distance	
2	0	0	0
3	5	5	5
4	8	8	2
5	13	13	7
6	16	16	4
7	21	21	9
8	24	24	6
9	29	29	11
10	32	32	8
11	37	37	13
12			
13			
14			

From the tables we set up for the drunkard earlier, we can get the

Average speed $=\frac{\mathbf{37\ m}}{\mathbf{37\ s}}$

and

Average velocity to be $=\frac{\mathbf{13m}}{\mathbf{37\ s}}$

Also, average speed nor average velocity implies a constant rate of motion. That is to say, an object might travel at 10 m/s for 10 s and then travel at 20 m/s for 5 s and then travel at 100 m/s for 5 s. the total distance covered is 700 m in 20 s and the average speed would be 35 m/s and yet at no time during the interval was the speed necessarily 35 m/s.

Let us understand the concept using examples

EXAMPLE

A car is moving along a straight line, say OP as shown in fig. below. It moves from O to P in 18 s and returns from P to Q in 6.0 s. What is the average velocity?

And average speed of the car in going

(a) From O to P?

(b) From O to P and back to Q?

Does the magnitude of average speed differ from average velocity? Give a reason for your answer?

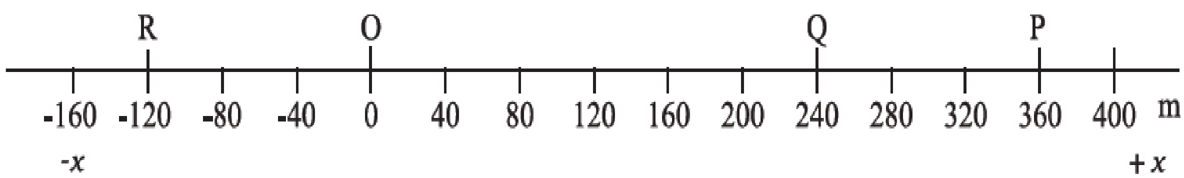


Fig shows X axis, origin and positions of a car at different times

SOLUTION

(a) Average velocity = $\frac{\text{displacement}}{\text{time interval}}$

$$\bar{v} = \frac{+360}{18\ s} = +\ 20\ m\ s^{-1}$$

Average speed = $\frac{\text{path length}}{\text{time interval}}$

$$= \frac{360 \text{ m}}{18 \text{ s}} = \mathbf{20\ ms^{-1}}$$

Thus, in this case average speed is equal to average velocity.

(b) In this case,

$$\text{Average velocity} = \frac{\text{displacement}}{\text{time interval}}$$

$$\bar{v} = \frac{+240}{(18+6)\text{ s}} = +\ \mathbf{10\ m\ s^{-1}}$$

$$\text{Average speed} = \frac{\text{path length}}{\text{time interval}} = \frac{OP+PQ}{\Delta t}$$

$$= \frac{(360+120)\text{ m}}{24\text{ s}} = \mathbf{20\ ms^{-1}}$$

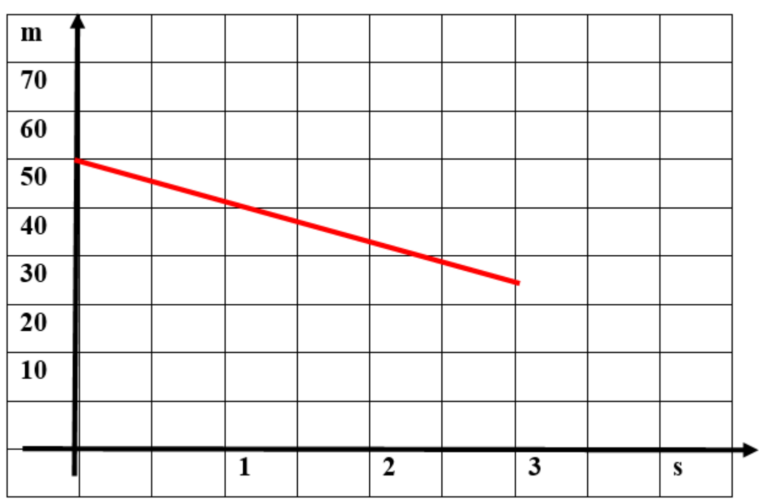
Thus, in this case average speed is not equal to the magnitude of the average velocity.

This happens because the motion here involves change in direction so that the path length is greater than the magnitude of displacement.

This shows that speed is, in general, greater than the magnitude of the velocity

EXAMPLE

The position of a runner as a function of time is plotted as moving along the x-axis of a coordinate system. During a 3.00 s time interval, the runner's position changes from x_1 = 50.0 m to x_2 = 30.5 m. What was the runner's average velocity?



SOLUTION:

Displacement = 30.5 m – 50.0 m = - 19.5 m

(The object was travelling back toward zero)

$$\Delta t = 3.00\ s$$

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{-19.5\ m}{3.00\ s} = -6.50\ m/s$$

9. INSTANTANEOUS VELOCITY

The average velocity does not tell us how fast the object moves at different instants of time during a time interval.

For this,

we define instantaneous velocity or simply velocity *v* at an instant *t*.

At an instant we cannot have any displacement!!!!

Then how do we define it?

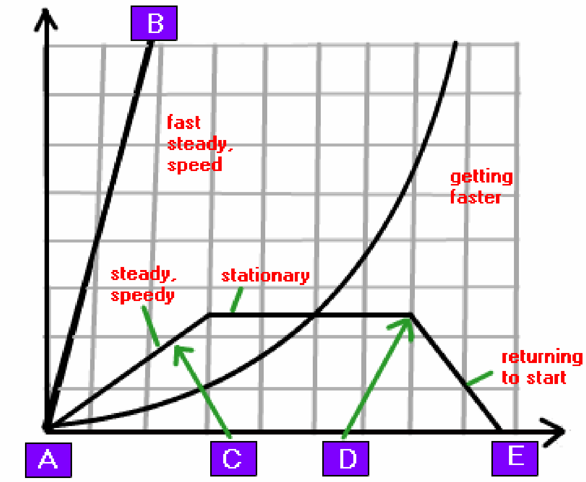
Our vehicles have speedometers which indicate the speed at any instant of time.

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

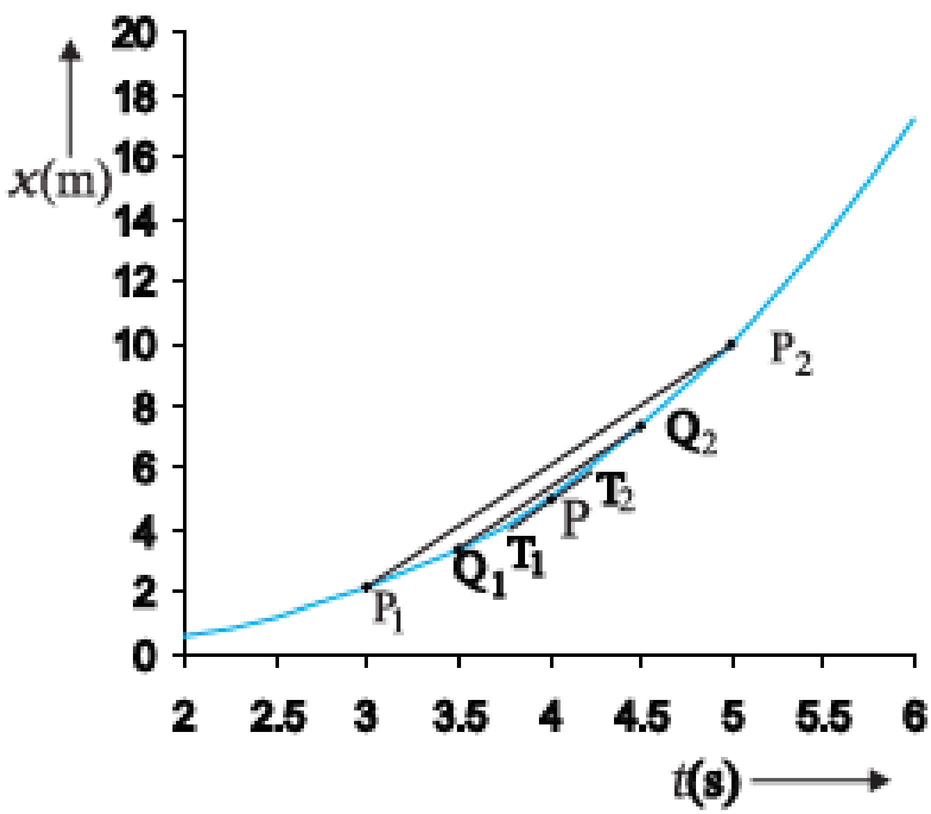
Taking a limit for time interval as small as possible to measure brings us closer to an instant of time.

The value of Δx need not be small , like in the case of speed of light it is 3 x 10^8m in one second and may be 2 cm per second for a snail

Example, consider the graph can you associate any real life example with the three graph lines in black



Calculating instantaneous velocity becomes easier using differential calculus, provided velocity function dependency with time is known.



Determining velocity from position-time graph. Velocity at t = 4 s is the slope of the tangent to the graph at that instant.

The distance time graph shows the position of an object at different instances of time.

To determine the velocity at t = 4 s from the graph

Let us take Δt = 2 s centered at t = 4 s then by definition of average velocity slope of line P_1P_2 gives the value of average velocity over the interval 3 to 5 s, on decreasing the value of Δt from 2 s to 1 s line P_1P_2 becomes Q_1Q_2 on further decreasing the time interval we get T_1T_2 and so on, which is not convenient.

NOT BAD, IF YOU USE CALCULUS.

EXAMPLE

The position of an object moving along x-axis is given by $x = a + bt^2$

Where a = 8.5 m, b = 2.5 m s^{-2} and t is measured in seconds.

a) Check whether the given equation is dimensionally correct

b) What is its velocity at t = 0 s and t = 2.0 s.?

c) What is the average velocity between t = 2.0 s and t = 4.0 s?

SOLUTION

Notice here the distance travelled is given by a polynomial dependent on t, which means its value is changing continuously. Because of this we cannot just divide the distance travelled by time and get the velocity at any instant.

The solution can be obtained using calculus.

$$v = \frac{dx}{dt}$$

$$\frac{d(x^n)}{dx} = nx^{n-1}$$

$$\frac{d}{dx}(constant) = 0$$

$$\frac{d(PQ)}{dx} = P\frac{dQ}{dx} + Q\frac{dP}{dx}$$

Calculus It is the study of continuous change of a function as given by a polynomial , you have seen that geometry is the study of shapes both in a plane and in 3 space and algebra is the study of generalizations of arithmetic operations like addition , subtraction multiplication and division .

Calculus has two major branches, differential calculus (concerning instantaneous rates of change and slopes of curves), and integral calculus (concerning accumulation of quantities and the areas under and between curves

As any other mathematical operation calculus also has its rules.

The three rules are given in the box

$x = a + bt^2$

$\mathrm{v} = \frac{\mathrm{dx}}{\mathrm{dt}} = \frac{\mathrm{da}}{\mathrm{dt}} + \mathrm{t}^2\frac{\mathrm{db}}{\mathrm{dt}} + \mathrm{b}\frac{\mathrm{d}(\mathrm{t}^2)}{\mathrm{dt}}$

i) So $v = 0 + 0 + 2bt$

ii) v = 2 bt m/s

At t = 0, v = 0

And t = 2, v = 10 m/s

iii) Average velocity between t = 2s and t = 4 s

$$v = \frac{X(4) - X(2)}{4 - 2}$$

$$v = \frac{(a+16b)-(a+4b)}{2} = 6\text{ b} \quad \text{or } 15\text{ m/s}$$

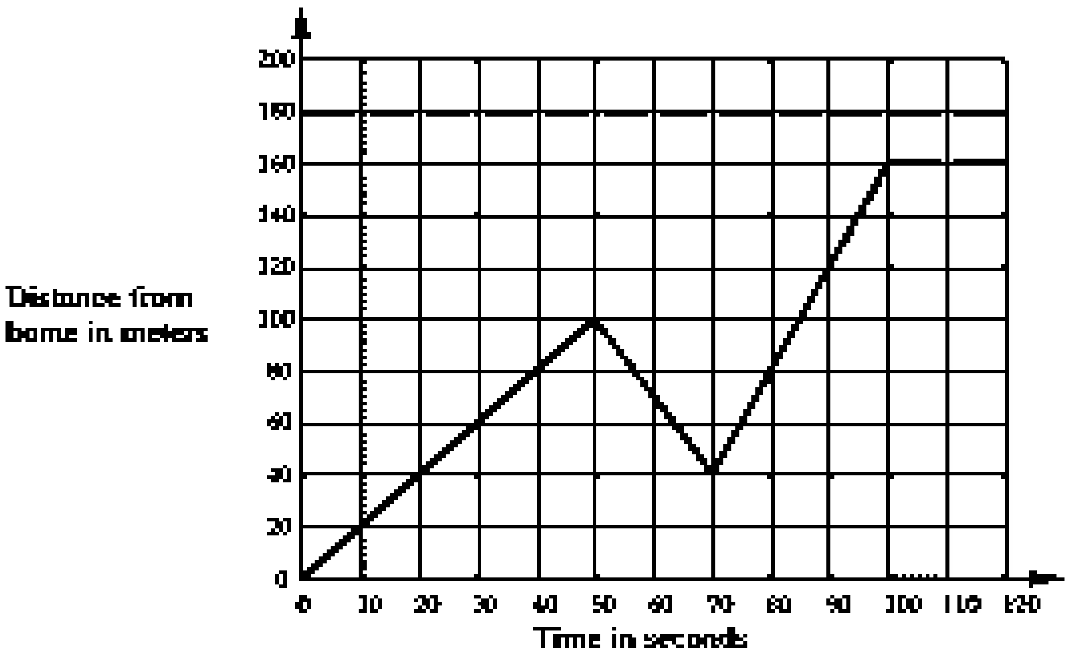
We need to distinguish between average speed and magnitude of average velocity. No such distinction is necessary when we consider instantaneous speed and magnitude of velocity.

The instantaneous speed is always equal to the magnitude of instantaneous velocity in one dimension. Why?

10. RELATING POSITION TIME AND VELOCITY TIME GRAPHS

Speed can be calculated by finding the slope of x-t graph, in case of non-uniform motion the slope of the tangent at any instant can be found.

Graph 1 –



Graph 2 –

We can find the slope of the line at any instant

Graph 1 –

i) What can you say about the slope at time 4 s?

ii) What can you say about the slope at time 11s?

Graph 2

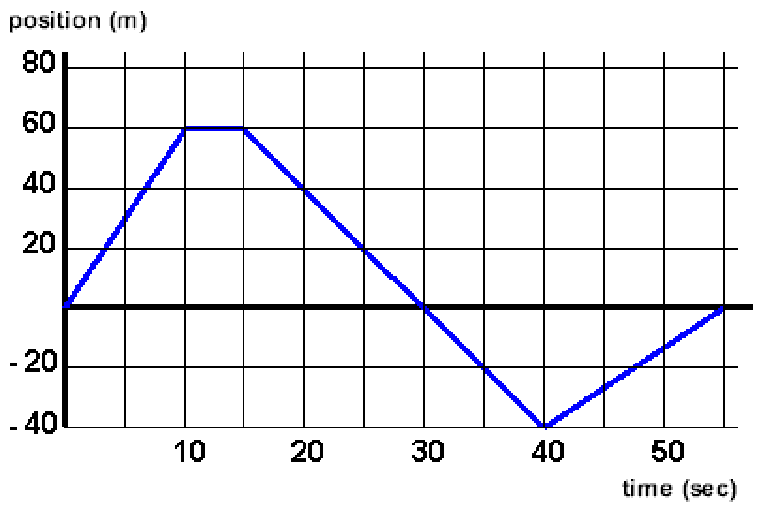
i) Is the speed from 0-50s the same as speed between 50-70s

ii) What about the speed after 100s?

iii) Can you also say the same about velocity? In all the cases.

EXAMPLE

From the given position time graph for a car



i) Is the car stationary in any time interval?

ii) Does it move with constant speed in any time interval?

iii) What can you say about the speed, velocity from 15s to 40 s?

iv) Calculate the average speed and average velocity from the graph.

SOLUTION

a) Yes from 10-15 s

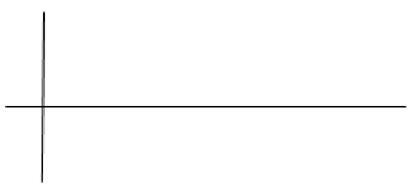
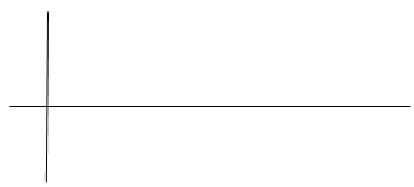
b) Yes `0-10,15-40,40-70s

c) And d) Speed = 100m/(40-15s)=4m/s velocity = - 4 m/s

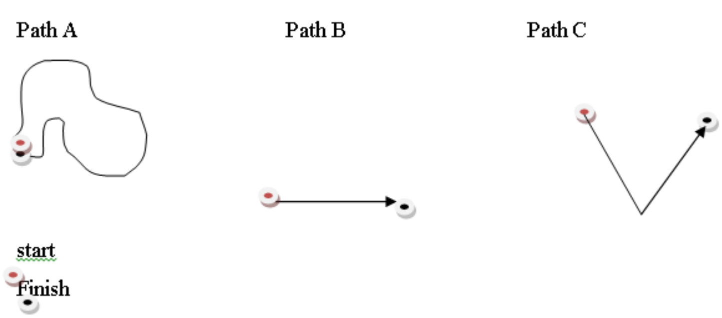
TRY YOURSELF:

1. **Complete the following graphs satisfying the given conditions**

Condition:	Condition:

i) object moves in positive direction ii)object moves with constant velocity a) positive b) negative	i)object moves in negative direction ii)object moves with constant velocity a) positive b) negative
position -time 	position –time 
Velocity –time 	Velocity –time 

2. Suppose that you run for 20s along three different paths



a) Which path has zero displacement?

b) Which path has same displacement?

c) Rank the three paths from lowest average speed to greatest average speed

d) Rank the three paths from lowest average velocity to greatest average velocity.

e) For path C, is the magnitude of average speed the same as the magnitude of average velocity?

1. Use the data to plot graphs using geogebra and predict the nature of motion

3. ***To use geo geogebra app to view the graph optional plot graphs on graph sheets***

Click on the geogebra app, you need to download it, it's free

Go to view, click, choose spread sheet

Fill the data keeping in mind the position at the end of the time interval

Select data right click choose, create polyline

The graph generated may be zoomed in or out for better visibility

Table 1

Position	**Time**
10	**0**
12	**2**
14	**4**
16	**6**
18	**8**

Table 2

Position	Time
5	1
5	2
5	3
4	4

3	5

Table 3

Table 4

Position	Time
0	0
1	1
4	2
9	3
16	4

Position	time
0	5
10	5
20	5
30	5
40	5

Table 5

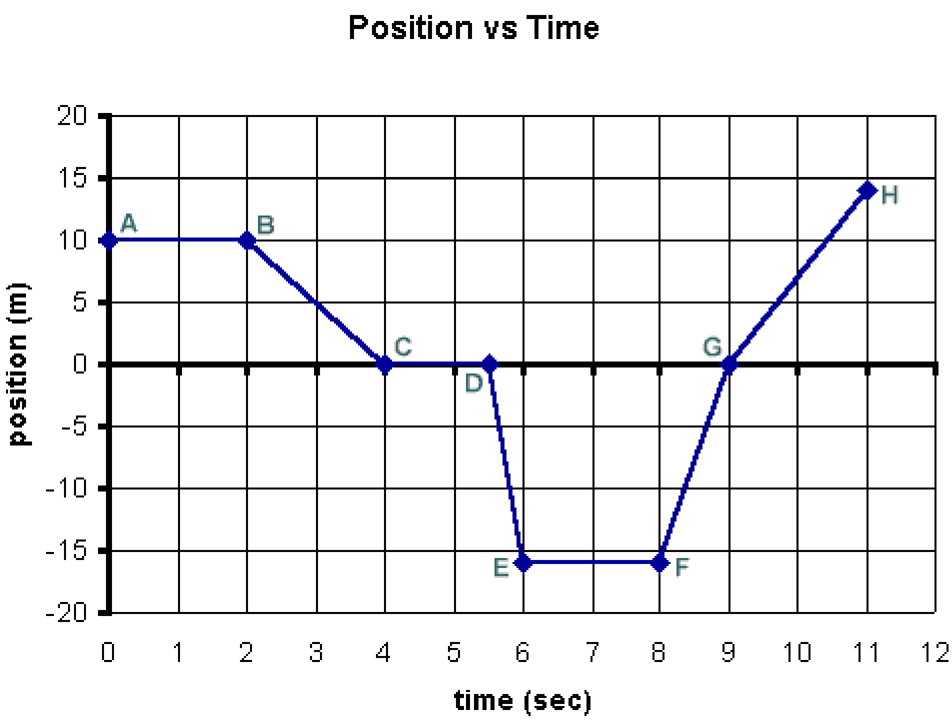
Position	Time
0	0
2	2
4	4
6	6
8	8

4. View the graph

A) write a table draw and check using geo gebra

B) predict whether the body is in uniform or non-uniform motion

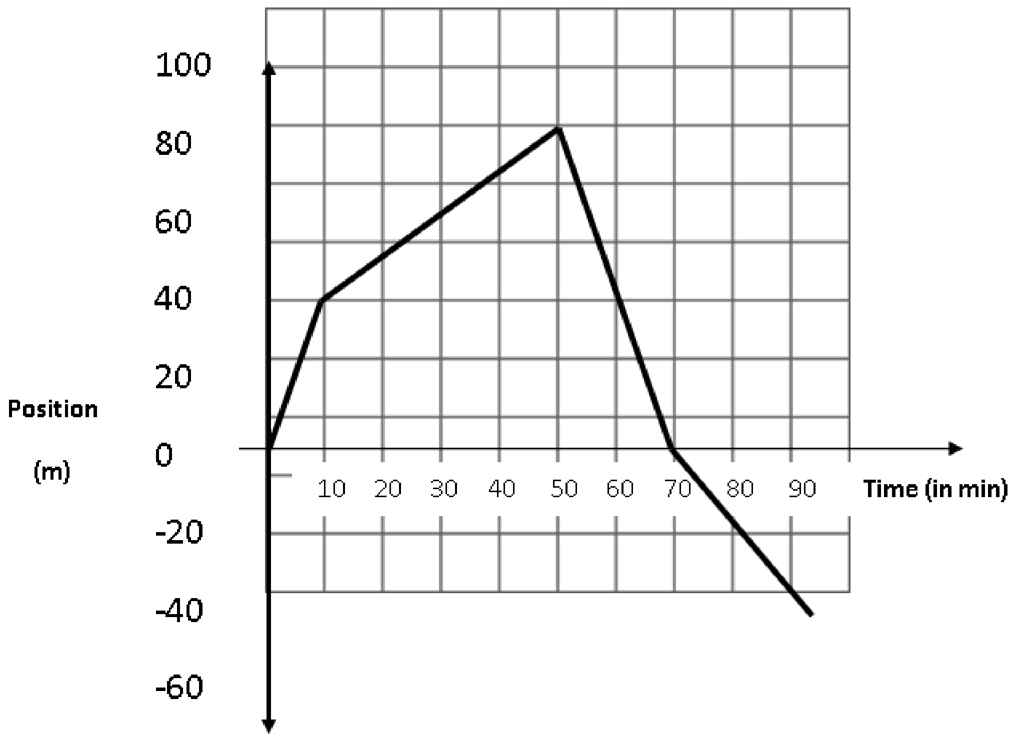
C) find the velocity from each section of the graph



time	position
0	0

5. Study the position time observations in the table given below, and use geogebra to plot and find velocity in each time segment(0-10)s ,(10-50)s…

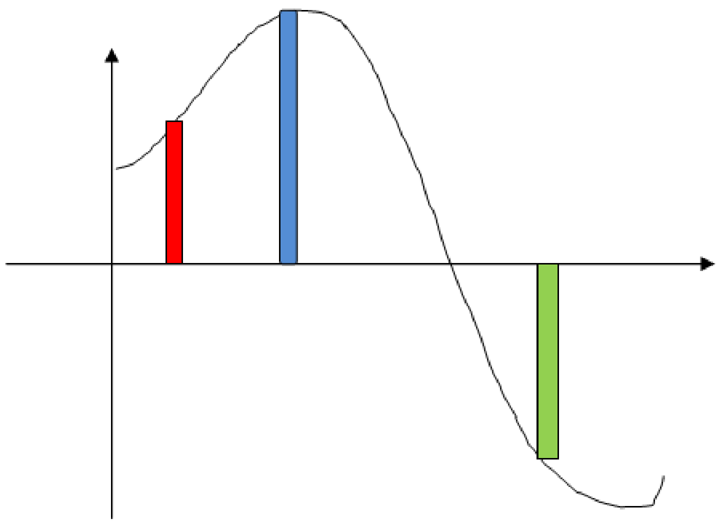
10	40
50	80
70	0
90	- 40



ANSWER THE FOLLOWING QUESTIONS

a) In which segment is the velocity maximum?
b) In which segment is the velocity least?
c) Calculate the distance travelled
d) What is the displacement from initial position?
e) Calculate the average speed
f) Calculate the average velocity

6. (x-t) graph of a particle in one dimensional motion is as shown. Three different equal intervals of time are red, blue and green. In which interval is the average speed greatest, and in which is it the least? Give the sign of average velocity for each interval



11. SUMMARY

In this module we have learnt

- Any object for which the motion as a whole can be described by any point on it, can be treated like a point object
- The rest and motion are always with respect to a reference frame, we are only considering a stationary frame, the three coordinate axis or a coordinate axis frame which moves with constant velocity
- A body may move in one dimension, two dimension or three dimension, the position coordinates will change in one or two or all three x, y, and z coordinates.
- In one dimensional motion the path length between a final and an initial position of the object is called distance travelled. it is always positive and unit is m
- Displacement is the difference between the ending position and starting position of motion. It is a vector quantity. It could be zero , positive or negative
- Speed is the rate of change of position. it is a scalar quantity unit is m/s
- Velocity is the rate of change of position in a particular direction It is vector quantity.

- Average speed can be computed finding the total distance divided by the total time or by a weighted average.
- The slope of a line in the position-time graph represents velocity.
- Instantaneous velocity is the velocity at an instant *t*, defined as the limit of the average velocity as the time interval Δt becomes infinitesimally small
- In uniform motion, velocity is the same as the average velocity at all instants.