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# Chapter # 02
# Kinematics

**Q1. Define Mechanics and Kinematics.**

**Ans.** **Mechanics:**

The branch of physics which deals with the study of motion of objects is called **Mechanics.** Atwood machine, lever, projectile motion and inclined plane are some examples where mechanics is applied.

**Kinematics:**

It is the branch of mechanics where we study motion of bodies without concerning the forces that can cause or change the motion of bodies.

**Q2. Define terms rest and motion. Show with the help of examples that state of rest and motion are not absolute but relative to observer.**

**Ans.** **Rest:**

A body is said to be in state of rest if it does not change its position with respect to its surroundings or an observer.

**Motion:**

A body is said to be in state of motion if it changes its position with respect to its surroundings or an observer.

**Examples:**

1. A flying bird
2. A moving car
3. A running boy etc.

**Rest and Motion are Relative:**

The rest and motion are not absolute. Both are relative because they need specification of observer.

**Explanation:**

Objects can be at rest and in motion at the same time. Sometimes it happens that a body "A" will be at rest with respect to body "B" but at the same time it will be in motion with respect to body "C". So for same events two observers can have different observations.

**Examples:**

1. A person travelling by train is at rest with respect to its fellow passenger but the same person is in motion with respect to all the bodies outside the train. Thus, the motion and rest are not absolute but relative. This means that we have to specify the observer while telling about the rest or motion of the body.

2. Similarly, a person standing on surface of earth is in state of rest with respect to earth but in state of motion with respect to moon, planets, sun and other stars. This shows that rest and motion not absolute are relative to observer.

**Q3. Differentiate between translational, rotatory and vibratory motion.**

**Ans:** **Types of Motion:**

| Translational Motion | Rotatory Motion | Vibratory Motion |
|---|---|---|
| Motion in which all points of body move along a straight or a curved path without changing orientation. | Spinning motion of a body in which it rotates about a fixed axis passing through it. | To and fro motion of a body about a mean position. |
| All particles move parallel to each other and cover same distance | All particles move in a circular path and cover different distances. | Particles of body cover all the points of path repeatedly |
| **Examples:** Car moving on a straight road, flying birds and motion of aeroplane. | **Examples:** Spinning of earth about its axis, spinning top, rotating wheel of a bicycle. | **Examples:** Children in a see-saw, baby in a cradle, pendulum, and strings of a guitar. |

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**Q4. Differentiate between rectilinear motion, curvilinear motion and random motion.**

**Ans.** These are the types of translational motion and differentiated as follows.

| Rectilinear Motion | Curvilinear/Circular Motion | Random Motion |
|---|---|---|
| The straight line motion of a body is called rectilinear motion | The motion of a body along a curved path about a point lying outside is called curvilinear motion. | Disordered or irregular motion of a body is called random motion. |
| **Examples:** Car moving on a straight road, flying birds and motion of aeroplane are | **Examples:** Satellite orbiting around a planet, stone attached to a string, a stone thrown in the air at an angle. | **Examples:** Brownian motion of gas particles, motion of butterfly, |

**Q5. Differentiate between circular motion and rotatory motion.**

**Ans.**

| Circular motion | Rotatory motion |
|---|---|
| It is the motion of the body on a curved path about a point lying outside the body. | It is the spinning motion of body around a fixed axis which lie inside the body |
| The radius of all particles of body remain almost same and there is no change in orientation. | The radius of all particles of body is not same so body changes its orientation constantly. |
| **Examples:** Satellite orbiting around a planet, stone attached to a string, car moving on a curved track, Riders in a ferris wheel. | **Examples:** Spinning of earth about its axis, spinning top, rotating wheel of a bicycle. |

**Q6. What is position?**

**Ans:** **Position:**

The location of an object relative to some reference point (origin) is known as position of that object.

**Explanation:**

Position of an object can be described in rectangular coordinate system where origin O can serve as a reference point. In the given figure, the position of an object at any point "P" is $(x, y)$ where $x$ and y are known as coordinates of point P.

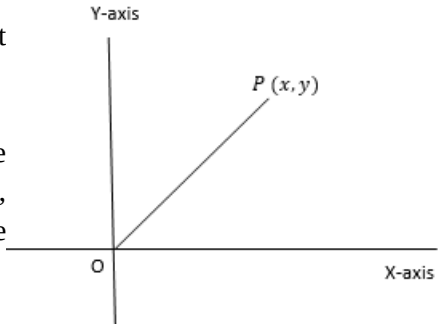


*Figure 1. Position*

**Q7. Differentiate between distance travelled and displacement.**

**Ans.**

| Distance | Displacement |
|---|---|
| The length of actual path covered between initial and final position by a body is called distance | The length of shortest path between initial and final position is called displacement. |
| It has magnitude only, so it is a scalar quantity. | It does have a direction with magnitude, so it is a vector quantity. |
| It can be greater than or equal to displacement | Its magnitude can be equal to distance but cannot be greater. |
| When a body follow a path and comes back to initial position, it has a non-zero magnitude. E.g. on a circular track when a body starts moving and covers whole circular path, its initial and final positions are same then distance travelled is equal to circumference of circle ($2\pi r$). | When a body follow a path and come back to initial position, its magnitude is zero. E.g. on a circular track when a body starts moving and covers whole circular path, its initial and final positions are same then displacement is zero because the length of shortest path is zero meters. |
| It is always positive. | It can be positive or negative both. |

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**Q8. Differentiate between speed and velocity.**

**Ans.**

| **Speed** | **Velocity** |
|---|---|
| The change of distance per unit change in time is called speed | The change in displacement per unit change in time is called velocity |
| It has magnitude only, so it is a scalar quantity. | It does have a direction with magnitude, so it is a vector quantity. |
| **Example:** A car travelling at 60 km/h | **Example:** A car travelling 60 km/h towards north. |
| On a curved track speed is uniform if its magnitude does not change. | On a curved track velocity cannot be uniform, because direction keeps on changing. |
| Can be calculated as $v = \frac{\Delta s}{\Delta t}$ where Δs is change in distance | Can be calculated as $\vec{v} = \frac{\Delta \vec{s}}{\Delta t}$ where $\Delta \vec{s}$ is change in displacement. |

**Q9. Differentiate between average and instantaneous speed.**

**Ans.**

| **Average Speed** | **Instantaneous Speed** |
|---|---|
| The total distance covered per total time taken between initial and final position is called average speed. | Speed at any instant of time is called instantaneous speed. |
| Can be calculated as $v_{av} = \frac{s}{t}$ where s is total distance covered and t is total time taken | Can be calculated as $v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t}$ Limit $\Delta t \to 0$ shows that time interval is small, such as it approaches to zero. |
| It is an average measure of how fast an object moved throughout its journey. | It is like taking snapshot of speed at exact movement at a point and measured using speedometer. |

**Q10. Differentiate between uniform speed and non-uniform speed.**

**Ans.**

| **Uniform Speed** | **Non-Uniform Speed** |
|---|---|
| If speed of a body does not change with passage of time, it has uniform speed | If speed of a body changes with passage of time, it has non-uniform speed. |
| When speed is uniform, instantaneous speed and average speed are equal. | When speed is non-uniform, instantaneous speed can be less than or greater than average speed. |
| Body covers equal distance in equal intervals of time | Body covers unequal distance in equal intervals of time. |

**Q11. Differentiate between instantaneous velocity and Average velocity.**

**Ans.**

| **Average velocity** | **Instantaneous velocity** |
|---|---|
| It is total displacement covered in total time taken between initial and final position. | It is the velocity during a very small interval of time. |
| Can be calculated as $\vec{v}_{av} = \frac{\vec{s}}{t}$ where $\vec{s}$ is total displacement and t is total time taken | Can be calculated as $\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{s}}{\Delta t}$ Limit $\Delta t \to 0$ shows that time interval is small, such as it approaches to zero. |
| It is average measure of how fast and in which direction an object moved | It is like taking snapshot of speed and direction at the same time. |

**Q12. Differentiate between Uniform and non-uniform velocity.**

| Uniform Velocity | Non- uniform/variable Velocity |
|---|---|
| If velocity of a moving body does not change with passage of time, it has uniform velocity. | If velocity of body does not change with passage of time, it has non-uniform velocity. |
| When velocity is uniform, average velocity and instantaneous velocity are equal. | When velocity is non-uniform, instantaneous velocity can be less than or greater than average velocity. |
| Magnitude of velocity and direction both remain same. | If anyone of the magnitude and direction changes, then velocity becomes non-uniform. |
| Body covers equal displacement in equal intervals of time | Body may cover unequal displacement in equal interval of time. |

**Q13. Define acceleration. How can we calculate acceleration?**

**Acceleration:**

The measure of change in velocity "$\Delta v$" with the passage of time "$\Delta t$" is called acceleration.

Or

Time rate of change of velocity is called acceleration.

**Mathematical Form:**

Mathematically, it can be written as:

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\overrightarrow{v_f} - \overrightarrow{v_i}}{\Delta t}$$

**Quantity and unit:**

Acceleration is a vector quantity and its SI unit is meter per second squared $or\ ms^{-2}$.

**Q14. Differentiate between uniform and non-uniform acceleration.**

**Ans.**

| Uniform Acceleration | Non-Uniform/variable Acceleration |
|---|---|
| A body is said to be moving with uniform acceleration, if equal change occurs in velocity in equal intervals of time. | A body is said to be moving with variable acceleration, if unequal change occurs in its velocity in equal intervals of time. |
| With uniform acceleration, a car speeding up on a straight road gains the same amount of speed in every second. | With non-uniform acceleration, the speed of car can increase at faster rate initially and then can increase at slower rate and vice versa. |
| In velocity-time graph, it is represented by a straight line inclined at horizontal axis | In velocity-time graph, it is represented by a curved line. |

**Q15. Differentiate between Positive and negative acceleration.**

**Ans.**

| Positive Acceleration | Negative acceleration/deceleration/retardation |
|---|---|
| If the magnitude of velocity increases with the passage of time, such type of acceleration is called positive acceleration. | If the magnitude of velocity decreases with the passage of time, such type of acceleration is called negative acceleration. |
| Direction of acceleration is same as direction of motion. | Direction of acceleration is opposite to the direction of motion. |
| **Example:** A car starts from rest and its speed increases along a straight line with the passage of time then the car is said to have positive acceleration. | **Example**: A car is moving with a certain speed then brakes are applied which decreases the speed of car, then the car is said to have negative acceleration. |

**Q16. What is free fall? what is its value near the surface of earth. Explain with example that rock and sheet of paper will fall at the same rate without air resistance.**

**Ans:** **Free Fall:**

The motion in which air resistance is neglected and the acceleration is nearly constant is known as free-fall.

**Explanation:**

The acceleration produces in a freely falling body due to attraction of earth is called acceleration due to gravity or gravitational acceleration. It is denoted by "g".

According to famous scientist Galileo, In the absence of air resistance, when bodies of different masses (light or heavy) are dropped at the same time from the same height then they fall towards earth with the same acceleration.

Furthermore, if the distance of the fall is small compared to the radius of earth, the acceleration can be considered constant throughout its fall.

**Value of "g":**

The value of "g" near the earth's surface is approximately "9.8 $m/s^2$" or "32.2Ft/$s^2$" and its value is constant for all bodies. It is directed downward towards the centre of the earth.

**Example:**

If we drop a rock and sheet of paper from the top of tube at the same time. It is found that in the presence of air resistance, rock is falling faster than a sheet of paper. The effect of air resistance is responsible for slower fall of the paper. When air is removed from the tube, both the rock and the paper have exactly the same acceleration due to the gravity. So, in the absence of air, the rock and the paper fall freely as shown in figure.

**Conditions:** While using these equations of motion there are two conditions.

1. If a body is thrown vertically downward, its initial velocity ($v_i$) will be zero and the value of "g" will be positive.
2. If a body is thrown vertically upward, its final velocity "$v_f$" will be zero and the value of "g" will be negative because with altitude, the value of "g" decreases.

**Q17. What is meant by graph and discuss how the slope of a graph can be calculated?**

**Ans:** **Graph:**

A graph is a pictorial way of presenting relationship between two physical quantities.

**Explanation:**

Usually, a graph contains horizontal and vertical lines at equal distances and coordinate systems to show relationship in various quantities. The horizontal lines are called x-axis while the vertical lines are called y-axis. The point of intersection of these two lines are called origin "O".

**Slope of Graph:**

The slope of graph means vertical coordinate difference divided by horizontal coordinate difference.

**Mathematical Form:**

Mathematically, it can be written as:

$$slope = \frac{\Delta y}{\Delta x}$$

Or

$$slope = \frac{y_f - y_i}{x_f - x_i}$$

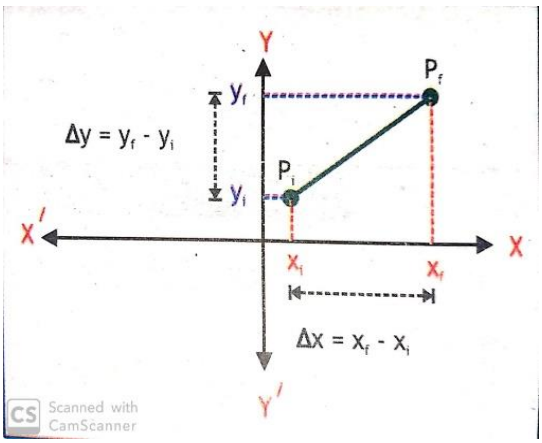


*Figure 2. slope*

**Calculation of slope of a graph:**

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The slope of a graph in Cartesian coordinate system can be calculated as,

1. Pick two points $P_i$ and $P_f$ on the line.
2. Determine the coordinates i.e. Pi $(x_i, y_i)$ and $P_f$ $(x_f, y_f)$ by drawing perpendicular on *x* and y-axis from both points.
3. Determine the difference between *x*-coordinates ($\Delta x = x_f - x_i$) and y-coordinates ($\Delta y = y_f - y_i$)
4. Dividing the difference in y-coordinates by difference in *x*-coordinates gives slope. i.e.

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{y_f - y_i}{x_f - x_i}$$

**Q18. Show that slope of distance-time graph gives speed.**
**Ans.** Follow page 50 on NBF book.

**Q19. Draw and explain the distance-time graph using concept of slope for body at rest, moving with constant speed, moving with increasing speed, and moving with decreasing speed.**
**Ans.** Follow page 51 on NBF book.

**Q20. Show that slope or gradient of speed-time graph gives magnitude of acceleration.**
**Ans.** Follow page 53 on NBF book.

**Q21. Show that area under speed-time graph gives distance travelled.**
**Ans.** Follow page 54 on NBF book.

**Q22. Draw and explain the speed-time graph using concept of slope for body at rest, moving with constant speed, moving with increasing speed, and moving with decreasing speed.**

**Ans.** **Speed-time graph of Body at Rest and zero acceleration:**

Line with zero height and zero slope represents a body at rest as shown in figure 3. It shows that time is changing but there is no value of speed on y-axis. Since there is no slope, so acceleration is also zero.

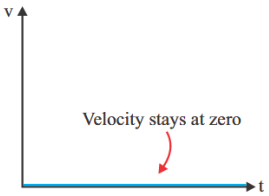


*Figure 3. Speed-time graph for body at rest*

**Speed-time graph of body moving with uniform speed and zero acceleration:**

A straight horizontal line parallel with time-axis at some height as shown in figure 4 represents a body moving with uniform speed. Since slope is zero, so again acceleration is zero in this case.

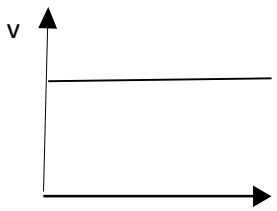


*Figure 4. Speed-time graph of body moving with uniform speed*

**Speed-time graph of body moving with uniformly increasing speed or uniform acceleration:**

A straight line inclined at time-axis with constant slope as shown in figure 5 represents a body moving with uniformly increasing speed or uniform or constant positive acceleration. If line is inclined at negative speed axis then it represents uniform deceleration.

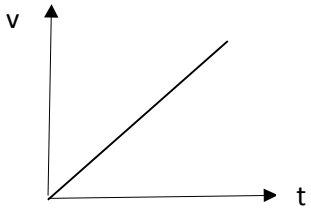


*Figure 5. Speed-time graph of body moving with uniform acceleration*

**Speed-time graph of a body whose positive acceleration is decreasing:**

A curved line whose slope decreases with time as shown in figure 6 represents motion of a body whose acceleration decreases with time. In this case time rate of change in speed decreases.

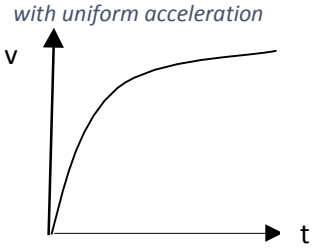


*Figure 6. Speed-time graph of body moving with decreasing acceleration*

**Speed-time graph of a body whose positive acceleration is increasing:**

A curved line whose slope increases with time as shown in figure 7 represents motion of a body moving with increasing acceleration. In this case rate of change in speed increases.

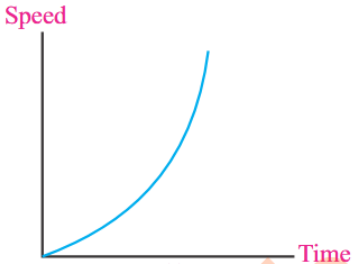



*Figure 7 Speed-time graph of a body moving with increasing acceleration*

## CONCEPTUAL QUESTIONS

**1. In a park, children are enjoying a ride on ferris wheel as shown. What kind of motion the big wheel has and what kind of motion the riders has?**

**Ans.** As the big wheel is rotating about its own axis, it has rotatory motion. Riders are revolving around an axis lying outside their body, so they have translational and circular motion.

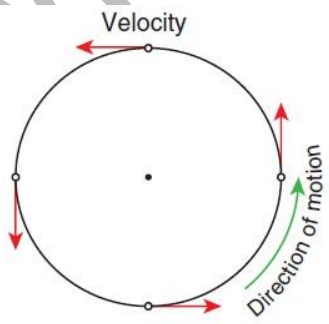
**2. A boy moves for some time, give two situations in which his displacement but covered distance is not.**

**Ans.** i) If the boy moves in forward direction and covers some distance then comes back to its starting position then distance will have a non-zero value but displacement will be zero.

ii) If the boy starts moving on a circular track, covers whole circular track and then reaches to starting point then distance will be equal to circumference of circle ($2\pi r$) but displacement will be zero.

**3. A stone is tied to a string is whirling in circle, what is the direction of velocity at any instant?**

**Ans.** The direction of motion of the stone is along circular path but direction of velocity is always tangent to the circular path




**4. Is it possible to accelerate an object without speeding it up or slowing it down?**

**Ans.** Yes. When an object moves on a curved track without changing the magnitude of its velocity, the direction of velocity keeps on changing which produces acceleration.

**5. Can a car moving towards right have direction of acceleration towards left?**

**Ans.** Yes, if a car moving towards right is slowing down then its acceleration will be negative and its direction will opposite to direction of motion of car i.e. towards left.

**6. With help of daily life examples, describe the situation in which:**

**a. Acceleration is in direction of motion.**

**b. Acceleration is against direction of motion.**

**c. acceleration is zero and body is in motion.**

**Ans.** Lets consider a moving car

**a.** When accelerator is pressed, car speeds up then acceleration will be positive than direction of motion and direction of acceleration will be same.

**b.** When breaks are pressed then car will slow down, acceleration will be negative then direction of acceleration will be opposite to the direction of motion.

**c.** When car moves with constant velocity then acceleration is zero but car is in motion. Because acceleration is change of velocity per unit time, not velocity per unit time.

**8. Which control in car can produce acceleration or deceleration in it?**

**Ans.** Accelerator in the car produces acceleration and break produces deceleration.

**9. If two stones of 10 kg and 1 kg are dropped from a 1km high tower, which will hit the ground with greater velocity?**

**Ans.** Both will hit the ground at the same time with same velocities, because they fall freely under action of gravity with acceleration due to gravity, which does not depend on mass of objects if air resistance is neglected.

**10. A 100 g ball is just dropped and another is thrown downward with velocity of 10 m/s, which will have greater acceleration?**

**Ans.** Both will have same amount of acceleration. As soon as both balls are released they fall under action of gravity with gravitational acceleration 9.8 $ms^{-2}$. Only difference will be that the ball with initial velocity 10 m/s will have greater final velocity.

**11. Is it possible that displacement is zero but not the distance? Under what condition displacement will be equal to distance.**

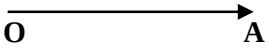
**Ans: (a)**
Yes, it is possible that the displacement is zero but not the distance if the initial and final point of a moving body are at the same place.

**For example:**


In figure ABCD, displacement is zero because starting and ending point is same i.e. "A" but distance covered by the body is ABCD which is the actual path of the body.

**(b)** The magnitude of distance and displacement will be equal when a body moves in a straight line because displacement is the shortest distance between two points in a straight line.

**For Example:**




In the given figure, a body moves from point "O" to "A". Now, in this case distance and displacement are equal.

**12. Does a speedometer measure a car's speed or velocity?**

**Ans:** As we know that speed is a scalar quantity. It has magnitude only but having no direction while velocity is a vector quantity and it has magnitude as well as direction. The speedometer of a car

displays only magnitude i.e. speed of a car but it does not tell us about the direction of the car. Thus, the speedometer measures only the speed of the car but not its velocity.

**13. Is it possible for an object to be accelerating and at rest at the same time? Explain with example.**

**Ans:** Yes, it is possible for an object to be accelerating and at rest at the same time.

**For example:**

If a body of mass "m" is thrown vertically upwards with initial velocity "vi" then it comes to rest after reaching at highest point. So, at that point, its final velocity "vf" becomes zero but forces acting on it will not be zero and still the body possess certain acceleration which is known as acceleration due to gravity i.e. $R = -9.8\ m/s2\cdot$ In such case, the acceleration will be negative because it is opposite to the direction of velocity.

**14. A person standing on a roof of a building throws a rubber ball down with a velocity of 8.0 m/s. What is the acceleration (magnitude and direction) of the ball?**

**Ans:** When a person throws a ball from the top of a building, the ball will fall towards earth due to force of gravity. According to famous scientist Galileo, all bodies falling towards earth with a constant acceleration of g=9.8m/s$^2$. So, if we ignore the air resistance, then the ball will fall freely with acceleration due to gravity "g". Its magnitude will be 9.8 m/s$^2$ and it will be directed towards earth.

**15. Describe a situation in which speed of an object is constant while velocity is not.**

**Ans:** A situation in which the speed of an object is constant while the velocity is not constant may be that of circular motion. For example, a body moving along a circular path may have a constant (uniform) speed. But its velocity is not constant because the direction of velocity changes at each point continuously during circular motion.

**16. Can an object have a northward velocity and a southward acceleration? Explain.**

**Ans:** Yes, it is possible for an object to have northward velocity and a southward acceleration in the following situations.

1. When a body is coming to the rest.
2. When the speed of a body is decreasing.

**Example:**

If a car is moving towards north and gradually its velocity decreases by applying breaks. Then, negative acceleration (deceleration) will produce which is opposite to the direction of the velocity. In this case, the acceleration produced will be acting towards south.

**17. As a freely falling object speeds up, what is happening to its acceleration does it increase, decrease, or stay the same?**

**Ans:** In the absence of air resistance, all bodies falling towards earth with a constant acceleration. So, for freely falling objects, the speed of the body increases uniformly at the rate of 9.8 m/s$^2$. Thus, the acceleration of the body does not increase, or decrease but remains constant during free-fall motion. i.e. we take g = 9.8 m/s$^2$ as a constant value for free-fall objects.

**18. A ball is thrown upward with an initial speed of 5m/s. What will be its speed when it returns to starting point?**

**Ans:** If a ball is thrown vertically upward with an initial speed of 5m/s, then in the absence of air resistance, the ball will return back to its starting point with the same speed of 5m/s. Because, in upward and a downward, the only force acting on ball is gravitational pull of earth.

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**Assignment Questions**

**1.** A stone dropped from the top of a really tall tower. Let us not worry about the wind and assume gravity pulls it down at a steady 10 m/s². How much time taken by the stone to gain a speed of 100 m/s? (10sec)

**2.** An object drops from a still helicopter and when it lands, it is going 30 m/s. How long did it take for the object to hit the ground and how much distance did it cover in that time? (ignore air effects) (3sec, 45m).

**3.** A cat jumps off a ledge and hits the ground in half a second?
(a) How fast is it going when it hits the ground?
(b) What is its average speed during the jump?
(c) How tall is the ledge? (5m/s, 2.5m/s ,1.25m)

**4.** On the speedometer of a car which starts from rest, if you record the speed of 50 km/h attained in half an hour, what is your average speed? (25km/h)

**5.** In the above question, find the distance covered by the car in half an hour. (25km)

**6.** If you drive 100 kilometres in 2 hours, stop for 1 hour, then drive another 100 kilometers in 2 hours, what is your average speed for the entire journey? (40km/h)

**7.** If an athlete runs 400 meters in 50 seconds and then walks 200 meters in 150 seconds, Estimate the instantaneous speed in 50 seconds. (8 m/s)

**8.** What is your average speed if you walk 10 meters forward and then 10 meters backward in 20 seconds? Also fine average velocity on reaching back to the initial point. (1m/s ,0)

**9.** An object is at rest for 5 seconds, then moves with a constant speed of 10 m/s for 10 seconds, and finally accelerates at 2 $m/s^2$ for another 5 seconds. Sketch the speed time graph.