KINEMATIC

OF LINEAR MOTION

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OF LINEAR MOTION

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NORHAYATI AHMAD

Preface

Welcome to "Kinematics of Linear Motion," an e-book meticulously designed for students pursuing diplomas and foundation courses in engineering science and physics. This book serves as a comprehensive guide to understanding the fundamental principles of linear motion, making it an invaluable resource for self-learners. The e-book covers essential topics such as linear motion, equations of motion, and projectile motion, providing a solid foundation in these key areas. Each topic is structured to facilitate self-paced learning, featuring detailed example problems that illustrate key concepts and problem-solving techniques. Additionally, a variety of practice problems are included to reinforce learning and build confidence, while challenging examination problems prepare students for assessments. To ensure thorough understanding, all problems come with complete solutions, allowing students to verify their work and grasp the problem-solving process. The book aims to make the study of kinematics engaging and accessible, with clear explanations and step-by-step solutions that help students master complex concepts. Whether you are a beginner or looking to reinforce your knowledge, this e-book is designed to support your academic journey and help you excel in your studies. I am grateful for the opportunity to produce this book.

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KINEMATICS
OF LINEAR MOTION

LINEAR MOTION

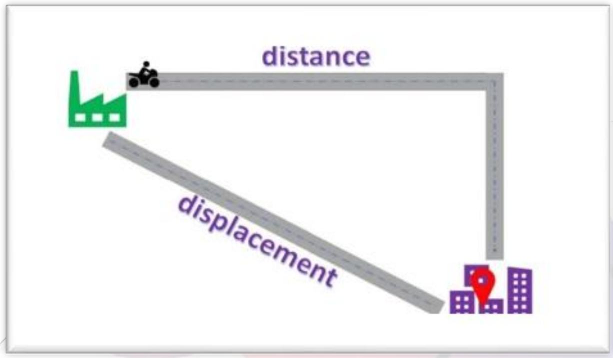
Key knowledge and skills

When you have finished this chapter, you should be able to:

- define instantaneous velocity, average velocity and uniform velocity; and instantaneous acceleration, average acceleration, average acceleration and uniform acceleration.
- interpret the physical meaning of displacement-time, velocity-time and acceleration-time graphs.
- determine the distance travelled, displacement, velocity and acceleration from appropriate graphs.

DEFINITION

Distance	Displacement
✓ The total length of the path traveled by an object.	✓ The shortest straight-line distance between the initial and final positions of an object.
✓ Represented by a positive value. ✓ Direction is not a factor when dealing with distance.	✓ Represented by an arrow or vector. ✓ Displacement can be positive, negative or zero. ✓ Displacement addresses the issue of the overall change position.
Symbol: d or x	Symbol: $\vec{s}$
Unit: meter (m)	Unit: meter (m)
Scalar Quantity	Vector Quantity



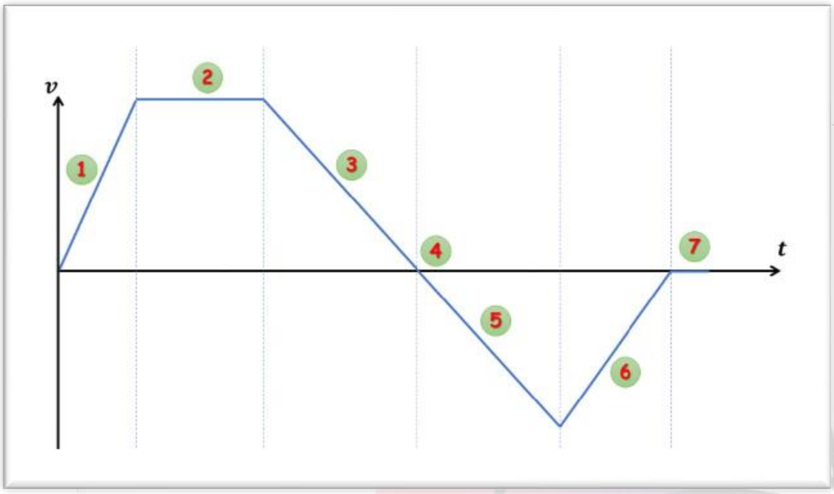
Speed	Velocity
✓ Speed: How fast the object is moving, regardless of direction. $$Speed = \frac{distance}{time}$$	✓ Velocity: measures how fast you are moving in a specific direction. $$\vec{v} = \frac{d\vec{s}}{dt}$$
✓ Average speed: ratio of total distance travelled to the total time taken during the course of motion. $$Average\ speed = \frac{Total\ distance}{Total\ time\ taken}$$	$$Average\ velocity, \vec{v} = \frac{Displacement}{Total\ time}$$ Instantaneous velocity o velocity of an object at a specific moment in time. o Example, if a ball is thrown upwards, its speed decreases as it reaches its highest point, but its velocity is still upward because it maintains its direction. $$Instantaneous\ velocity, \vec{v} = \frac{Instantaneous\ Displacement}{Total\ time}$$ ✓ Can be ZERO.
d or x	$\vec{v}$
m/s	m/s
Scalar Quantity	Vector Quantity

Acceleration, $\vec{a}$	Average acceleration, $\vec{a}_{av}$	Instantaneous acceleration, $\vec{a}$
✓ the rate of change of velocity. $\vec{a} = \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$	✓ Change in velocity divided by time taken. $\vec{a}_{av} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$	✓ Acceleration at a specific point of time. $\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$
✓ Positive acceleration = speeding up ✓ Negative acceleration = slowing down ✓ If a car moves at a constant velocity, then its acceleration is zero		
$\vec{a}$	$\vec{a}_{av}$	$\vec{a}$
m/s^2	m/s^2	m/s^2
Vector Quantity	Vector Quantity	Vector Quantity

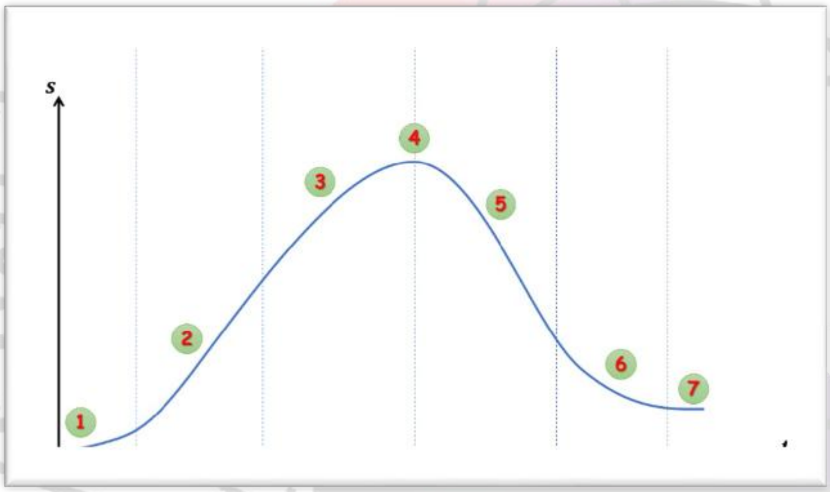
THE LINEAR MOTION GRAPH

Summary of the graphical interpretations of displacement, velocity and acceleration

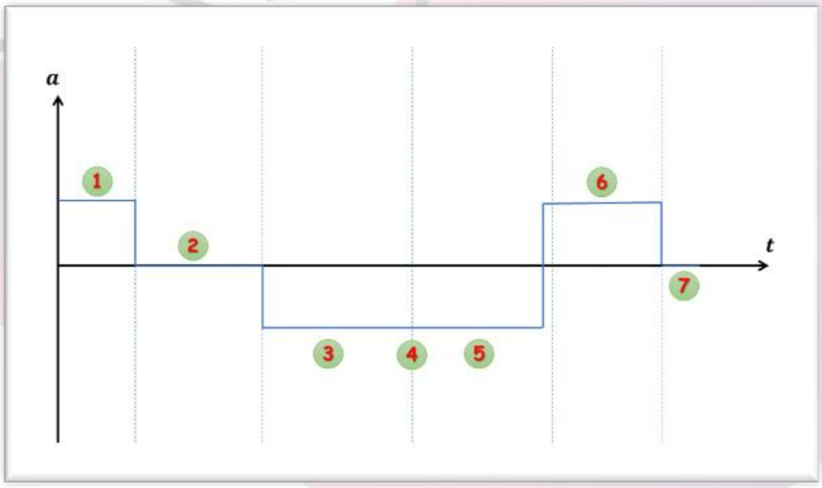
		Graph $s-t$	Graph $v-t$	Graph $a-t$
1	1.	Increasing positive gradient	• Increasing positive velocity • Positive uniform gradient	Positive uniform acceleration
2	2.	Positive uniform gradient	• Positive uniform velocity • Zero gradient	Zero acceleration
3	3.	Decreasing positive gradient	• Decreasing positive velocity • Negative uniform gradient	Negative uniform acceleration
4	4.	Horizontal point (zero gradient)	Zero velocity	Negative uniform acceleration
5	5.	Increasing negative gradient	• Increasing negative velocity • Negative uniform gradient	Negative uniform acceleration
6	6.	Decreasing negative gradient	• Decreasing negative velocity. • Positive uniform gradient	Positive uniform acceleration
7	7.	Continuing zero gradient implies object is at rest	Zero velocity	Zero velocity



(a) Velocity versus time



(b) Distance versus time



(c) acceleration versus time

EXAMPLE 1

1. A student walks 550m to school along a road and returns home along the same road. Determine the displacement of the student and the distance he has travelled?

Solution

$$\text{Displacement} = (+550\text{ m}) + (-550\text{ m})$$
$$= 0 \ \ (\text{Vector quantity})$$

$$\text{Distance} = 550\text{ m} + 550\text{ m}$$
$$= 1100\text{ m (Scalar Quantity)}$$

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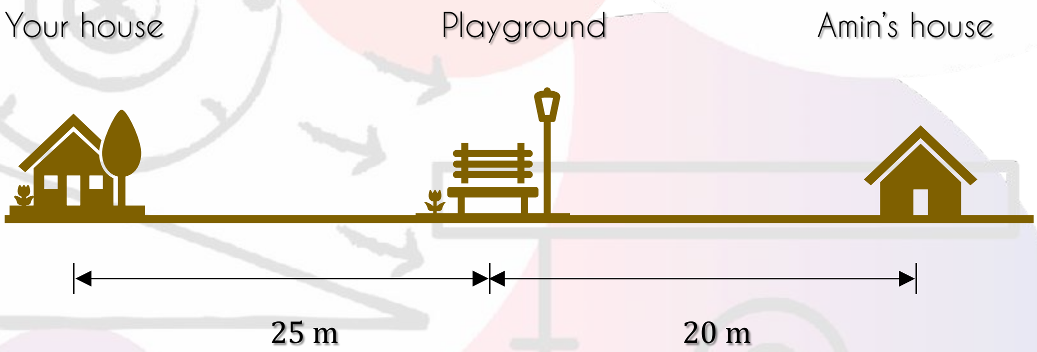
2. You walk from your house to Amin's house, then to the playground. Calculate:
   a. the distance travelled
   b. the displacement



Solution

a. $\text{Distance} = 25\text{ m} + 20\text{ m} + 20\text{m}$
$$= 65\text{ m (Scalar quantity)}$$

b. $\text{Displacement} = (+25\text{ m}) + (+20\text{ m}) + (-20\text{ m})$
$$= 25\text{ m} \ \ (\text{Vector quantity})$$

3. Aminah drives with an average speed of 70kmh^{-1} for 30 minutes. Calculate the distance traveled.

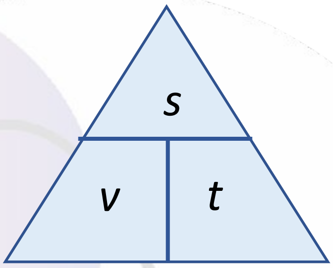
Solution

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

$$\frac{70\text{ km}}{1\text{ h}} = \frac{x}{30\times 60\text{ s}}$$

$$x = \frac{70\times 10^3\times 1800}{1\times 60\times 60}$$

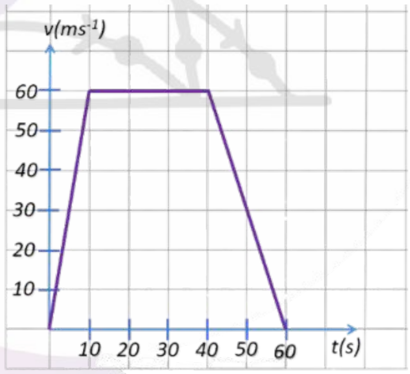
$$= 3.5\times 10^4\text{ m}$$



4. The velocity-time graph represents part of the performance data of a car.

a. Calculate the average velocity of the car.

b. Draw a graph of its acceleration against time between t = 0 and t = 60s. Show your calculation.



Solution

a. Calculate the average velocity of the car.

Total displacement (area under the graph)

$$= \frac{1}{2}(10)(60) + (30)(60) + \frac{1}{2}(20)(60)$$

$$= 3300\text{ m}$$

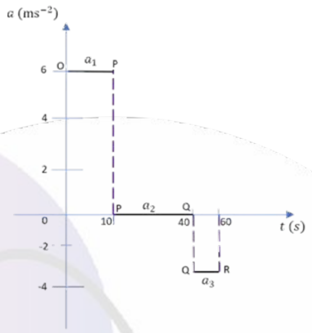
Average velocity, $\vec{v}$

$$= \frac{\text{Displacement}}{\text{Total time}}$$

$$= \frac{3300}{60}$$

$$= 55\text{ ms}^{-1}$$

b. $a = \textbf{Gradient of the velocity} - \textbf{time diagram}$



OP: $a_1 = \frac{60\ \mathrm{ms^{-1}}}{10\ \mathrm{s}} = 6.0\ \mathrm{ms^{-2}}$

PQ: $a_2 = 0\ \mathrm{ms^{-2}}$

QR: $a_3 = \frac{-60\ \mathrm{ms^{-1}}}{20\ \mathrm{s}} = -3.00\ \mathrm{ms^{-2}}$

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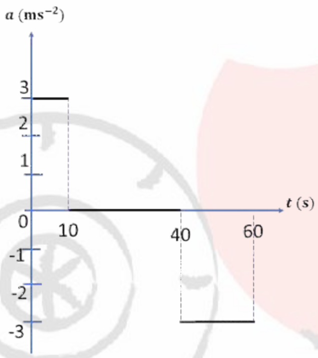
5. A graph of acceleration-time of a car which starts from rest is shown in figure below.



a. Calculate the velocities at t=10s, t=40s and t=60s.

b. Sketch the velocity time graph for the whole journey. Label the values of the velocities at 10s, 40s, and 60s.

c. Determine the total distance travelled by the car.

Solution

a. Calculate the velocities at t 10s, t = 40s and t = 60s.

When t_0, $v = 0$

When t_{10},

$a = \frac{v-u}{t} \quad \rightarrow v = 0 + 3(10)$

$= 30\ \mathrm{ms^{-1}}$

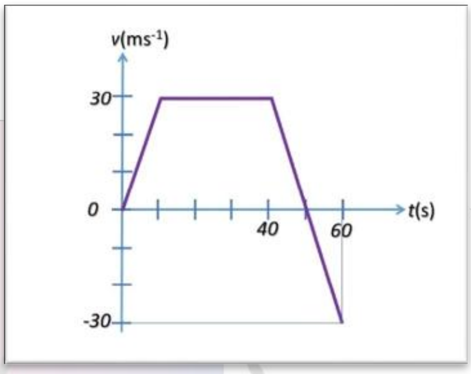
When t_{40}, $\rightarrow v = 30\ \mathrm{ms^{-1}}$

When t_{60},

$a = \frac{v-u}{t} \quad \rightarrow v = 30 + (-3)(20)$

$= -30\ \mathrm{ms^{-1}}$

b. Sketch the velocity time graph for the whole journey. Label the values of the velocities at **10 s, 40 s** and **60 s**.



c. Determine the total distance travelled by the car.

Total distance = area under graph

$$= 150\text{ m} + 900\text{ m} + 600\text{ m}$$

$$= 1650\text{ m}$$

---

6. A student took 20 minutes to ride a motorcycle from her house to school. She started from rest and reached a maximum speed of 12.5 ms^{-1} in 5.0 minutes at constant acceleration. After reaching the maximum speed, she decelerated uniformly to 9.0 ms^{-1} in 3.0 minutes and continued to move at this speed for 5.0 minutes. She then took 7.0 minutes to decelerate uniformly to stop.

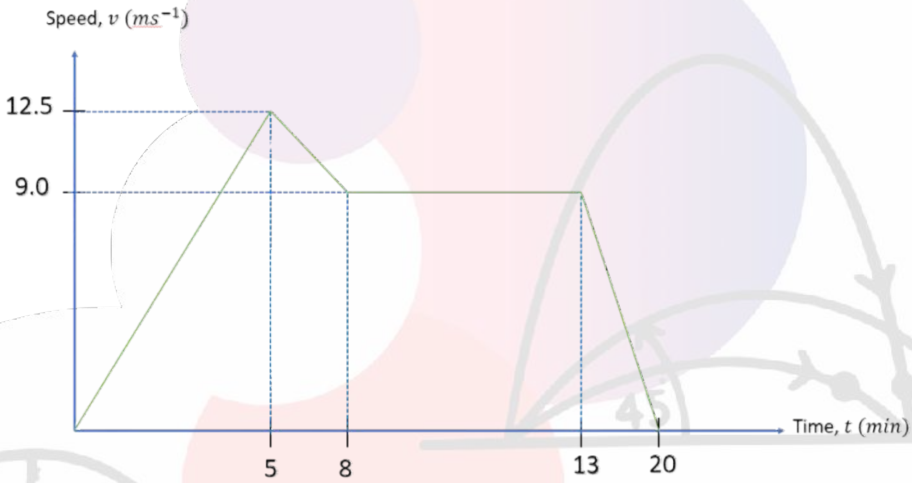
a. Sketch a labelled graph of speed versus time for the whole journey.

b. Calculate the acceleration of the motorcyclist for the period of 0 -5 minutes and 13 -15 minutes.

c. Determine the total distance from her house to school.

Solution

a. Sketch a labelled graph of speed versus time for the whole journey.



b. Calculate the acceleration of the motorcyclist for the period of 0 -5 minutes and 13 -20 minutes.

$$a_1 = \frac{12.5 - 0}{5 \times 60}$$

$= \mathbf{0.042\ ms^{-2}}$ (0-5 min)

$$a_2 = \frac{0 - 9.0}{7 \times 60}$$

$= \mathbf{-0.021\ ms^{-2}}$ (13-15 min)

Negative sign shows that the motorcyclist was moving at deceleration.

c. Determine the total distance from her house to school.

Total distance = area under graph

$$= \left(\frac{1}{2} \times 5(60) \times 12.5\right) + \left(\frac{1}{2} \times (12.5 + 9) \times 3(60)\right) + (5(60) \times 9) + \left(\frac{1}{2} \times 7(60) \times 9\right)$$

$$= 1875\ \text{m} + 1935\ \text{m} + 2700\ \text{m} + 1890\ \text{m}$$

$$= 8400\ \text{m}$$

PRACTICE ZONE 1

a) A honeybee flies 1 km east from its hive to a flower, then 1 km west back to the hive.

i. What is the distance travelled by the bee?

ii. What is the displacement travelled by the bee?

b) A squirrel runs 300 meters up a tree, then 300 meters back down to the ground.

i. What is the total distance travelled by the squirrel?

ii. What is the displacement of the squirrel from its starting point?

c) If a car can maintain a constant speed of 60 km/h, it will cover 60 kilometers every hour. At this rate, how far will it travel in 2 hours? In 30 minutes?

d) A cyclist maintains a constant speed of 20 km/h. How far will the cyclist travel in 3 hours? In 45 minutes?

e) A train travels at a constant speed of 80 km/h. How far will the train travel in 1.5 hours? In 15 minutes?

f) One afternoon, a couple walks three-fourths of the way around a circular lake, the radius of which is 1.50 km. They start at the west side of the lake and head due south to begin with.

i. Calculate the distance travelled by the couple.

ii Determine the magnitude and direction (relative to due east) of the couple's displacement.

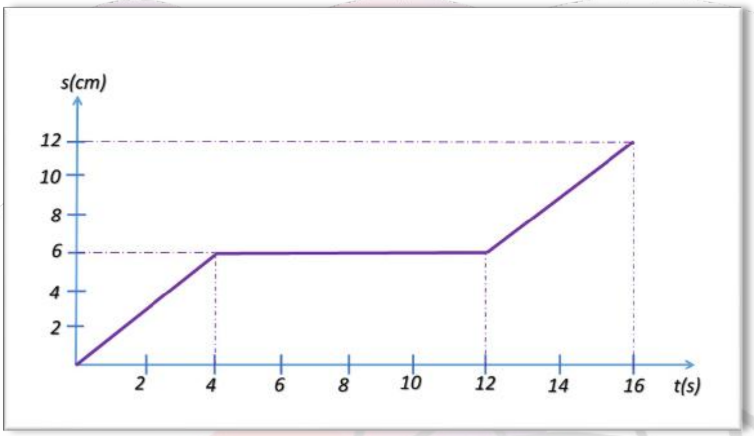
g) A student took 35 minutes to ride a train from her house to a museum. She started from rest and reached a maximum speed of 25.0 m/s in 8.0 minutes at constant acceleration. After reaching the maximum speed, the train decelerated uniformly to 18.0 m/s in 6.0 minutes and continued to move at this speed for 15.0 minutes. She then took 6.0 minutes to decelerate uniformly to stop.

i. Sketch a labelled graph of speed versus time for the whole journey.
ii. Calculate the acceleration of the train for the period of 0 - 8 minutes and 29 - 35 minutes.
iii. Determine the total distance from her house to the museum.

h) A student took 25 minutes to ride a bicycle from her house to a park. She started from rest and reached a maximum speed of 8.0 m/s in 5.0 minutes at constant acceleration. After reaching the maximum speed, she decelerated uniformly to 5.0 m/s in 3.0 minutes and continued to move at this speed for 10.0 minutes. She then took 7.0 minutes to decelerate uniformly to stop.

i. Sketch a labelled graph of speed versus time for the whole journey.
ii. Calculate the acceleration of the cyclist for the period of 0 - 5 minutes and 18 - 25 minutes.
iii. Determine the total distance from her house to the park.

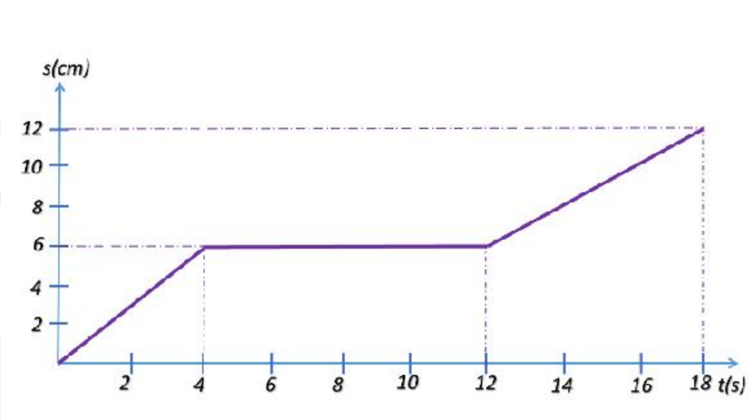
i) A toy train moves slowly along a straight track according to the displacement, s against time, t graph in figure below.



i. Determine the average velocity for the whole journey.

ii. Calculate the instantaneous velocity at t = 16 s.

j) A remote-controlled boat moves along a straight path according to the displacement, (s), against time, (t), graph shown below.



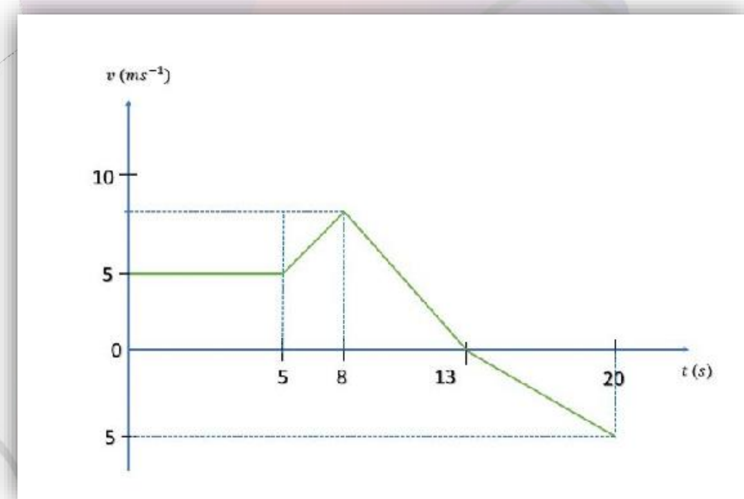
i. Determine the average velocity for the whole journey.

ii. Calculate the instantaneous velocity at t = 18 s.

k) Figure below shows a velocity-time graph of a toy car.

i. Calculate the average velocity and average speed of the entire motion.

ii. Sketch the shape of the corresponding acceleration-time graph.



ANSWER

SCAN ME

https://bit.ly/3Zv2c86

UNIFORMLY ACCELERATED MOTION

Key knowledge and skills

When you have finished this chapter, you should be able to:

- Derive and apply equations of motion with uniform acceleration

$$\boxed{v = u + at} \qquad \boxed{v^2 = u^2 + 2as}$$

$$\boxed{s = \frac{1}{2}(u + v)t} \qquad \boxed{s = ut + \frac{1}{2}at^2}$$

INTRODUCTION

- Uniformly accelerated motion is the motion of an object undergoing constant acceleration that does not change with time.
- In other words, uniformly accelerated motion means a constant acceleration.
- Uniformly accelerated motion in the horizontal dimension is a constant acceleration along the x-axis plane.
- When an object is traveling in a straight line with an increase in velocity at equal intervals of time, then the object is said to be in uniform acceleration.
- Uniformly accelerated motion is characterized by a constant or uniform acceleration of a body or a system of bodies.

EQUATION OF MOTION

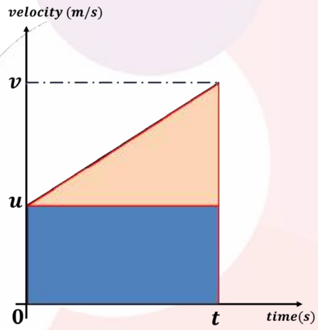
In case of acceleration in linear motion is constant, the four physical quantities of displacement, velocity, time and acceleration can be related by using the Linear Motion Equation, that is:

$v = u + at$

$s = \frac{1}{2}(u+v)t$

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

$v^2 = u^2 + 2as$



From the equation, the symbol of:

s = displacement

u = initial velocity,

v = final velocity,

a = acceleration

SUVAT EQUATIONS

Graphical analysis & algebraic manipulation

Calculus and algebraic manipulation

Rearrange for v

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

$$v = u + at$$

Distance travelled,
s = area under the graph.

Area of the rectangle $= A_1 = ut$

Area of the triangle $= A_2 = ½\,(v-u)t$

Total area $= A_1 + A_2$

$$= ut - \frac{1}{2}ut + \frac{1}{2}vt$$

$$= \frac{1}{2}ut + \frac{1}{2}vt$$

$$v = u + at$$

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

So that

Eq. 1 $\quad s = \frac{(u+v)t}{2}$

Eq. 2 $\quad t = \frac{v-u}{a}$

From Eq. 1, Substitute in Eq. 2:

$$s = \frac{(u+v)}{2}\left(\frac{v-u}{a}\right) = \frac{v^2-u^2}{2a}$$

Rearrange;

$$v^2 = u^2 + 2as \quad \text{....... Eq. 3}$$

Substitute Eq. 1 in Eq. 2:

$$s = \frac{(u+(u+at))t}{2}$$

Rearrange:

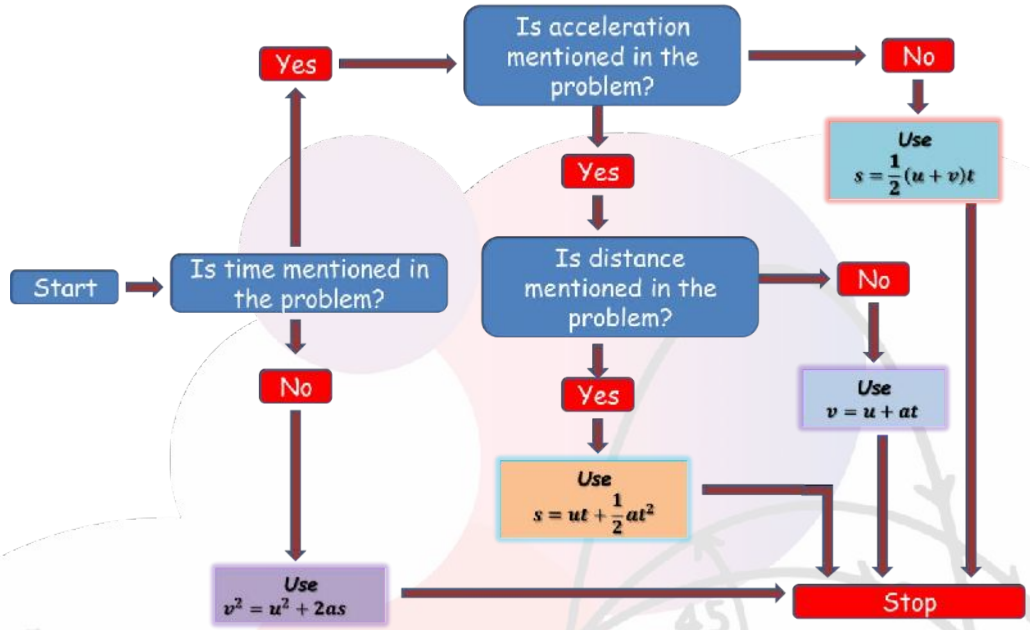
$$s = ut + \frac{1}{2}at^2 \quad \text{......... Eq. 4}$$

<u>How do we select the right equation?</u>

The flow chart below can be used to help you to select the correct equation of motion to use:

Notes on the application of equation

- s, u, v, a are vector quantities, always consider the signs.
- List down the quantities given to you in the problem; **s, t, u, v, a**



EXAMPLE 2

1. A bullet is shot from a gun at a speed of $255\ \mathrm{m/s}$ towards a piece of polystrene with $6.0\ \mathrm{cm}$ thickness and emerges with a speed of $230\ \mathrm{m/s}$. Calculate
   a. the deceleration through the polystyrene,
   b. time taken to get through the polystyrene.

Solution

a. The deceleration through the polystyrene,

Step 1: Given	$s = 6.0\ cm$ $= 0.06\ m$ $a = ?$ $t = NA$ $u = 255 m/s$ $v = 230\ m/s$
Step 2: Choose equation	$v^2 = u^2 + 2as$

Step 3: Substitute	$230^2 = 255^2 + 2a(0.06)$
Step 4: Solution	$a = \left(\frac{230^2 - 255^2}{(0.06)(2)}\right)$ $= -1.01 \times 10^5 \text{ m/s}^2$ (negative: deceleration)
Step 5: Answer	Hence, deceleration, a is $1.01 \times 10^5 \text{ m/s}^2$

b. Time taken to get through the polystyrene.

Step 1: Given:	$s = 6.0 \text{ cm}$ $\quad v = 230 \text{ m/s}$ $= 0.06\, m$ $\quad a = -1.01 \times 10^5 \text{ m/s}^2$ $u = 255 \text{ m/s}$ $\quad t = ?$
Step 2: Choose equation	$v = u + at$
Step 3: Substitute	$t = \frac{230 - 255}{-1.01 \times 10^5}$
Step 4: Solution	$t = 2.48 \times 10^{-4} \text{ s}$
Step 5: Answer	Hence, time taken, t is $2.48 \times 10^{-4} \text{ s}$

2. A taxi moving with an initial speed $30\ \mathrm{m\,s^{-1}}$ is decelerated at a constant rate of $5\ \mathrm{m\,s^{-2}}$ in order to stop in front of a road block. Determine the stopping distance of this taxi.

Solution

The stopping distance of this taxi

Step 1: Given:	$s = ?$ $a = 5\ \mathrm{m/s^2}$ $u = 30\mathrm{m/s}$ $t = NA$ $v = 0\ \mathrm{m/s}$
Step 2: Choose equation	$v^2 = u^2 + 2as$ $s = \dfrac{v^2 - u^2}{2a}$
Step 3: Substitute	$s = \dfrac{v^2 - u^2}{2a}$
Step 4: Solution	$s = \dfrac{0^2 - 30^2}{(2)(-5)}$ $= 90\mathrm{m}$
Step 5: Answer	Hence, the stopping distance of this taxi is $90\ \mathrm{m}$

3. A stationary airplane accelerates 6m/s^2 and travels for 50 s before it takes off. Calculate;

a. the minimum length of the runway,
b. the velocity of the airplane at takeoff.

Solution

a. the minimum length of the runway,

Step 1: Given:	$s = ?$ $a = 6\ \mathrm{m/s^2}$ $u = 0\mathrm{m/s}$ $t = 50\ \mathrm{s}$ $v = NA$

Step 2: Choose equation	$s = ut + \frac{1}{2}at^2$
Step 3: Substitute	$s = (0)(50) + \frac{1}{2}(6)(50)^2$
Step 4: Solution	$s = \frac{1}{2}(6)(50)^2$ $= 7500\ \text{m}$
Step 5: Answer	Hence, the minimum runway length, s is $7500\ \text{m}$

b. the velocity of the airplane at takeoff.

Step 1: Given:	$s = 7500\ \text{m}$ $a = 6\text{m/s}^2$ $u = 0\ \text{m/s}$ $t = 50\ \text{s}$ $v = ?\ \text{m/s}$
Step 2: Choose equation	$v = u + at$
Step 3: Substitute	$v = 0 + (6)(50)$
Step 4: Solution	$v = 300\ \text{m/s}$
Step 5: Answer	Hence, the velocity of airplane at takeoff, v is $300\ \text{m/s}$.

PRACTICE ZONE 2

a) Calculate the missing values, a to x

initial speed m/s	final speed m/s	acceleration m/s^2	time s	distance m
1	11	2.5	4	4
2	6	0.8	5	20
3	9			
4		0.1		45
	15		8	80
6		-0.6	5	
	12	0.5		95
	4		10	60
	16	0.35		250
10		-1.6	5	
	1		10	65
		1.125	24	636

b) A plane lands on a runway at velocity 20 ms^{-1} and decelerates at constant rate. The plane travels 3.2 km before stops. Calculate:

i. the deceleration of the plane.

ii. the time taken for the plane to stop.

c) The speed limit in a school zone is 40 km/h. A driver traveling at this speed sees a child run onto the road 13 m ahead of his car. He applies the brakes and the car decelerates at a uniform rate of 80 m/s^2. If the driver's reactiontime is 0.25 s, will the car stop before hitting the child?

d) A bus accelerates with an acceleration of 5.0 ms^{-2} in 5 seconds after picking up some people at a bus stop. Calculate the:

i. final velocity

ii. distance

e) A car accelerates from rest to a speed of 20 m/s in 5 seconds.

i. What is the acceleration of the car?

ii. How far does the car travel during this time?

f) In the long jump event, Yusri was running at a velocity of 7 m/s towards the long jump pit. He needed to achieve a velocity of 8 m/s after covering a distance of 6 m before lifting himself off the ground from the jumping board. Find the;

i. acceleration

ii. time taken

g) Hasrul was running at 2.5 m/s towards the lift. When he was 15 m away from the lift, the door of the lift was due to close completely in 5 s. In order to be able to enter the lift before its door closed completely. Calculate the minimum acceleration needed by Hasrul, so that he is able to enter the lift.

h) The speed limit in a residential area is 50 km/h. A driver traveling at this speed sees a dog run onto the road 20 m ahead of his car. He applies the brakes and the car decelerates at a uniform rate of 7.0 m/s^2. If the driver's reaction time is 0.3 s, will the car stop before hitting the dog?

i) The speed limit in a parking lot is 20 km/h. A driver traveling at this speed sees a pedestrian 10 m ahead of his car. He applies the brakes and the car decelerates at a uniform rate of 5.0 m/s^2. If the driver's reaction time is 0.2 s, will the car stop before hitting the pedestrian?

j) A cement lorry from the rest travels to a construction site with an acceleration of 0.25 m/s^2 and the final velocity of the cement lorry is 30 m/s. Determine the:

i. Time of the cement lorry arrived at the construction site.

ii. Distance travelled to the construction site.

k) An object starting from 2 m/s accelerated at 4 m/s^2 for 8 seconds. Find:

i. The velocity of the object.

ii. The distance traveled by the object.

l)

i. A motorcycle starts from rest and accelerates at a rate of 1.2 m/s^2 until it reaches a speed of 25 m/s.

ii. Determine the:

iii. Time taken for the motorcycle to reach this speed.

iv. Distance travelled by the motorcycle during this time.

m) A bicycle starts from rest and accelerates at a rate of 0.1 m/s^2 until it reaches a speed of 5 m/s.

Determine the:

i. Time taken for the bicycle to reach this speed.

ii. Distance travelled by the bicycle during this time.

n) A sports car starts from rest and accelerates at a rate of 2.5 m/s^2 until it reaches a speed of 50 m/s.

Determine the:

i. Time taken for the sports car to reach this speed.

ii. Distance travelled by the sports car during this time.

ANSWER

SCAN ME

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PROJECTILE MOTION

Key knowledge and skills

When you have finished this chapter, you should be able to:

- describe projectile motion launched at an angle, as well as special cases when θ.
- solve problems related to projectile motion.
- determine the acceleration due to gravity, g using free fall and projectile motion.

INTRODUCTION

- Projectile motion is the motion of an object thrown or projected into the air, subjected to only the acceleration of gravity.
- The object is called a projectile, and its path is called trajectory.

FREE FALLING BODIES

- Free fall is the motion of an object that occurs under the influence of the gravity (ignore air resistance)
- The acceleration due to gravity, a=$-g$ where, g= acceleration of gravity that always directed downwards. The value of gravity, g = 9.81 ms^{-2}.
- Free fall formula adapted from the linear motion formula

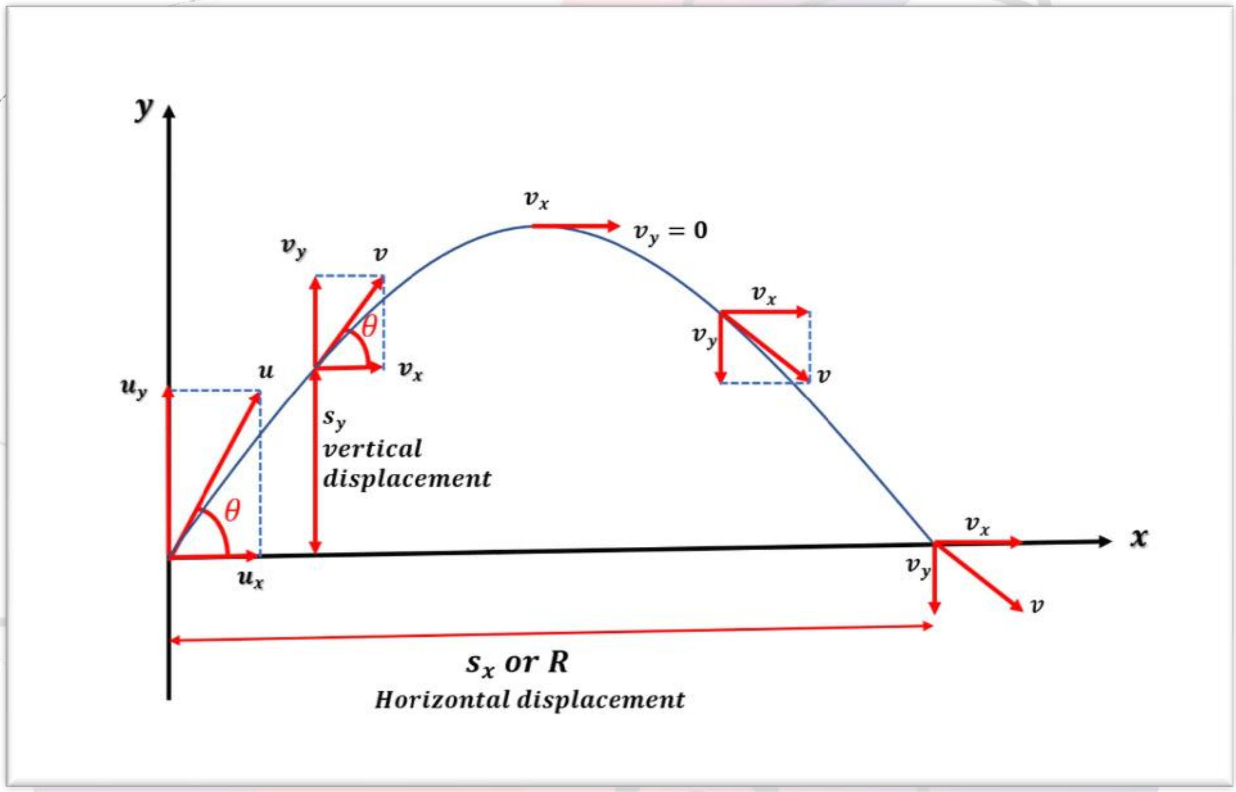
Linear motion		Free fall
i) $v = u + at$	→	*i)* $v = u - gt$
ii) $s = ut + \frac{1}{2}at^2$	→	*ii)* $s = ut - \frac{1}{2}gt^2$
iii) $v^2 = u^2 + 2as$	→	*iii)* $v^2 = u^2 - 2gs$
iv) $s = \frac{1}{2}(u + v)t$	→	*iv)* $s = \frac{1}{2}(u + v)t$

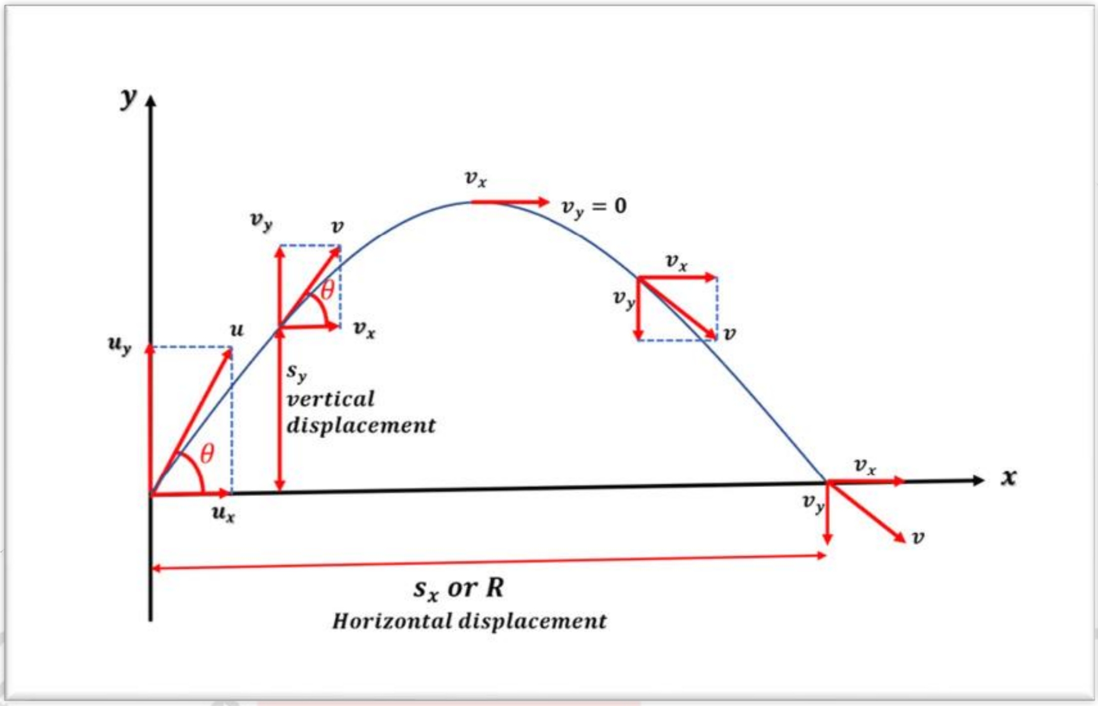
You need to determine the direction of v, u and s.

Upward direction-> positive sign of v, u, and s.

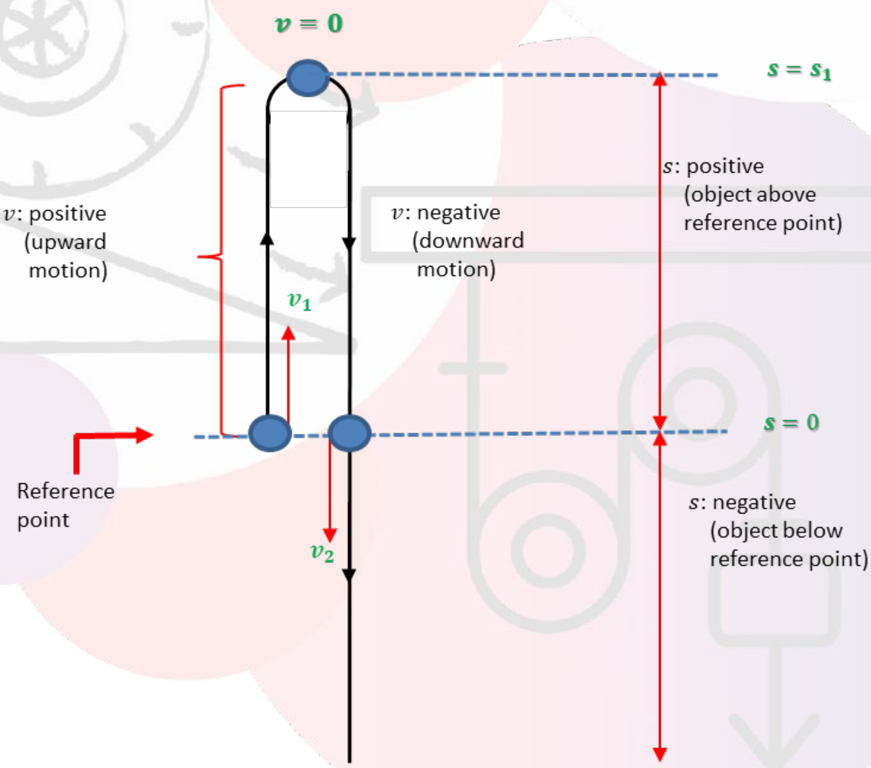
Downward direction is indicated from the negative sign of v, u and s.

- The agreement of sign
- You need to determine the direction of v, u and s.
  - Upward direction-> positive sign of v, u, and s.
  - Downward direction is indicated from the negative sign of v, u and s.

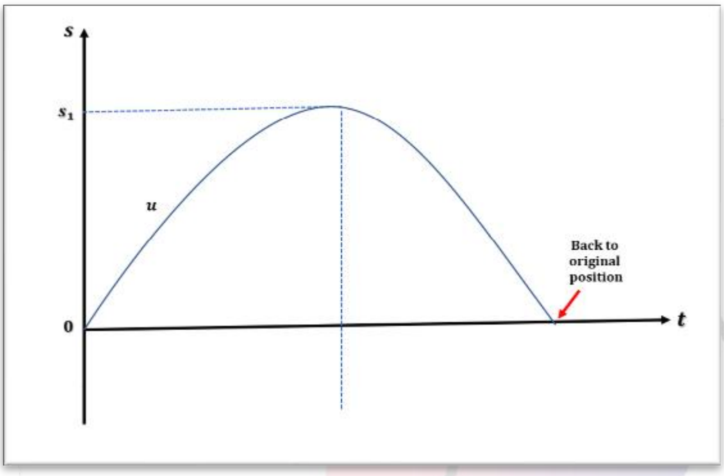




y
v_x
$v_y = 0$
v_y
v
θ
v_x
v_y
v
u_y
u
θ
s_y
vertical displacement
u_x
v_x
x
v_y
v
s_x or R
Horizontal displacement



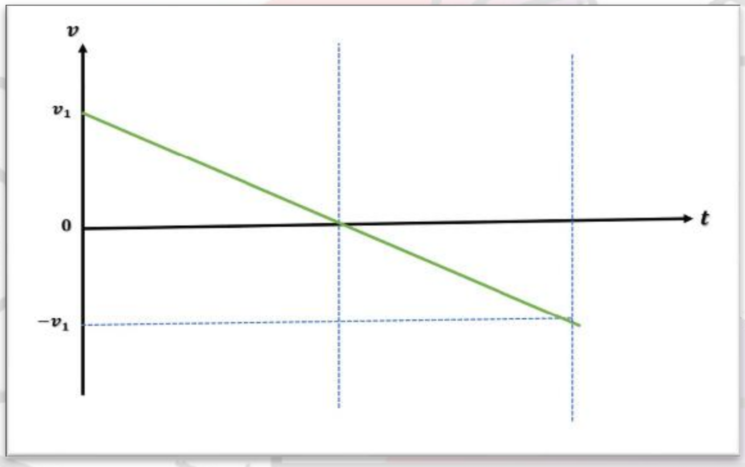
$v = 0$
$s = s_1$
s: positive (object above reference point)
v: positive (upward motion)
v: negative (downward motion)
v_1
$s = 0$
Reference point
v_2
s: negative (object below reference point)



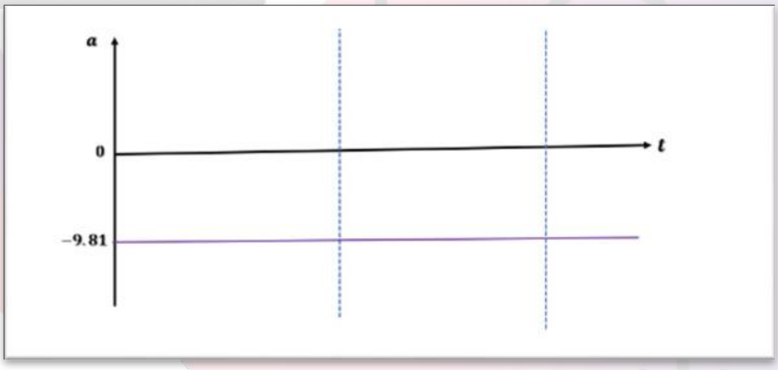
(a) Displacement versus time

graphical interpretations of displacement, velocity and acceleration

(projectile motion)



(b) Velocity versus time



(c) Acceleration versus time

TYPES OF PROJECTILE PATHS

Vertical Projectile Motion	Horizontal Projectile Motion	Oblique Projectile Motion
- The angle between the initial velocity and the horizontal direction is 90°. - The body moves in a vertical direction under the action of gravity.	- In this type of projectile motion, the initial velocity of the projectile is horizontal, and there is no initial vertical velocity. - The projectile moves in a straight line with a constant horizontal velocity.	- In this type of projectile motion, the initial velocity of the projectile has both horizontal and vertical components. - The projectile moves in a curved path, known as a parabolic trajectory, under the influence of gravity.

THE ASSUMPTIONS OF PROJECTILE MOTION

Constant Acceleration due to Gravity

The acceleration of the projectile is always directed downward and has a constant value of approximately 9.81 ms^{-2} on Earth.

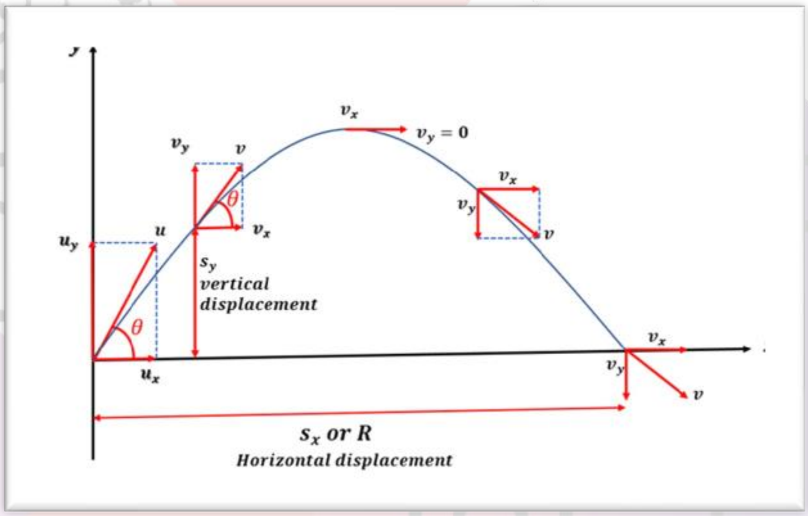
Negligible Air Resistance

Air resistance is negligible for objects where the surface area to mass ratio of the projectile is small.

This assumption simplifies the analysis of projectile motion by ignoring the effects of air resistance on the motion of the projectile.

BASIC EQUATION OF PROJECTILE MOTION

$x - component$	$y - component$
$u_x = u\cos\theta$	$u_y = u\sin\theta$
$v_x = u_x - \cancelto{0}{gt}$ because, $g = 0\ \mathrm{ms}^{-2}$ therefore $v_x = u\cos\theta$	$v_y = u_y - gt$ $v_y = u\sin\theta - gt$ but, $g \neq 0\ \mathrm{ms}^{-2}$
$v_x^2 = u_x^2 - \cancelto{0}{2gs}$ therefore $v_x = u_x$	$v_y^2 = u_y^2 - 2gs_y$ $= (u\ \sin\theta)^2 - 2gs_y$
$s_x = u_xt - \cancelto{0}{\frac{1}{2}gt^2}$ $s_x = (u\cos\theta)t$	$s_y = u_yt - \frac{1}{2}gt^2$ $= (u\sin\theta)t - \frac{1}{2}gt^2$



EXAMPLES 3

1. A stone is thrown horizontally at 13 m/s from the edge of a cliff and it hits the ground 7s later.

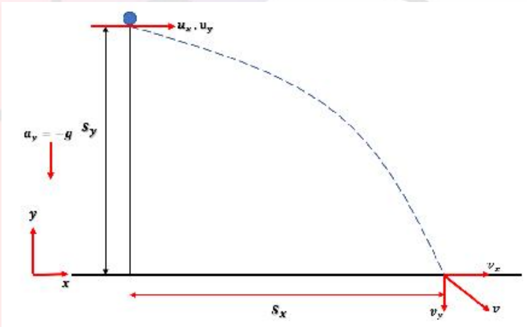
a. What is the height of the cliff?

b. Determine the horizontal distance of the stone and its speed when it hits the ground.

Solution

a. What is the height of the cliff?

Step 1: Visualise the motion.



Step 2: List down the quantities given to you in the problem.

$s_y = ?$ $\quad u_y = 0\ \text{ms}^{-1}$

$s_x = ?$ $\quad v_y = ?$

$u_x = v_x = 13\ \text{ms}^{-1}$ $\quad a_y = g = 9.81\ \text{ms}^{-2}$

$v_y = ?$ $\quad t = 7\ \text{s}$

Step 3: Choose suitable equation (vertical component)

$$s_y = u_y t - \frac{1}{2} a_y t^2$$

Step 4: Apply the equation.

$$s_y = (0)t - \frac{1}{2}(9.81\ ms^{-2})(7)^2$$

Step 5: Compute your solution

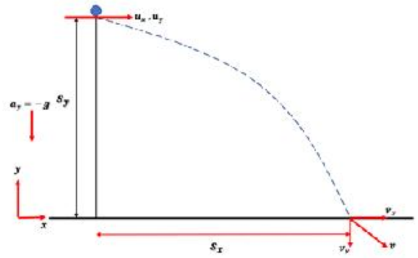
$$s_y = -240.35\ \text{m}$$

Step 6: Answer

Hence, height of the cliff, s_y is $\mathbf{240.35\ m}$.

b. Determine the horizontal distance of the stone and its speed when it hits the ground.

Step 1: Visualise the motion



Step 2: List down the quantities given to you in the problem.

$s_y = ?$ $\quad v_x = 0$

$s_x = ?$ $\quad v_y = ?$

$u_x = 13\ \text{ms}^{-1}$ $\quad a_y = g = 9.81\ \text{ms}^{-2}$

$u_y = 0\ \text{ms}^{-1}$ $\quad t = 7\ \text{s}$

Step 3: Choose suitable equation

$s_x = u_x t$

(horizontal component)

$v_y = u_y - a_y t$

(vertical component)

s_x

$= (13\ \text{ms}^{-1})(7\text{s})$

$= 91\ \text{m}$

$= 0 - 9.81(7)$

$= -68.67\ \text{m/s}$

$v_x = u_x$

$= 13\ ms^{-1}$

$v_y = 0 - (9.81)(7)$

$= -68.67\ \text{ms}^{-1}$

Step 4: Apply the equation

$$\text{Velocity} = \sqrt{v_x^2 + v_y^2}$$

$$= \sqrt{(13^2) + (-68.67)^2}$$

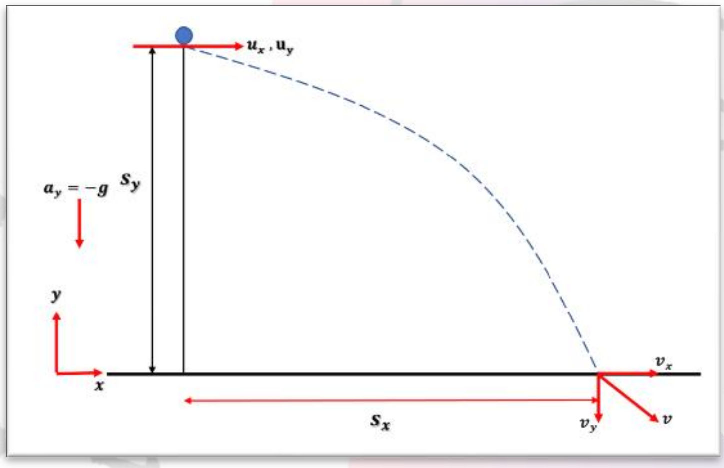
$$= 69.9\ \text{ms}^{-1}$$

Hence, the horizontal distance, s_x is 91 m; speed, v is $69.9\ \text{ms}^{-1}$

2. A ball is rolled horizontally from the top a cliff at the height of 80 m with a speed of 4.6 ms^{-1}. What is the range between the ball and the cliff when the ball reaches the ground? Determine the time of flight and speed of the ball the moment it hits the ground.

Solution

Step 1: Visualise the motion.



Step 2: List down the quantities given to you in the problem.

$s_y = -80$ m

$s_x = ?$

$u_x = v_x$

$= 4.6\ \text{ms}^{-1}$

$u_y = 0\ \text{ms}^{-1}$

$v_y = ?$

$a_y = g$

$= 9.81\ \text{ms}^{-2}$

$t = ?$ s

Step 3: Choose suitable equation

$s_y = u_y t - \frac{1}{2} a_y t^2$ (vertical component)

$s_x = u_x t$

$v = \sqrt{v_x^2 + v_y^2}$

$v_y = u_y - a_y t$

Step 4: Apply the equation

$$-80 = (0)t - \frac{1}{2}(9.81)(t)^2$$
$$t^2 = 16.31$$
$$t = 4.04\text{ s}$$

Step 5: Compute your solution

$t = 4.04$ s, so that $s_x = u_x t$

$$s_x = 4.6(4.04)$$
$$= 18.6\text{ m}$$
$$v_y = u_y - a_y t$$
$$= 0 - 9.81(4.04)$$
$$= -39.63\text{ ms}^{-1}$$
$$v = \sqrt{4.6^2 + (-39.63)^2}$$
$$= 39.90\text{ ms}^{-1}$$

Step 6: Answer

Hence, the range between the ball and the cliff when the ball reaches the ground is 18.6m.

Time of flight is 4.04s and speed of the ball the moment it hits the ground is 39.90 ms^{-1}.

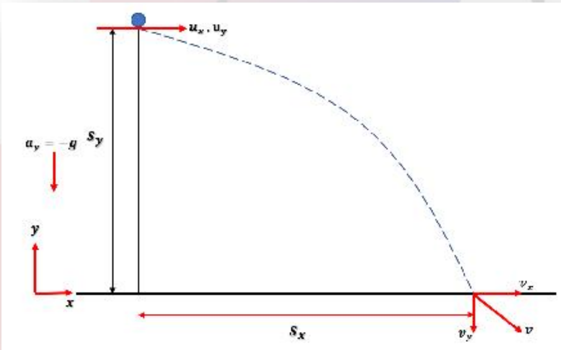
3. A marble ball with a horizontal speed 1.8 ms^{-1} rolls off a bench 1.3m height.

a. How long will the ball take to hit the floor?

b. What is the range of the ball from the edge of the bench?

Solution

Step 1: Visualise the motion.



Step 2: List down the quantities given to you in the problem.

$s_y = -1.3$ m $u_y = 0$ ms^{-1}

$s_x = ?$ $v_y = ?$

$u_x = v_x = 1.8$ ms^{-1} $a_y = g$

$= 9.81$ ms^{-2}

$t = ?$ s

Step 3: Choose suitable equation

$$s_y = u_y t - \frac{1}{2} a_y t^2$$

(vertical component)

$$s_x = u_x t$$

(horizontal component)

$$v = \sqrt{v_x^2 + v_y^2}$$

$$v_y = u_y - a_y t$$

Step 4: Apply the equation

$$-1.3 = (0)t - \frac{1}{2}(9.81\ \mathrm{ms^{-2}})(t)^2$$

$$t = 0.51\ \mathrm{s}$$

Step 5: Compute your solution

$t = 0.51$ s, so that $s_x = u_x t$

$$s_x = 1.8(0.51)$$
$$= 0.92\ \mathrm{m}$$

$$v_y = u_y - a_y t$$
$$= 0 - 9.81(0.51)$$
$$= -5.00\ \mathrm{ms^{-1}}$$

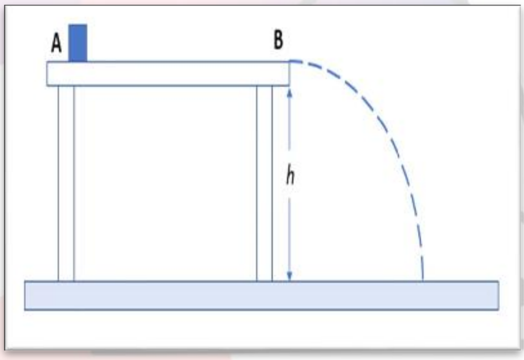
$$v = \sqrt{1.8^2 + (-5.00)^2}$$
$$= 5.31\ \mathrm{ms^{-1}}$$

Hence, the range between the marble and the bench when the marble reaches the ground is $\mathbf{0.92\ m}$.

a) Time the marble takes to hit the floor is $\mathbf{0.51s}$ and

b) speed of the marble the moment it hits the floor is 5.31ms^{-1}

4. The figure below shows a stationary block on a smooth table at a height h above the floor. The block moves 1.8 m from position A to B with uniform acceleration 1.5ms^{-2}. At B the block moves under gravity and falls to the floor in 0.48s.



Calculate,

a. the velocity of the block at B, and

b. the value of h.

Solution

a. the velocity of the block at B, and

$$v^2 = u^2 + 2as$$

$$v^2 = 0 + 2(1.5)(1.8)$$

$$v = 2.32 \text{ ms}^{-1}$$

b. the value of h

$$s_y = u_y t - \frac{1}{2} a_y t^2$$

$$h = 0 - \frac{1}{2}(9.81)(0.48)^2$$

$$= -1.13 \text{ m}$$

The value of h **is 1.13 m**

PRACTICE ZONE 3

a) A stone is thrown horizontally at $12 ms^{-1}$ from the edge of a cliff and it hits the ground 5s later.

i. What is the height of the cliff?

ii. Determine the horizontal distance of the stone and its speed when it hits the ground.

b) A rock is thrown horizontally from a tower with a speed of $8 ms^{-1}$ and hits the ground 4 seconds later. Determine the height of the tower and the horizontal distance covered by the rock.

c) A ball is thrown horizontally from a height of 20 meters with a speed of $5\ ms^{-1}$. How long does it take to hit the ground, and what is the horizontal distance travelled?

d) A stone is projected horizontally from the top of a building with a speed of $12 ms^{-1}$ and hits the ground after 3 seconds. What is the height of the building, and what is the horizontal distance covered by the stone?

e) A ball rolls off a table with a horizontal velocity of $2\ ms^{-1}$ and lands 1.5 meters away from the base of the table. How high is the table, and how long does it take for the ball to hit the ground?

f) A ball is rolled horizontally from the top a cliff at the height of 75m with a speed of $4.5 ms^{-1}$. What is the range between the ball and the cliff when the ball reaches the ground? Determine the time of flight and speed of the ball the moment it hits the ground.

g) A ball rolls off a shelf with a horizontal velocity of $3ms^{-1}$ and lands 2 meters away from the base of the shelf. How high is the shelf, and how long does it take for the ball to hit the ground?

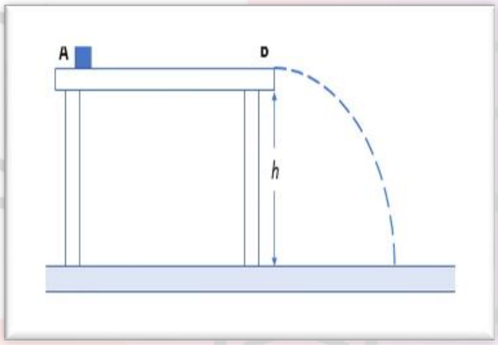
h) A projectile is launched horizontally from a height of 40 meters with a speed of $6ms^{-1}$. Calculate the time it takes to reach the ground and the horizontal distance it travels before hitting the ground.

i) A marble ball with a horizontal speed $1.8ms^{-1}$ rolls off a bench 1.4m height.

i. How long does it take for the ball to hit the floor?

ii. What is the range of the ball from the edge of the bench?

j) The figure below shows a stationary block on a smooth table at a height h above the floor. The block moves 1.8 m from position A to B with uniform acceleration $1.5\ ms^{-1}$. At B the block moves under gravity and fall onto the floor in 0.48s.



Calculate

i. the velocity of the block at B, and

ii. the value of h.

ANSWER

SCAN ME

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EXAMINATION PRACTICE

QUESTION 1

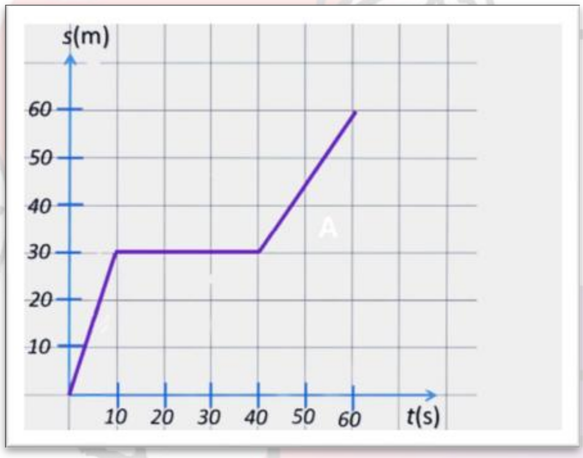
(a) Define:

i. Displacement.

ii. Instantaneous speed.

iii. Uniform acceleration.

(b) The position-time graph below represents the motion of a cyclist.



i. Calculate the average speed of the cyclist.

ii. Draw a graph of its velocity against time between (t = 0s) and (t = 60s). Show your calculations.

(c) A ball rolls off a table with a horizontal velocity of 2 ms^{-1} and lands 1.5 meters away from the base of the table. How high is the table, and how long does it take for the ball to hit the ground?

QUESTION 2

(a) i. Define instantaneous velocity.

ii. Is there any difference between instantaneous velocity and instantaneous speed of a car if it is moving in one direction on a straight road? Explain why.

(b) A runner jogs 300m to a park along a path and returns home along the same path. What is the displacement of the runner and the distance he has travelled?

(c) A stone is thrown horizontally from a height of 25 meters with a speed of 7 ms_{-1}. How long does it take to reach the ground, and what is the horizontal distance travelled?

QUESTION 3

3(a) i. Define linear motion and provide TWO (2) examples.

ii. State **TWO (2)** characteristics of distance and displacement.

(b) A car is accelerated at $2ms^{-2}$ from an initial velocity of $15ms^{-1}$ for 1.5 minutes. Calculate the final velocity of the car.

(c) A cyclist took 20 minutes to ride from his house to the park. He started from rest and reached a maximum speed of 15 m/s in 6 minutes at constant acceleration. After reaching the maximum speed, he decelerated uniformly to 10 m/s in 4 minutes and continued to move at this speed for 8 minutes. He then took 2 minutes to decelerate uniformly to stop.

i. Sketch a labelled graph of speed versus time for the whole journey.
ii. Calculate the acceleration of the cyclist for the periods of 0-6 minutes and 18-20 minutes.
iii. Determine the total distance from his house to the park.

(d) A ball is projected horizontally from a balcony with a speed of 9ms-1 and hits the ground after 4 seconds. What is the height of the balcony, and how far does the ball travel horizontally?

QUESTION 4

(a) Explain the following terms when a car moves from one town to another town:

a. Displacement
b. Average speed
c. Acceleration

(b) A car starts from $30ms^{-1}$ and maintains its velocity for15s. The car then accelerates at a constant rate of $8ms^{-2}$ for 10s. For the next 20s, the car maintains the velocity before decelerating and stopping in 5s.

i. Sketch a velocity-time graph to represent the motion of the car.

ii. Calculate the deceleration of the car.

iii. Calculate the total distance travelled by the car using the graph.

(c) A rock is thrown horizontally from a bridge with a speed of 11 m/s. If it takes 5 seconds to reach the water below, what is the height of the bridge, and what is the horizontal distance covered by the rock.

QUESTION 5

(a) Define the following terms and state their SI unit:

i. Distance

ii. Displace

iii. Velocity

iv. Deceleration

(b) A car starts from rest and accelerates uniformly at a rate of $3ms^{-2}$. Calculate the distance it covers in 5 seconds.

(c) A cyclist accelerates from rest at a rate of $2ms^{-2}$ for 8s. Calculate the final velocity and the distance covered.

(d) A ball is thrown horizontally with a speed of 15 ms^{-1} from the top of a cliff that is 80 meters high. Ignore air resistance.

i. How long does it take for the ball to hit the ground?

ii. How far does the ball land from the base of the cliff?

iii. What is the velocity of the ball just before it hits the ground?

ANSWER

SCAN ME

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