NUMERICAL QUESTIONS

1. Write the number in prefix to power of ten **a.** Mechanical nano-oscillators can detect a mass change as small as 10^{-21} kg. **b.** The nearest neutron star (a collapsed star made primarily of neutrons) is about 3.00×10^{16} m away from Earth. **c.** Earth to sun distance is 149.6 million km

2. An angstrom (symbol Å) is a unit of length (commonly used in atomic physics), defined as 10^{-10} m which is of the order of the diameter of an atom.
   - a. How many nanometers are in 1.0 angstrom?
   - b. How many femtometers or fermis (the common unit of length in nuclear physics) are in 1.0 angstrom?
   - c. How many angstroms are in 1.0 m?

3. The speed of light is c = 299,792,458 m/s.
   - a. Write this value in scientific notation.
   - b. Express the speed of light to
     - i. five significant figures, ii. three significant figures.

4. Express the following in terms of powers of 10.
   - a. 7 nanometre b. 96 megawatt c. 2 gigabite
   - d. 43 picofarad e. 2 millimetre.

5. Write the following numbers in standard form:
   - a. Mass of Bacterial cell: 0.000,000,000,005 kg
   - b. Diameter of Sun: 1,390,000,000 m

WEB LINKS

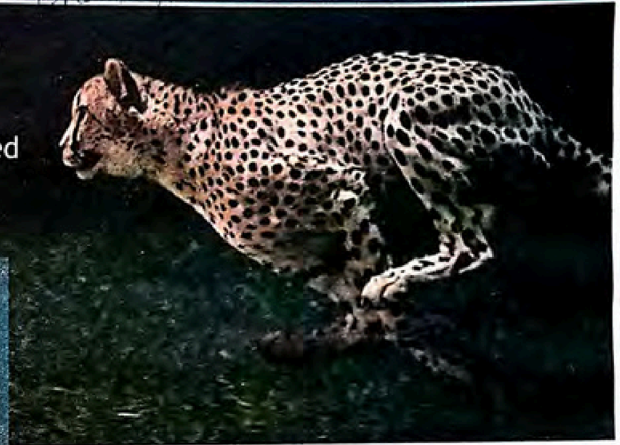
http://www.introduction-to-physics.com/

http://www.bipm.org/en/about-us/

http://www.rapidtables.com/convert/number/scientific-notation-converter.htm

http://www.flippingphysics.com/significant-figures.html

Cheetah is the fastest land animal with maximum speed of 114 km/h



Unit 2

KINEMATICS

CHECK LIST

After studying this unit you should be able to:

- ✓ describe using examples how objects can be at rest and in motion simultaneously.
- ✓ identify different types of motion i.e; translatory, (rectilinear, curvilinear, and random); rotatory and vibratory motions and distinguish among them.
- ✓ differentiate with examples between scalar and vector quantities.
- ✓ differentiate with examples between distance and displacement, speed and velocity.
- ✓ represent vector quantities by drawing.
- ✓ define the term speed, velocity and acceleration.
- ✓ plot and interpret distance-time graph and speed-time graph.
- ✓ determine and interpret the slope of distance-time and speed-time graph.
- ✓ determine from the shape of the graph, the state of a body.
- ✓ i. at rest ii. moving with constant speed iii. moving with variable speed.
- ✓ calculate the area under speed-time graph to determine the distance traveled by the moving body.
- ✓ derive equations of motion for a body moving with a uniform acceleration in a straight line using graph.
- ✓ solve problems related to uniformly accelerated motion using appropriate equations.
- ✓ solve problems related to freely falling bodies using 10 ms^{-2} as the acceleration due to gravity.

Mechanics is the oldest of all physical sciences. Mechanics deals with the study of motion of objects.

Everything in our universe is in a state of motion. Our solar system moves through space in the Milky Way Galaxy. Earth revolves around the Sun while rotating about its own axis. People, animals, air, and countless other objects move about on Earth's surface. The elementary particles that make up all matter, too, are constantly in motion.

There are two main branches of mechanics. They are Kinematics and Dynamics. Kinematics will be focus of study in this unit.

Kinematics is derived from the Greek word for motion. Kinematics is the branch of physics which deals with the study of motion without going into detail of what causes the motion.

2.1 REST AND MOTION

A body is at **rest** with respect to an observer if it does not change its position with respect to an observer. A body is in state of **motion** with respect to an observer if it changes its position with respect to that observer.

POSITION:

In order to describe the motion of an object, we must first be able to describe its position—where it is at any particular time. More precisely, we need to specify its position relative to a convenient reference.

Position is the location of object relative to some reference.

Earth is usually taken as reference, and we often describe the position of an object as it relates to stationary objects on earth. For example, a teacher's position could be described in terms of where she is in relation to the nearby teaching board.

We can equally use references that are not stationary but are in motion relative to the Earth. For example, to describe the position of a person in an airplane, we use the airplane as the reference, not the Earth as shown in the figure.

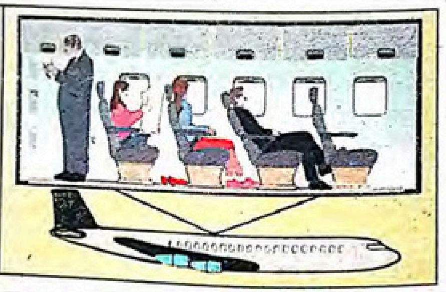


TABLE 2.1 TYPES OF MOTION

Type	Description	Examples
1. Translatory Motion	Changes in position of a body as a whole. The line or path of motion could be straight or curved.	Motion of a horse or motion of a ball, moving car, falling bodies, rowing boats, flying birds
Translatory motion is again divided into following types		
A. Rectilinear Motion	Straight line motion	Motion of free falling bodies
B. Curvilinear Motion	Circular or curved path motion	Motion of cricket ball being hit for six
C. Random Motion	Irregular motion	Flight of butterfly or motion of gas molecules
2. Rotatory Motion	Rotation of a body as a whole around a fixed axis, in this type of motion the particles of the body moves in a circle	Motion of wheel of a cycle, the hands of a clock, the wings of a turning fan
3. Vibratory Motion	The repeated forward and backward motion of an object about its mean position	The oscillation of a mass attached to an elastic spring, motion of swing and the vibration of a plucked violin string.

The motion of a body can be translatory, rotatory, vibratory or any combination of the three at the same time. e.g The motion of a cricket ball can have translatory as well as spin (rotatory) motion. The atoms/ molecules of gas can vibrate, rotate on its axis and at the same time can move freely in its container.

Objects can be at rest and in motion at same time:

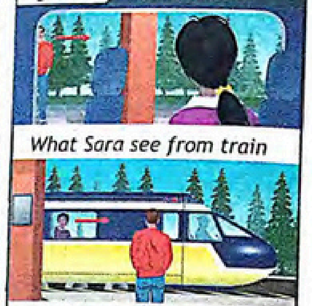
For same event two observers can have different observations. For example a body in train is in motion with respect to an observer on ground. Whereas the same object is at rest with respect to another observer in train moving with the object. Thus the motion and rest are not absolute but relative. This means that we have to specify the observer while telling about the rest or motion of the body.

Rest and motion are relative:

As position needs reference, therefore rest and motion also need specification of observer.

For example when teacher changes her position in the classroom while students are sitting on their chairs. According to students observation the teacher is in motion. Interestingly, teacher while moving also observes the students to move as well. Similarly, when Sara leaves in train and her cousin John sees her off. As the train starts moving Sara see John moving to the right, (as shown in the figure 2.1) with same speed as John see Sara moving to the left.

Figure 2.1 Relative Motion



What Sara see from train

What John see from platform

2.2 SCALARS AND VECTORS

Physical quantities can also be categorized on the basis of their directional properties.

In order to fly a plane, pilots needs not only to know how much crosswind is blowing but in what direction in which they intend to fly. In order to build bridges, engineers need to know what load a particular design will support. In such conditions the directional properties of physical quantities become more important.

Figure 2.2 Importance of Vectors

A. Scalars or Scalar Quantities:

Physical quantities which can be completely described by only its magnitude (or size). Magnitude means number with proper unit, for example mass is a scalar quantity and can be specified as 2 (number) with kilogram (proper unit). We do not need to know in what direction mass is needed.

These quantities can be added, subtracted and multiplied by using ordinary algebra. For example if we took 2 kg of sugar and add another 3 kg of sugar we will have (2kg + 3kg) 5 kg of sugar.

Examples of scalars are density, speed, distance, energy, charge, volume, power, temperature, electrical resistance, electric current and heat etc.

B. Vectors or Vector Quantities:

Physical quantities which can be completely described by its magnitude (or size) as well as direction are called vectors or vector quantities. Some quantities (such as weight, velocity, or friction) require both a magnitude (or size) and a direction for a complete description and are called vectors or vector quantities.

Representation of vectors:

Vectors can be represented in two ways.

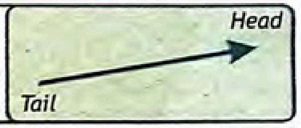
A. Symbolic representation:

Symbolically a vector is represented by a bold face letter either capital or small. (e.g **A**, **a**). Vector can also be represented by a simple face letter with an arrow over or below it. In this book we will represent vectors by letter with an arrow over it. For example $\vec{A}$, $\vec{B}$, $\vec{C}$ or $\vec{D}$.

B. Graphical Representation:

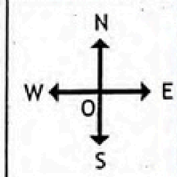
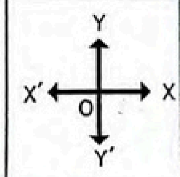
A graph is a visual representation of information, showing how one quantity varies with another related quantity. **Graphically a vector is represented by an arrow, the length of the arrow gives the magnitude (under certain scale) and the arrow head points the direction of the vector.**

The starting point of the vector is called tail of the vector and the ending point is called head of the vector as shown in the figure.



Coordinate Systems are used to represent vectors:

Vectors are considered with reference to coordinate axes (any sets of values that indicate the position of a point in a given reference system). To use vectors in applications we place them on a coordinate system. Description of two coordinate systems (Geographical Coordinate System and Cartesian coordinate system) is given in figure 2.3

Figure 2.3	Coordinate Systems
 	**Geographical Coordinate System:** One coordinate system is the Geographical Coordinate System having different directions as North (N), East (E), West (W) and South (S) NEWS as shown in figure.
 	**Cartesian Coordinate System:** The Cartesian coordinate system consists of a horizontal line called the x-axis (XOX′) and a vertical line called the y-axis (YOY′) intersecting at a point called the origin O.

Steps to Represent a Vector in Coordinate System

The following method is used to represent a vector

1. Draw a coordinate system.
2. Select a suitable scale.
3. Draw a line in the specified direction. Cut the line equal to the magnitude of the vector according to the selected scale.
4. Put an arrow in the direction of the vector.

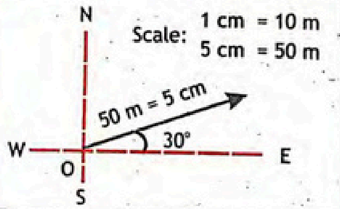
For example the representation of Al-Khalid tank (main battle tank jointly developed by China and Pakistan) as it moves to 50 m from origin towards 30° North of East, in both coordinate systems is

Figure 2.4 The position of Al khalid tank

Draw NEWS coordinate system and select a suitable scale

10 m = 1 cm, therefore 50 m = 5 cm

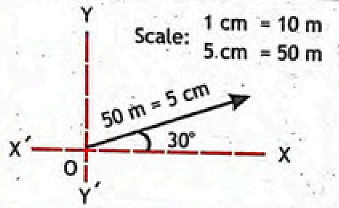
We draw a line of length 5 cm an angle of 30° from East towards North.



Draw Cartesian coordinate system corresponding to Geographical Coordinate System and select a suitable scale

10 m = 1 cm, therefore 50 m = 5 cm

We draw a line of length 5 cm at an angle of 30° from X-axis (taken as east).



2.3 Terms associated with motion:

Position of an object can be described in rectangular coordinate system. Where origin O can serve as a reference point. If one or more coordinates of an object change, we say that the object is in motion. The choice of a set of axes in a frame of reference depends upon the situation. For example, for describing motion in one dimension, we need only one axis. To describe motion in two/three dimensions, we need a set of two/ three axes.

Position of an object is usually represented with letters x, r, s, l or d.

2.3.1 DISTANCE

'The length of path traveled between two positions is called distance'.

Distance has no direction and therefore it is a scalar quantity. Distance is usually denoted by Δx, Δr, Δs, Δl or Δd, and has SI unit as meter.

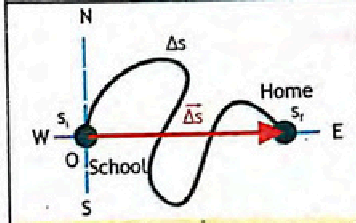
2.3.2 DISPLACEMENT

'The shortest directed distance between two positions is called displacement. Straight distance from one point to another is called displacement'.

Displacement has direction and therefore it is a vector quantity. Displacement is usually denoted by $\Delta\vec{x}$, $\Delta\vec{r}$, $\Delta\vec{s}$, $\Delta\vec{l}$ or $\Delta\vec{d}$, and has SI unit as meter (same as distance).

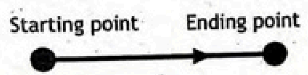
For example, if your friend asks you how far is your home from school and you tell him that it is about 4 km from school. You actually told him the length of the path covered by road, it could be a complicated motion (twisted, zig-zag and curved), you specified distance of your home. On the other hand if you reply that it 1.6 km straight towards east, this time you are telling him displacement of your home. The situation is shown in figure 2.5.

Figure 2.5 Displacement

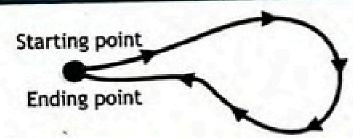


School is taken at the origin of geographical coordinate system. distance to home is shown with blue color line and displacement to home is shown with red arrow.

Figure 2.6 Distance and Displacement



The magnitude of displacement can be equal to the path length traversed by an object (distance). For example straight line motion.



The magnitude of the displacement for a course of motion may be zero but the corresponding path length (distance) is not zero. For example same starting and ending points.

2.3.3 SPEED

'Measure of the distance (Δs) covered with passage of time (Δt) is called speed (denoted by v)'. Mathematically

$$speed = \frac{\text{distance}}{\text{elapsed time}} \quad \text{or} \quad v = \frac{\Delta s}{\Delta t} \quad \text{or} \quad v = \frac{s_f - s_i}{t_f - t_i} \qquad (2.1)$$

TABLE 2.2: TYPICAL SPEED VALUES

Item	speed (m/s)	speed (km/h)
Continental drift.	3×10^{-10}	1×10^{-9}
Moon receding from the Earth	1.3×10^{-9}	4.68×10^{-9}
Growth rate of bamboo	1.4×10^{-5}	5.0×10^{-5}
Comfortable bicycling speed.	6-7	20-25
Car (freeway); cheetah	30	110
Fastest recorded ball speed (a golf ball)	91	328
Wind speed of a powerful tornado	130	468
Muzzle velocity of M16 rifle	975	3510
Speed of the Earth in orbit around Sun.	29,800	107,280
Speed of light (fastest speed)	299,792,458	1.1×10^{9}

2.3.4 VELOCITY

'Measure of displacement covered ($\vec{s}$) with passage of time ($\vec{t}$) is called velocity (denoted by $\vec{v}$)'. Mathematically

$$velocity = \frac{\text{displacement}}{\text{elapsed time}} \quad \text{or} \quad \vec{v} = \frac{\vec{s}}{t} \qquad \text{— 2.4}$$

As displacement is a vector quantity, therefore velocity is also a vector quantity having same direction as displacement vector. The SI unit of velocity is meter per second (m/s).

When we know both the speed and the direction of an object, we simply call it as velocity.

A) Average Velocity:

'Average Velocity is the net (total) displacement divided by the total time "t"; unlike speed the average velocity can be positive and negative depending upon the sign of displacement'. Mathematically

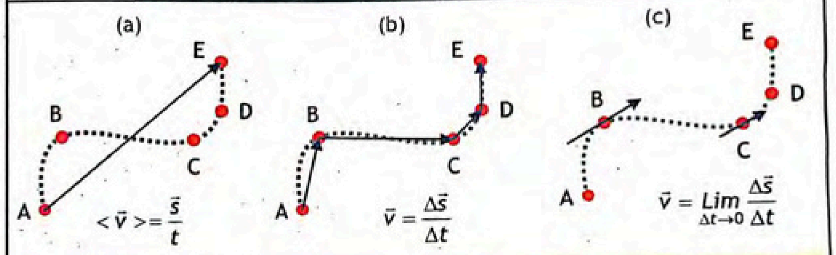
$$<\vec{v}> = \frac{\text{Total displacement}}{\text{Total time}} \quad \text{or} \quad <\vec{v}> = \frac{\vec{s}}{t} \qquad \text{— 2.5}$$

B) Instantaneous Velocity:

Things in motion often have variations in speed or direction. *'The instantaneous velocity is the velocity for very short time interval Δt (very small such that limit approaching to zero)'.* Mathematically

$$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{s}}{\Delta t} \qquad \text{— 2.6}$$

Figure 2.7 Velocity



The average velocity does not convey detailed information about the motion during the corresponding time interval Δt. Suppose a car moves on a curved track, through points A, B, C, D and E as shown in the figure. **(a)** The average velocity is defined over the entire journey, **(b)** the measure of velocity in shorter interval of time is different both in magnitude and direction at different points. **(c)** The instantaneous velocity will be tangent to the curved path of the motion of car.

A body is said to have **uniform velocity** if its average and instantaneous velocity become equal. Otherwise it is non uniform.

Example 2.2 STRAIGHT ROAD

A straight track is 1200 m in length. A runner begins at the starting line, runs due east for the full length of the track, turns around and runs halfway back. The time for this run is five minutes. What is her (a) average velocity, and (b) average speed?

GIVEN:

Distance covered Δs = 1200 m + 600 m = 1800 m

Displacement Δs = 1200 m - 600 m = 600 m

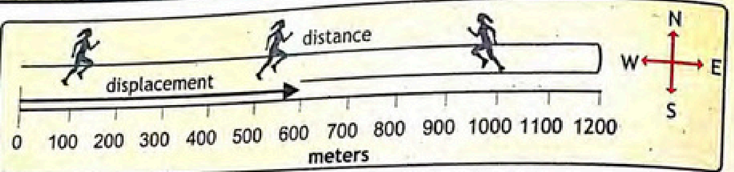
time Δt = 5 min = (5 × 60 s) = 300 s

REQUIRED:

(a) average speed <v> = ?

(b) average velocity <v> = ?

SOLUTION



From the definition of average velocity, equation 2.5 we have

$$<\vec{v}> = \frac{\vec{s}}{t} \qquad \text{putting values} \quad <\vec{v}> = \frac{600\,m\,(East)}{300\,s}$$

therefore $<\vec{v}> = 2\,m/s\ East$ — **Answer**

From the definition of average speed, equation 2.3 we have

$$<v> = \frac{s}{t} \qquad \text{putting values} \quad <v> = \frac{1800\,m}{300\,s}$$

therefore $<v> = 6\,m/s$ — **Answer**

Her average velocity is **2 m/s East**, while her average speed is **6 m/s.**

Assignment 2.2 AVERAGE VELOCITY OF COMPLETE LAP

A runner makes one lap around a 270 m circular track in 30 s. What is his (a) average speed and (b) average velocity?

2.3.5 ACCELERATION:

'The measure of change in velocity Δv with the passage of time 'Δt' is called acceleration. (or) Time rate of change of velocity is called acceleration $\vec{a}$'.

Mathematically

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}} \quad \text{or} \quad \vec{a} = \frac{\Delta\vec{v}}{\Delta t} \quad \text{or} \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \qquad \text{—— 2.7}$$

Acceleration is also a vector quantity having same direction as change in velocity. SI Unit of acceleration is meter per second squared (m/s^2). Acceleration is a measure of how rapidly the velocity is changing.

A) Average Acceleration:

'Average acceleration $<\vec{a}>$ is the net (total) velocity $\vec{v}$ divided by the total time t'.

$$<\vec{a}> = \frac{\text{Total change in velocity}}{\text{Total time}} \quad \text{or} \quad <a> = \frac{\vec{v}}{t} \qquad \text{—— 2.8}$$

B) Instantaneous Acceleration:

'Acceleration 'a' at particular instant of time is known as instantaneous acceleration'. The value of instantaneous acceleration is obtained, if Δt is made smaller and smaller such that it approaches to ZERO.

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta\vec{v}}{\Delta t} \qquad \text{—— 2.9}$$

Uniform Acceleration:

A body is said to have **uniform acceleration** if its average and instantaneous acceleration become equal.

LAB WORK

To find the acceleration of a ball rolling down an angle iron by drawing a graph between 2S and T^2.

Deceleration/Retardation:

When an object is slowing down, we can say it is decelerating. But be careful: deceleration/retardation does not mean that the acceleration is necessarily negative. The velocity of an object moving to the right along the positive x-axis is positive; if the object is speeding up, the acceleration is positive; however if the object is slowing down, the acceleration is negative. But the same object moving to the left (decreasing x), and slowing down, has positive acceleration that points to the right. We have a deceleration whenever the magnitude of the velocity is decreasing; thus the velocity and acceleration point in opposite directions when there is deceleration.

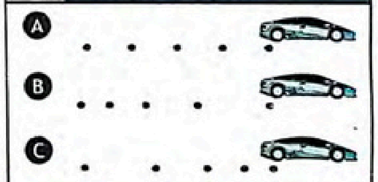
TID-BIT

People Enjoy acceleration, amusement rides thrill us by accelerating our bodies. Each curve, drop, loop, launch, or brake alters the rider's state of motion and cause acceleration. The balance between comfort and thrill is maintained which amuses the riders.

POINT TO PONDER

Velocity is a vector quantity it can change with change in direction. If the speed of the object is not changing and only direction is changing will it still be acceleration?

CAN YOU TELL?



A car is dripping mobile oil at constant rate. Which diagram describe the car moving with steady speed, speeding and slowing down.

Example 2.3 ACCELERATION OF CAR

You observe that your car accelerate from rest to 140 km/h in just 17.6 seconds on straight road towards east. What is the acceleration of your car.

SOLUTION

GIVEN:

initial velocity v_i = 0 km/h East = 0 m/s East

final velocity v_f = 140 km/h East = 38.88 m/s East

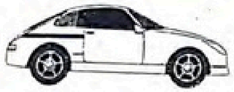
time elapsed Δt = 17.6 s

REQUIRED:

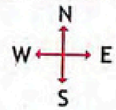
acceleration a = ?

Conversion from km/h to m/s

$$140\,km/h = \frac{140\times10^3\,m}{60\times60\,s} = \frac{140{,}000}{3600\,s} = 38.9\,m/s$$



$\vec{a}$



From the definition of acceleration, equation 2.7 gives

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \quad \text{or} \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad \text{putting values} \quad \vec{a} = \frac{(38.9-0)m/s}{17.6\,s}\,East$$

$$\text{or} \quad \vec{a} = \frac{38.9\,m/s}{17.6\,s}\,East$$

therefore $\vec{a} = 2.2\,m/s^2\,East$ — **Answer**

EXTENSION EXERCISE 2.2

In this example, when the driver apply breaks in what direction will the resulting acceleration points?

Assignment 2.3 CAR'S ACCELERATION

If in the same experiment you take the readings of the speedometer of the car as 20 km/h in the 4th second and 32 km/h in the 9th second. What is the acceleration of your car in this interval?

INTERESTING INFORMATION CONTINENTAL DRIFT

Continental Drift is the movement of the Earth's continents relative to each other, thus appearing to 'drift' across the ocean bed. The continental plates (therefore continents) move across the surface of the Earth at the geologically slow rate of 1-10 cm/year or 1-10 m/century. This is about the same speed that fingernails and hair grow.

2.4 GRAPHICAL ANALYSIS OF MOTION

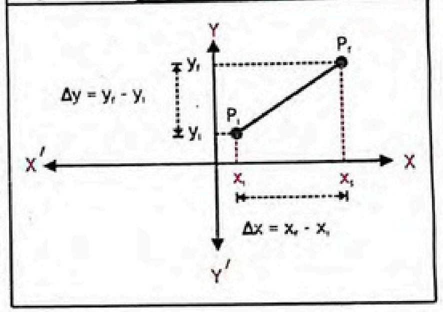
Graph is an effective way for showing the relationship between physical quantities. Graph contains horizontal and vertical lines at equal distances and coordinate systems to show relationship in various quantities. Interpretation of graph is an effective tool for Physicist.

Slope of Graph:

The slope of the graph means vertical coordinate difference divided by horizontal coordinate difference. The slope of the graph in cartisian coordinate system can be calculated as

1. Pick two points P_i and P_f.
2. Determine the coordinates $P_i(x_i, y_i)$ 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. Mathematically

Figure 2.8 Graph



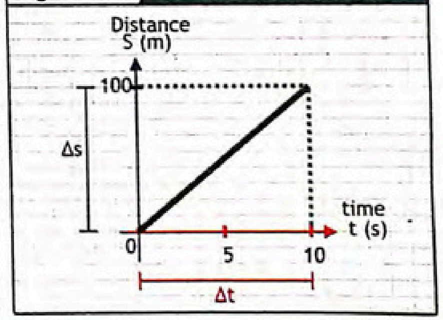
$$slope = \frac{\Delta y}{\Delta x} = \frac{y_f - y_i}{x_f - x_i} \quad \text{——— 2.10}$$

2.4.1 DISTANCE-TIME GRAPH

The graph plotted between distance (s) and time (t) is called distance-time graph. In this graphical analysis the distance is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Distance time graph is always in the positive XY plane, as with passage of time distance never goes to negative axis, irrespective of the direction of motion.

The slope of distance time curve only gives speed. Consider the motion of the

Figure 2.9 Distance Time Graph

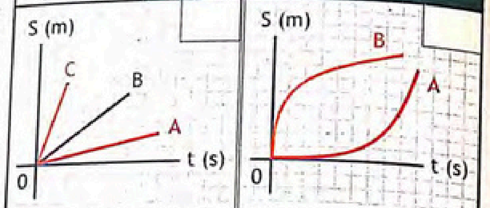


object which covers a distance of 100 m in 10 s, the slope of distance time graph will give speed as equation 2.10 can be written as

$$slope = \frac{\Delta s}{\Delta t} = \frac{s_f - s_i}{t_f - t_i}$$

from equation 2.1 it is definition of speed, therefore

QUIZ — DISTANCE- TIME GRAPH

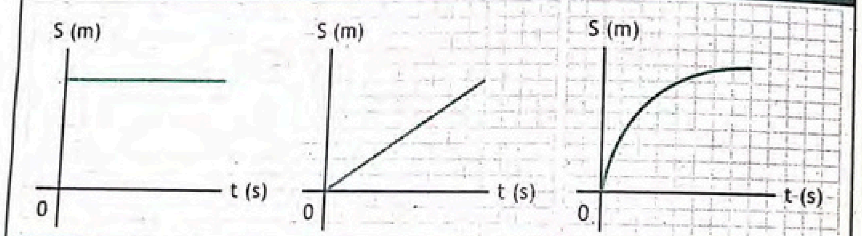


Which of these graphs has higher speed?

Which of these graphs show increasing speed?

$$speed\ v = \frac{100m - 0m}{10s - 0s} = \frac{100m}{10s} = 10ms^{-1}$$

Figure 2.10 Graphical Interpretation



ZERO SPEED	UNIFORM SPEED	VARIABLE SPEED
Time is passing and no change in distance is seen. It means the body is at rest. Since there is no slope so the speed is zero.	*The distance is increasing linearly with time. The slope is constant therefore object is moving with uniform speed.*	*The distance is changing non-linearly with time (spiking down). The slope is changing therefore object is moving with variable speed.*

2.4.2 SPEED - TIME GRAPH

The graph plotted between speed (v) and time (t) is called speed-time graph. In this graphical analysis the speed is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Speed time graph is useful for two purposes.

A. Slope or gradient of the graph gives magnitude of acceleration

B. Area under the graph gives distance traveled.

A. The slope of speed time curve gives magnitude of acceleration.

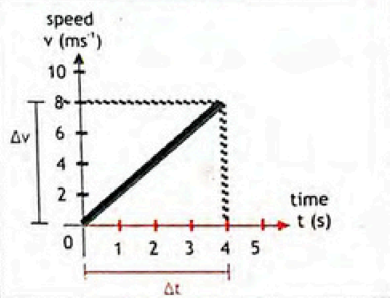
Consider the motion of the object which speeds up from 0 m/s to 8 m/s in 4

s, the slope of speed time graph will give magnitude of acceleration which can be written as

$$slope = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

Since acceleration is change in velocity with respect to time. Therefore change in speed with respect to time will only give magnitude of acceleration.

Figure 2.11 Speed Time Graph Slope



$$\text{Magnitude of acceleration} |a| = \frac{8ms^{-1} - 0ms^{-1}}{4s - 0s} = \frac{8ms^{-1}}{4s} = 2\ ms^{-2}$$

B) Area under speed time graphs represent the distance traveled:

When we speak of the area under a graph, we are not talking about the literal number of square centimeters of paper but the quantities under discussion. From equation 2.1 the speed is defined as

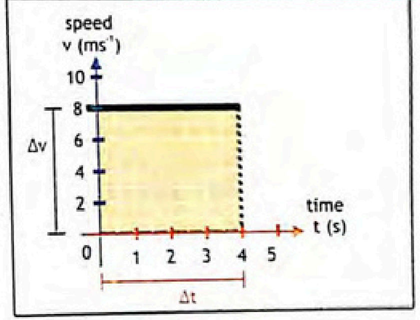
$$\text{speed} = \frac{\text{distance}}{\text{elapsed time}} \quad \text{or} \quad v = \frac{\Delta s}{\Delta t}$$

The above equation can be written as

$$\text{distance} = \text{speed} \times \text{elapsed time}$$

$$\text{or} \quad \Delta s = v \times \Delta t \qquad \textbf{2.11}$$

Figure 2.12 Speed Time Graph Area



This quantity in speed-time graph is represented as area under the curve. For example if we want to calculate the area of rectangular shaded region for the speed time graph of an object in motion as shown in figure 2.12 The area 'A' of rectangle mathematically is length 'l' into width 'w'.

$$Area = length \times width \quad \text{or} \quad A = l \times w \quad \text{or} \quad A = \Delta t \times \Delta v = \Delta v \times \Delta t$$

putting values from graph $A = (8-0)ms^{-1} \times (4-0)s$ or $A = 8\frac{m}{s} \times 4s$

therefore $A = 32m$

CASE STUDIES OVER SPEEDING & MOTORCYCLE ACCIDENTS

According to an estimate, at least 6 million more people will die and 60 million will be injured during the next 10 years in road accidents all over the world if proper preventive measures are not taken.

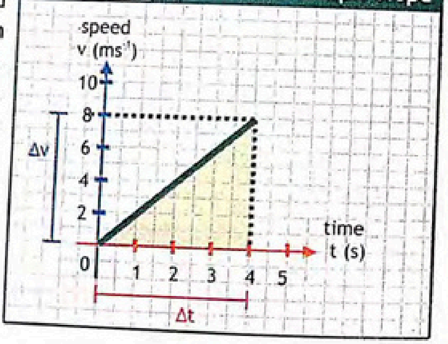
Traffic rules violation and lack of adequate road safety standards in Pakistan has claimed 45,000 lives in 90,000 road accidents in the last nine years. It is also recorded that about 87 percent of these accidents were just due to the negligence of drivers that indulged in over-speeding, and wrong overtaking.

Motorcyclists are most vulnerable to fatal injuries, for not following traffic rules. Therefore KIDS when you grow up, you first have to acquire license and then make yourself aware of safety standards before driving and remember the words - **SPEEDING THRILLS BUT IT KILLS.**

The area of rectangular shaded region in figure is 32 m. The quantity it represents is actually distance the body traveled.

Similarly, if we want to calculate the area of triangular shaded region for the speed time graph of an object in motion as shown in figure. The area (A) of triangle is half of area of rectangle, which can be written mathematically as

Figure 2.13 Speed Time Graph Slope



$$Area = \frac{1}{2} length \times width$$

$$A = \frac{1}{2} \times l \times w$$

or $$A = \frac{1}{2} \times \Delta t \times \Delta v = \frac{1}{2} \times \Delta v \times \Delta t$$

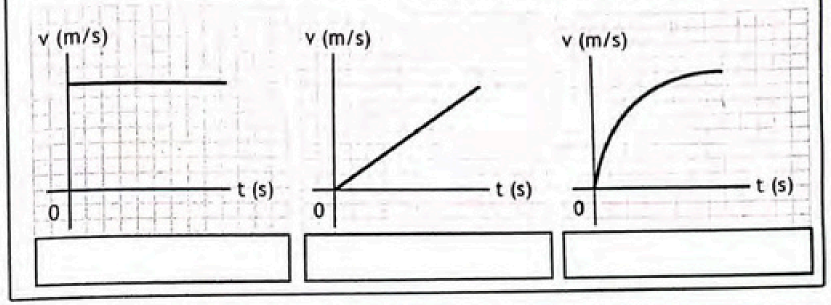
putting values from graph $A = \frac{1}{2} \times (8-0)ms^{-1} \times (4-0)s$

or $A = \frac{1}{2} \times 8\frac{m}{s} \times 4s$ therefore $A = 16m$

The area of triangular shaded region in figure 2.13 is 16 m. The quantity it represents is actually distance the body traveled.

ACTIVITY SPEED- TIME GRAPH

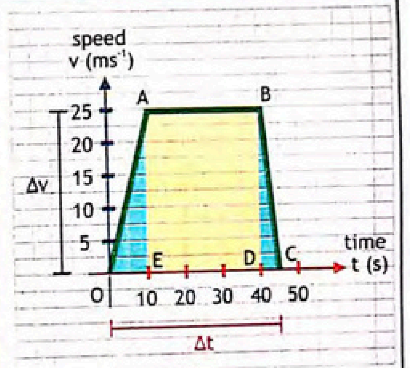
What does the slope of these graphs tells about magnitude of acceleration?



Example 2.4 GRAPHICAL ANALYSIS OF CAR'S SPEED

A car increases its speed from ZERO to a 25 ms^{-1} in 10 s. Then it moves with uniform speed for the next 30 seconds and then the driver apply brakes and the speed of the car decreases uniformly to ZERO in the next 5 seconds. The graph is plotted for the journey, use this graph to calculate:

a. magnitude of acceleration (i) in first 10 s. (ii) from 10 s to 40 s and (iii) in last 5 seconds, b. total distance covered and c. average speed of the car for whole journey.



SOLUTION

a. The slope of the graph will give magnitude of acceleration

$$slope = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = magnitude\ of\ acceleration$$

(i) For the first 10 seconds, OA line represents the slope

$$\text{Magnitude of acceleration } a = \frac{25ms^{-1} - 0ms^{-1}}{10s - 0s} = \frac{25ms^{-1}}{10s} = 2.5ms^{-2}$$

(ii) From 10 s to 40 s, The slope is represented by line AB

$$\text{Magnitude of acceleration } a = \frac{25\,ms^{-1} - 25\,ms^{-1}}{40\,s - 30\,s} = 0\,ms^{-2}$$

(iii) In the last 5 seconds

$$\text{Magnitude of acceleration } a = \frac{0\,ms^{-1} - 25\,ms^{-1}}{45\,s - 40\,s} = -\frac{25\,ms^{-1}}{5\,s} = -5\,ms^{-2}$$

> In the first 10 s the cars acceleration is 2.5 m/s², from 10 s to 40 s it is 0 m/s², while in the last 5 s it is -5 m/s², the negative gradient indicates the car is slowing down. **Answer**

b. Now the total distance covered is equal to the area under the speed-time graph.

Total distance covered = Area of triangle Δ OAE + Area of rectangle ABDE + Area of triangle Δ CDB

$$S = \{\frac{1}{2} \times (25ms^{-1} \times 10\,s)\} + \{25ms^{-1} \times 30\,s\} + \{\frac{1}{2} \times (25ms^{-1} \times 5\,s)\}$$

or $S = 125m + 750m + 62.5m = 937.5m$ — **Answer**

The total distance covered by car is 937.5 m

c. Now the average speed can be calculated when distance s is divided by total time t.

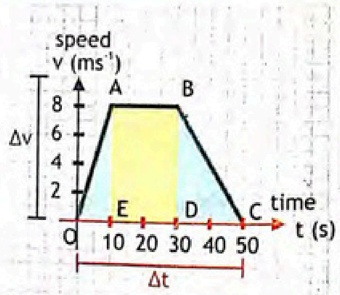
$$<v> = \frac{\text{Total distance}}{\text{Total time}} \quad \text{or} \quad <v> = \frac{937.5\text{ m}}{45\text{ s}}$$

therefore $<v> = 20.8\,m/s$ — **Answer**

The average speed of the car is 20.8 m/s

Assignment 2.4 GRAPHICAL ANALYSIS OF CYCLIST

A cyclist increases his speed from ZERO to 8 ms⁻¹ in 10 s. Then he moves with uniform speed for the next 20 seconds and then its speed decreases uniformly to ZERO in the next 20 seconds. The graph is plotted for the journey, use this graph to calculate the total distance covered.



2.5 EQUATIONS OF MOTION

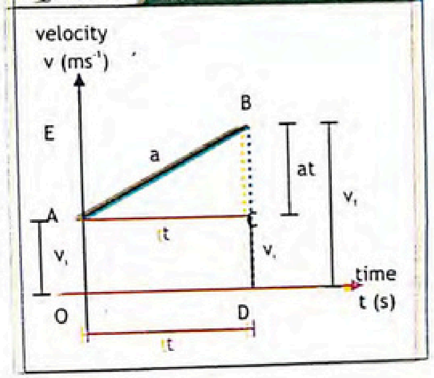
Terms associated with motion can be related and calculated from equations called equations of motion. These equations can be utilized for any motion that can be described as being either a constant velocity motion (an acceleration of 0 m/s²) or a constant acceleration motion (i.e. the instantaneous and average accelerations are equal). They can never be used over any time period during which the acceleration is changing. Graphical method will be used to prove the equations of motion for uniformly accelerated motion.

We use the definitions of average velocity and acceleration to derive a set of valuable equations that relate x, a, v and t when a is constant, allowing us to determine any one of these variables if we know the others. We can then solve many interesting Problems.

In this discussion we chose the initial time to be zero $t_i = 0$, and final time $t_f = t$ such that $\Delta t = t_f - t_i = t - 0 = t$. Also we chose initial position to be zero $s_i = 0$ and final position $s_f = s$, such that displacement $\Delta s = s_f - s_i = s - 0 = s$.

The object has initial velocity v_i at point A, which changes uniformly to point B as v_f. In the plot OA = DC represents initial velocity v_i and DB represent final velocity v_f. Here time t is represented by OD = AC = t. The slope of the line AB is

Figure 2.14 Equations of Motion



$$slope = \frac{\overline{CB}}{\overline{AC}}$$

The slope of velocity-time graph gives acceleration a, since AC = t, therefore

$$a = \frac{\overline{CB}}{t} \quad \text{or} \quad \overline{CB} = at$$

A. First Equation of Motion:

First equation of motion gives the relation of final velocity 'v_f' in terms of initial velocity 'v_i' and acceleration 'a' in time t. From the graph it is clear that

Line DB represents, final velocity v_f	$\overline{DB} = v_f$
Line DC represents, initial velocity v_i	$\overline{DC} = v_i$
Line segment CB, in terms of slope gives	$\overline{CB} = at$

$$\overline{DB} = \overline{DC} + \overline{CB}$$

putting these values in graph equation we get

$$v_f = v_i + at \quad \text{—— 2.12}$$

B. Second Equation of Motion:

Second equation of motion relates displacement s with initial velocity 'v_i' and acceleration 'a' in time 't'. As the area under velocity-time curve represents the displacement 's' as shown in figure 2.14. Therefore, the displacement s of the object is:

$$\underset{s}{\text{displacement}} = \underset{\text{OACD}}{\text{Area of rectangle}} + \underset{\Delta\,\text{ACB}}{\text{Area of triangle}}$$

$$s = (\overline{OA} \times \overline{AC}) + \frac{1}{2} \times (\overline{AC} \times \overline{CB})$$

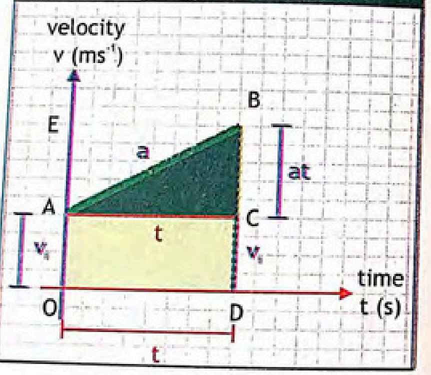
Line segment AC represents, time t	$\overline{AC} = t$
Line OA represents, initial velocity v_i	$\overline{OA} = v_i$
Line segment CB, in terms of slope is	$\overline{CB} = at$

putting values

$$s = v_i \times t + \frac{1}{2} \times (t \times at)$$

therefore $s = v_i t + \frac{1}{2} at^2$ —— 2.13

Figure 2.15 Equations of Motion



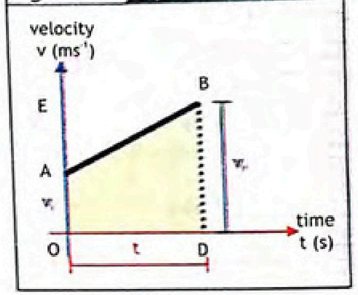
C. Third Equation of Motion:

Third equation relate position s, velocity v (both final velocity v_f and initial velocity v_i), and constant acceleration a **without including time t**. The area under the curve can be calculated by taking the total area of the trapezium OABD. The velocity-time graph the area of a trapezoid OABD will give the total displacement

$$s = \frac{1}{2}(\overline{OA} + \overline{DB}) \times \overline{OD}$$

Line DB represents, final velocity v_f	$\overline{DB} = v_f$
Line OA represents, initial velocity v_i	$\overline{OA} = v_i$
Line segment OD represents, time t	$\overline{OD} = t$

Figure 2.16 Equations of Motion



putting values $s = \frac{1}{2}(v_i + v_f) \times t$

From first equation of motion

$$v_f = v_i + at$$

or $at = v_f - v_i$ or $t = \frac{v_f - v_i}{a}$

The above equation becomes

$$s = \frac{1}{2}(v_i + v_f) \times \frac{(v_f - v_i)}{a}$$

$$s = \frac{1}{2a}(v_i + v_f)(v_f - v_i)$$

since $(a+b)\times(a-b) = a^2 - b^2$

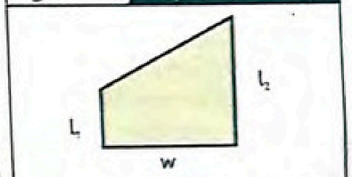
therefore $(v_i + v_f)(v_f - v_i) = v_f^2 - v_i^2$

or $s = \frac{v_f^2 - v_i^2}{2a}$

therefore $2as = v_f^2 - v_i^2$ —— 2.14

TIP	km/h to m/s
To convert km/h to m/s, divide by 3.6	

Figure 2.17 Trapezoid



The area of a trapezoid is given by

$$A = \frac{1}{2}(l_1 + l_2) \times w$$

which is simply the average of the parallel sides multiplied by the base.

Example 2.5 SPEEDING MOTORCYCLIST

A motorcyclist starts from rest and moves with uniform acceleration of 1.9 m/s² for 22s. Find the (a) velocity and (b) distance covered?

GIVEN:

initial velocity v_i = 0 m/s

acceleration a = 1.9 m/s²

Total time t = 22 s

REQUIRED:

a. Final velocity v_f = ?

b. Distance s = ?

a. To find final velocity we can use the first equation of motion

$v_f = v_i + at$ putting values $v_f = 0\,m/s + 1.9\,m/s^2 \times 22\,s$

therefore $v_f = 41.8\,m/s$ — Answer

b. For the distance covered, we will use second equation of motion

putting values $s = v_i t + \frac{1}{2}at^2$

$s = 0\,m/s \times 22\,s + \frac{1}{2} \times 1.9\,m/s^2 \times (22\,s)^2$

therefore $s = 459.8\,m$ — Answer

EXTENSION EXERCISE 2.3

This problem is captioned speeding motorcyclist. Is 41.8 m/s safe speed for motorcycle ride? Also verify the distance covered in this problem by third equation of motion.

Assignment 2.5 CYCLIST MOTION

A cyclist is moving with uniform acceleration of 1.2 m/s². How much time will it require to change his velocity from 6 m/s to 12 m/s.

Example 2.6 COMMERCIAL AIRCRAFT RUNWAY LENGTH

A Boeing 777 aircraft takes off at 295 km/h after accelerating from rest at 2.80 m/s². What is the minimum runway length required?

GIVEN:

initial velocity v_i = 0 km/h = 0 m/s

final velocity v_f = 295 km/h = 81.9 m/s

acceleration = 2.80 m/s²

REQUIRED:

distance s = ?

Conversion from km/h to m/s

$$295\,km/h = \frac{295 \times 10^3\,m}{60 \times 60\,s} = \frac{295{,}000}{3600\,s} = 81.9\,m/s$$

Time is not given so we will use the third equation of motion

$2as = v_f^2 - v_i^2$ or $s = \frac{v_f^2 - v_i^2}{2a}$ putting values $s = \frac{(81.9\,ms^{-1})^2 - (0\,ms^{-1})^2}{2 \times 2.80\,ms^{-2}}$

$$s = \frac{6707.61\,m^{\cancel{2}}/\cancel{s^2}}{5.6\,\cancel{m}/\cancel{s^2}}$$

or $s = 1197.7875\,m$ — Answer

The units came out correctly as for displacement (meters) but we have to correct the number and express in three significant figures.

$s = 1200\,m$ $s = 1.20 \times 10^3\,m$ $s = 1.20\,km$

A runway needs to be longer than 1.2 km as this was calculated minimum length to give a margin of safety. Most commercial airport runways are between 2 km and 4 km long.

EXTENSION EXERCISE 2.4

At landing, the 777 s velocity is about the same as at takeoff, and after touchdown its acceleration is normally between -2.0 m/s² to -2.4 m/s². How does this affect consideration of a safe runway length?

Assignment 2.6 BREAKING CAR

On Motorway M1, a car is moving at speed limit of 120 km/h. By applying breaks the car comes to rest after covering a distance of 30 m. What is the deceleration of the car?

2.5 MOTION DUE TO GRAVITY:

Everyone has observed the effect of gravity as it causes objects to fall downward. In the absence of air resistance, it is found that all bodies at the same location above the earth fall vertically with the same acceleration. Furthermore, if the distance of the fall is small compared to the radius of the earth, the acceleration can be considered constant throughout its fall. **The motion, in which air resistance is neglected and the acceleration is nearly constant, is known as free-fall.**

The acceleration of a freely falling body is called the acceleration due to gravity, and its magnitude (without any algebraic sign) is denoted by the symbol g. The acceleration due to gravity is directed downward, toward the center of the earth. Near the earth's surface, g is approximately

$g = 9.80\,m/s^2$ or $32.2\,ft/s^2$

Figure 2.18 Free Fall


(a) Air filled tube (b) Evacuated tube

(a) In the presence of air resistance, the acceleration of the rock is greater than that of the paper.

(b) In the absence of air resistance, both the rock and the paper have the same acceleration.

Figure a shows the well-known phenomenon of a rock falling faster than a sheet of paper. The effect of air resistance is responsible for the slower fall of the paper. When air is removed from the tube, as in Figure b, the rock and the paper have exactly the same acceleration due to gravity. In the absence of air, the rock and the paper both fall freely.

Since the acceleration is constant in free-fall, the equations of kinematics can be used. In these equations we replace acceleration 'a' with acceleration due to gravity 'g' and distance 's' with height 'h'.

$$v_f = v_i + gt \quad \text{——— 2.15}$$

$$h = v_i t + \frac{1}{2} gt^2 \quad \text{——— 2.16}$$

$$2gh = v_f^2 - v_i^2 \quad \text{——— 2.17}$$

When an object moves with the gravity acceleration due to gravity is taken as positive (+g) and when object moves against gravity, acceleration due to gravity is taken negative (-g).

LAB WORK

Find the value of "g" by free fall method.

Example 2.7 HEIGHT OF BRIDGE FROM WATER SURFACE

A stone is dropped from the Attock Bridge. The stone reaches the water in 3.2 s. Find the a. height of the bridge from water and b. velocity of the stone when it strikes the water.

SOLUTION

GIVEN:

Time t = 3.2 s

Initial velocity $v_i = 0\ ms^{-1}$

Acceleration due to gravity $g = 9.8\ ms^{-2}$

REQUIRED:

a. Height h = ?

b. Final velocity v_f = ?

a. By second equation of motion $h = v_i t + \frac{1}{2}gt^2$

putting values $h = 0ms^{-1} \times 3{:}2s + \frac{1}{2} \times 9.8ms^{-2} \times (3.2)^2$

therefore $h = 50.176m$

Rounding off to correct significant figures $h = 50m$ —— Answer

b. By First equation of motion $v_f = v_i + gt$

putting values $v_f = 0ms^{-1} + 9.8ms^{-2} \times 3.2s$

therefore $v_f = 31.36ms^{-1}$

Rounding off to correct significant figures $v_f = 31ms^{-1}$ —— Answer

Assignment 2.7 CRICKET BALL

In a cricket match ball go straight up with a velocity of 40 m/s. Calculate
a) maximum height ball will reach b) time to reach that height.

KEY POINTS

Mechanics: The branch of Physics, which deals with the motion of bodies.

Kinematics: The branch of physics, which deals with discussion of motion of object without reference to the forces causing the motion.

Dynamics: It is the study of motion of bodies under the action of a force.

Rest: A body is said to be at rest if it does not change its position with respect to an observer.

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

Types of Motion: There are three main types of motion

a) Translatory Motion b) Rotatory Motion c) Vibratory Motion

Scalars: Physical quantities completely specified by its magnitude, that is, a proper unit and a number are called scalars.

Vectors: Physical quantities completely specified by magnitude, as well as direction are called vectors.

Position: The distance and direction of a body from a fixed point shows its position.

Displacement: The shortest distance from the initial and final position of a body is called displacement.

Speed: time rate of change of distance is called speed it is a scalar quantity.

Velocity: The time rate of change of displacement is called velocity it is a vector quantity.

Acceleration: The time rate of change of velocity is called acceleration.

Equations of Motion: The inter-relationship of velocity, uniform acceleration, time interval and displacement of an object are expressed by the following equations:

a. $v_f = v_i + at$ b. $s = v_i t + \frac{1}{2} at^2$ c. $2as = v_f^2 - v_i^2$

P R O J E C T S

GROUP - A

GALILEO'S WORK: Research Galileo's work on falling bodies. What did he wanted to demonstrate? What arguments did he use to prove that he was right? Did he used experiments, logic, findings of other scientists, or other approaches?

GROUP - B

SPEEDS AND ACCELERATIONS OF ANIMALS: Research typical values for speeds and accelerations of animals. Find out how long it gets for different animals to attain their top speed. Why the predators (lion or cheetah) likes to get close to the prey (gazelle, deer or buffalo) to launch an attack? How the predator to prey distance affect a kill.

GROUP - C

OVER SPEEDING: Write a publication essay for school library on over-speeding issues related to different means of transportation and speed limits.

GROUP - D

DESIGN OF PARK RIDES AND TRANSPORTATION DEVICES: Research the maximum acceleration a human body can withstand without blacking out. Discuss how acceleration impacts the design of common entertainment (such as park rides) or transportation devices.

GROUP - E

CAR RIDE: Go by a car, record the odometer, and the speedometer for every 20 s for about 5 min. Create representation of the car's motion by distance-time and speed-time graphs. And show that area under the speed-time curve gave the same result as the difference in the initial and final readings on odometer.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. The average speed of a bus is $20ms^{-1}$, how far can it travel in 10s?
   A. 100 m B. 200m C. 150m D. 250m
2. A truck accelerates uniformly from $15ms^{-1}$ to $20m^{-1}$ in 5 s. What is the acceleration of the truck?
   A. 2 ms^{-2} B. 1.5 ms^{-2} C. 1 ms^{-2} D. 2.5 ms^{-2}
3. A car moving along a straight line at 20 m s^{-1} under goes an acceleration of $4ms^{-2}$. After 2s, its speed will be
   A. 28 ms^{-1} B. 16 ms^{-1} C. 12 ms^{-1} D. 8 ms^{-1}
4. A bird begins to accelerate at a constant 0.3 m/s^2 for 3 s. Its change in velocity is
   A. 0.9 m/s B. 1.5 m/s C. 1.95 m/s D. 2.4 m/s
5. A car is going backwards at 5 m/s. After 10 s of uniform acceleration, the car is going forward at 10 m/s. The acceleration is
   A. 0.5 m/s^2 B. 0.75 m/s^2 C. 1.5 m/s^2 D. 5 m/s^2
6. The slope of distance-time graph represents:
   A. acceleration B. change in acceleration C. speed D. distance
7. The area under a speed-time graph represents:
   A. acceleration B. change in acceleration C. distance D. velocity
8. A student riding his bicycle on a straight flat road covers one block every 7 seconds. If each block is 100m long, he is traveling at:
   A. Constant speed B. Constant velocity C. 10m/s D. Both A and B
9. You drop a rock from a bridge to the river below. When the rock has fallen 4 m, you drop a second rock. As the rocks continue their free fall, their separation
   A. increase B. decrease C. stay the same D. none

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Is it possible that displacement is zero but not the distance. Under what condition displacement will be equal to distance.
2. Does a speedometer measure a car's speed or velocity?
3. Is it possible for an object to be accelerating and at rest at the same time? Explain with example.
4. Can an object have zero acceleration and nonzero velocity at the same time? Give example.
5. A person standing on the 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?
6. Describe a situation in which the speed of an object is constant while the velocity is not.
7. Can an object have a northward velocity and a southward acceleration? Explain.
8. As a freely falling object speeds up, what is happening to its acceleration — does it increase, decrease, or stay the same?
9. A ball is thrown upward with an initial speed of 5 m/s. What will be its speed when it returns to starting point?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. What is motion? Describe that motion is relative. How two observers in relative motion can have conflicting views about same object?
2. Explain different types of motion and give an example of each.
3. Define scalar and vector quantities. Explain with example the graphical representation of vector quantities.
4. What is position. Explain the difference between distance traveled, displacement, and displacement magnitude.
5. State and explain the terms:

   a. speed b. velocity c. acceleration

6. Use velocity-time graph to prove the following equations of motion

   a. $v_f = v_i + at$ b. $s = v_i t + \frac{1}{2} at^2$ c. $2as = v_f^2 - v_i^2$

7. 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.

NUMERICAL QUESTIONS

1. A squash ball makes contact with a squash racket and changes velocity from 15 m/s west to 25 m/s east in 0.10 s. Determine the vector acceleration of the squash ball.
2. A golf ball that is initially traveling at 25 m/s hits a sand trap and slows down with an acceleration of $-20\ m/s^2$. Find its displacement after 2.0 s.
3. A bullet accelerates the length of the barrel of a gun 0.750 m long with a magnitude of $5.35 \times 10^5\ m/s^2$. With what speed does the bullet exit the barrel?
4. A driver is traveling at 18 m/s when she sees a red light ahead. Her car is capable of decelerating at a rate of $3.65\ m/s^2$. If she applies brakes when she is only 20.0 m from the intersection when she sees the light, will she be able to stop in time.
5. An antelope moving with constant acceleration $2\ m/s^2$ covers crosses a point where its velocity is 5 m/s. After 6.00 s how much distance it has covered and what is its velocity ?
6. With what speed must a ball be thrown vertically from ground level to rise to a maximum height of 50 m?

WEB LINKS

http://www.physicsclassroom.com/Physics-Interactives/1-D-Kinematics

https://phet.colorado.edu/en/simulations/category/physics/motion