Kinematics

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Vocabulary List

Distance	路程/距离	Average	平均的
Displacement	位移	Gradient	斜率
Speed	速率	Free fall	自由落体
Velocity	速度	Force of Gravity	重力
Acceleration	加速度	Terminal velocity	终端速度
Instantaneous	瞬时的		

Introduction

Kinematics is the **science of describing the motion of objects using words, diagrams, graphs, and equations**.

The goal of kinematics is to develop mental models to describe the motion of real-world objects.

We will learn to describe motion using:

1. Words
2. Diagrams
3. Graphs
4. Equations

Describing Motion with words

The motion of objects can be **described by words**.

Even a person without a background in physics has a collection of words, which can be used to describe moving objects. For example, going faster, stopped, slowing down, speeding up, and turning provide a sufficient vocabulary for describing the motion of objects.

In physics, we use these words as the language of kinematics.

1. Distance and Displacement
2. Speed and Velocity
3. Acceleration

These words which are used to describe the motion of objects can be divided into two categories.

The quantity is either a **vector** or **scalar**.

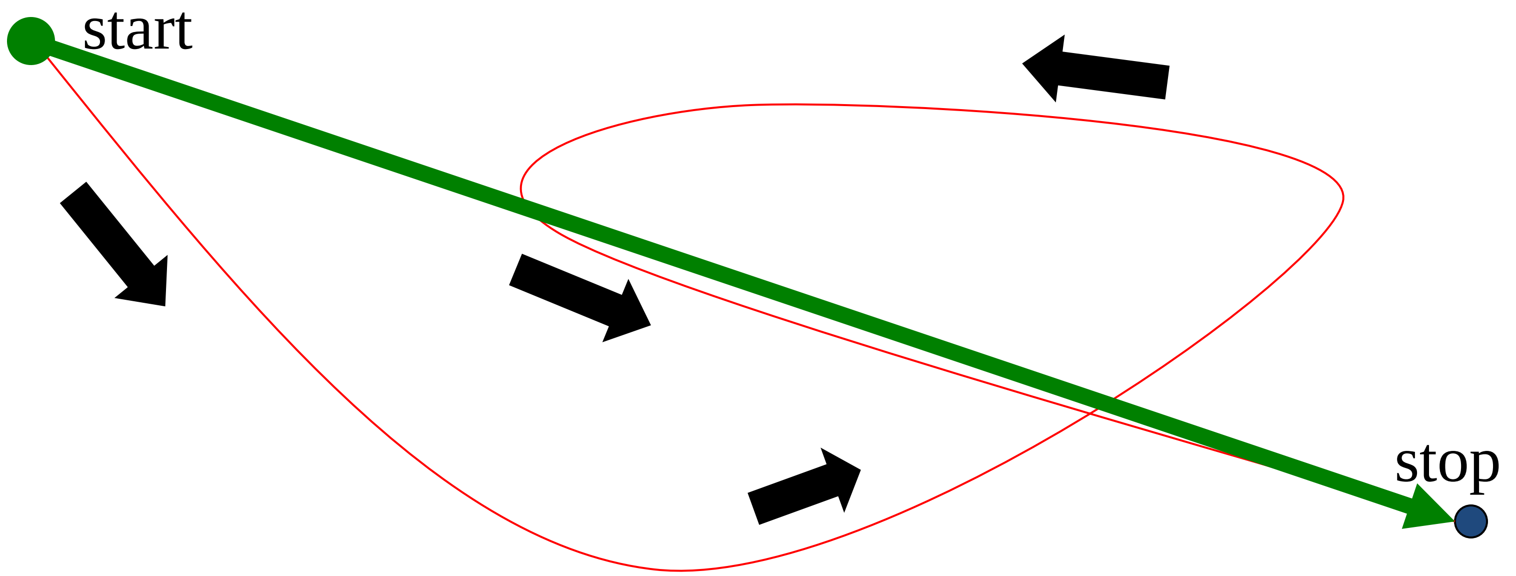
1. Scalars are quantities which are described by a magnitude only.

2. Vectors are quantities which are described by both a magnitude and a direction.

Distance	**Displacement**
Distance refers to **the total length of travel irrespective of the direction of the motion.** It is a **scalar quantity.** SI unit: metre (m) Other common units: kilometre (km), centimetre (cm)	Displacement refers to **the distance moved in a particular direction.** It is the object's overall change in position. It is a **vector quantity.** SI unit: metre (m) Other common units: kilometre (km), centimetre (cm)

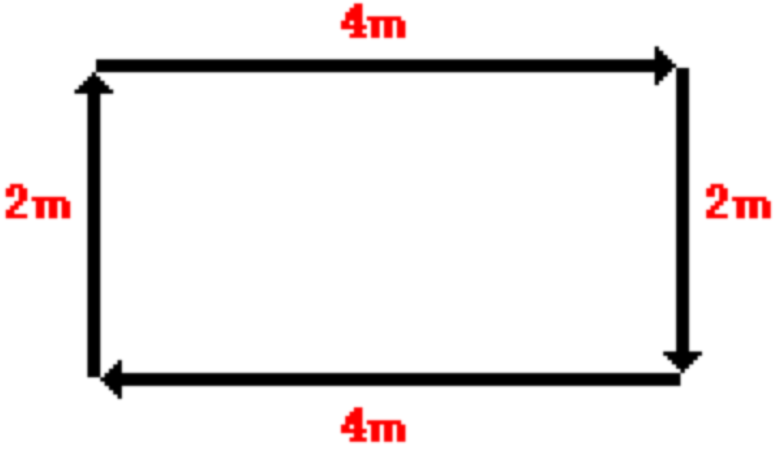
Distance vs. Displacement

- You drive the path, and your odometer goes up (your distance).
- Your displacement is the shorter <u>directed</u> distance from start to stop (green arrow).



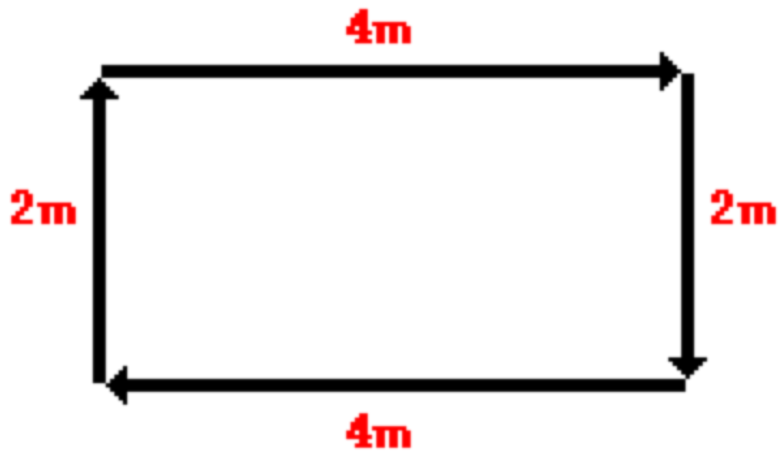
Example 1

A student walks 4 m East, 2 m South, 4 m West, and finally 2 m North.



Total distance = 12 m

During the course of his motion, the total length of travel is 12 m.



Total displacement = 0 m

When he is finished walking, **there is no change in his position.** The 4 m east is "canceled by" the 4 m west; and the 2 m south is "canceled by" the 2 m north.

Speed	Velocity
Speed is **the rate of change of distance.** It is a **scalar quantity.** $$Speed = \frac{distance\ travelled}{time\ taken}$$	Displacement is the **distance travelled in a specific direction.** Velocity is defined as **the rate of change of displacement.** It is a **vector quantity.** $$Velocity = \frac{change\ in\ displacement}{time\ taken}$$

Instantaneous Speed and Average Speed

As an object moves, it often undergoes changes in speed.

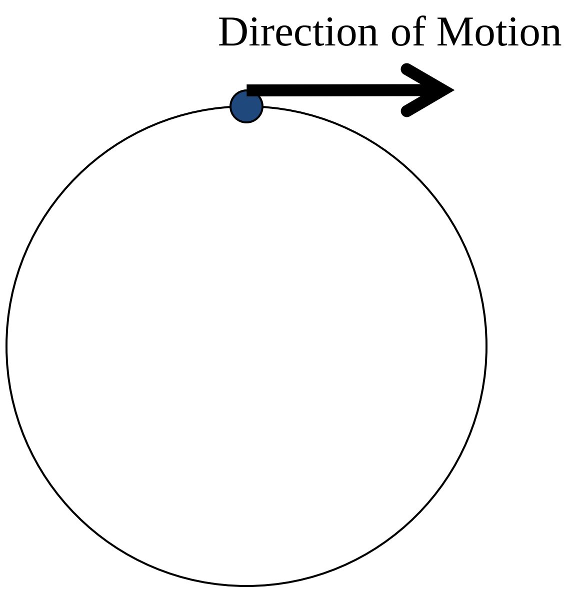
The speed at any instant is known as the **<u>instantaneous speed</u>**. (From the value of the speedometer)

The <u>average speed of the entire journey</u> can be calculated:

$$\text{Average Speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

Speed Vs Velocity

An object is moving in a circle at a **constant speed** of 10 m s^{-1}.
We say that it has a constant speed but **its velocity is not constant.**
Why?



The direction of the object keeps changing.

Acceleration

- An object whose velocity is changing is said to accelerate.
- If the direction and / or speed of a moving object changes, the object is accelerating
- Acceleration is the rate of change of velocity

Time (s)	Velocity (m/s)
0	0
1	10
2	20
3	30
4	40
5	50

Acceleration

Acceleration is a vector quantity

SI unit: ms^{-2}

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

where a = acceleration, v =final velocity, u = initial velocity and t = time.

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

Describing Motion with Graphs

1.Plot and interpret a distance-time graph and a speed-time graph.

2. Deduce from the shape of a distance-time graph when a body is:
   (a) at rest
   (b) moving with uniform speed
   (c) moving with non-uniform speed

3. Deduce from the shape of a Velocity-time graph when a body is:
   (a) at rest
   (b) moving with uniform speed
   (c) moving with uniform acceleration
   (d) moving with non-uniform acceleration

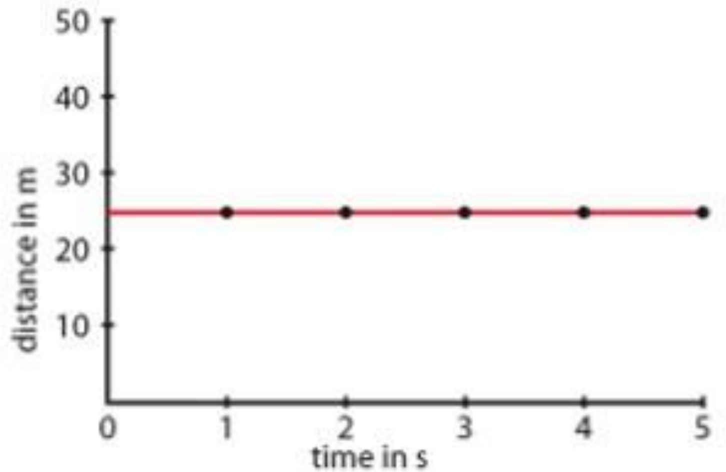
4. Calculate the area under a speed-time graph to determine the distance travelled for motion with uniform speed or uniform acceleration.

Distance-time Graph

A car has travelled past a lamp post on the road and the distance of the car from the lamp post is measured every second. The distance and the time readings are recorded and a graph is plotted using the data. The following pages are the results for four possible journeys:

(a) Car at rest

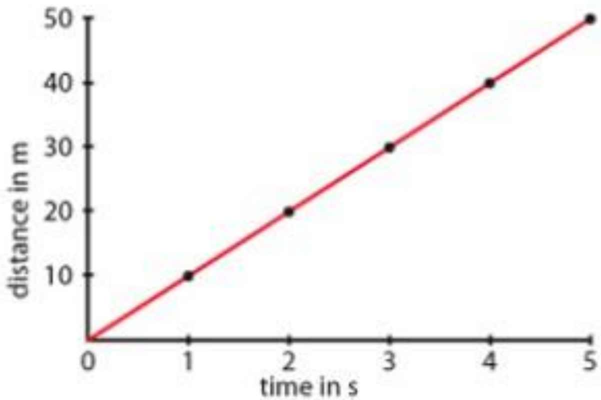
Time in s	0	1	2	3	4	5
Distance in m	25	25	25	25	25	25



The car is parked 25 m from the post, so the distance remains the same.

(b) Car moving with a uniform speed of 10 m s^{-1}

Time in s	0	1	2	3	4	5
Distance in m	0	10	20	30	40	50

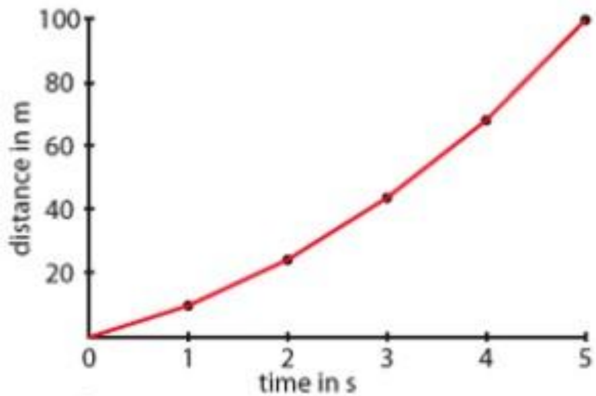


Distance increases 10 m for every 1 s.

(c) Car moving with non-uniform speed

(i) Car accelerating

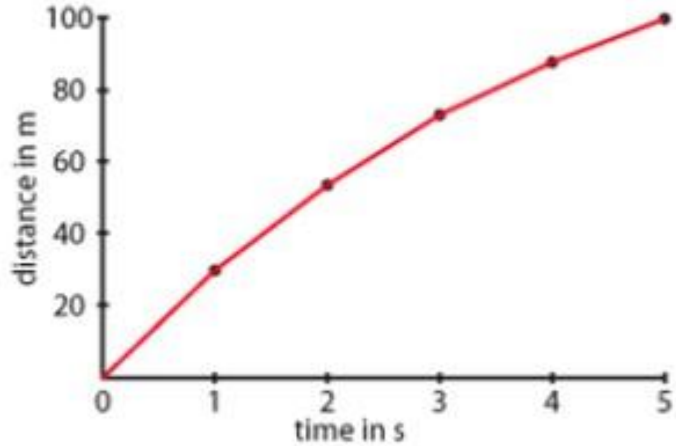
Time in s	0	1	2	3	4	5
Distance in m	0	10	25	45	70	100



Speed increases, so the car travels a longer distance as time increases.

(ii) Car decelerating

Time in s	0	1	2	3	4	5
Distance in m	0	30	55	75	90	100

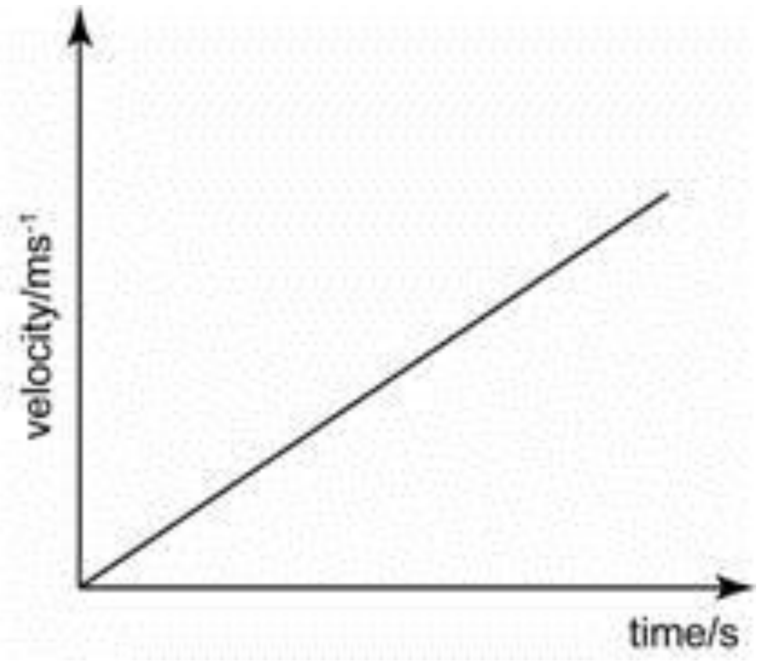


Speed decreases, so the car travels a shorter distance as time increases.

The gradient of the distance-time graph gives the speed of the moving object.

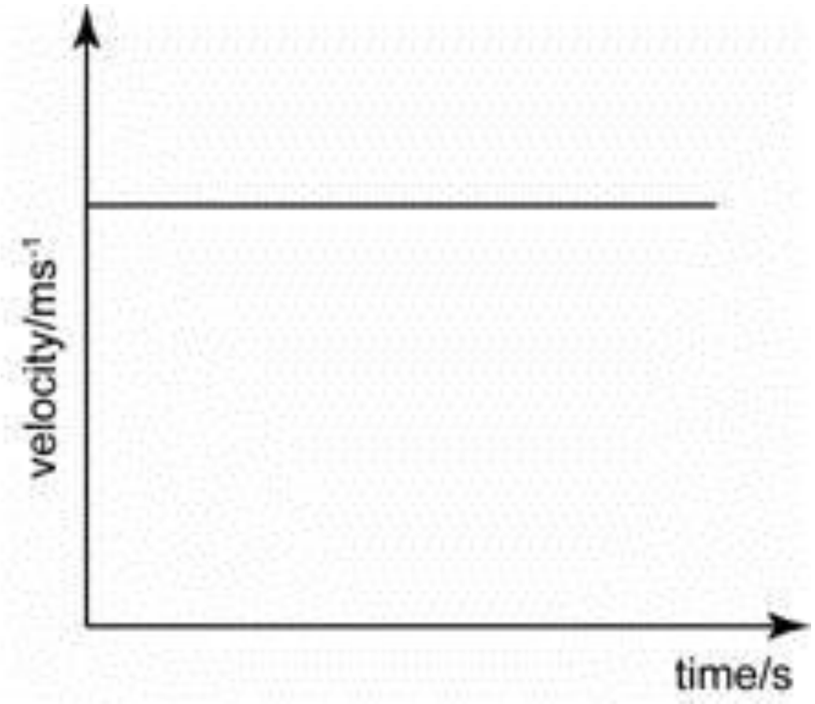
Velocity - Time Graph

- The **gradient** of the velocity-time gradient gives a value of the changing rate in velocity, which is the **acceleration** of the object.
- The **area** below the velocity-time graph gives a value of the object's **displacement**.

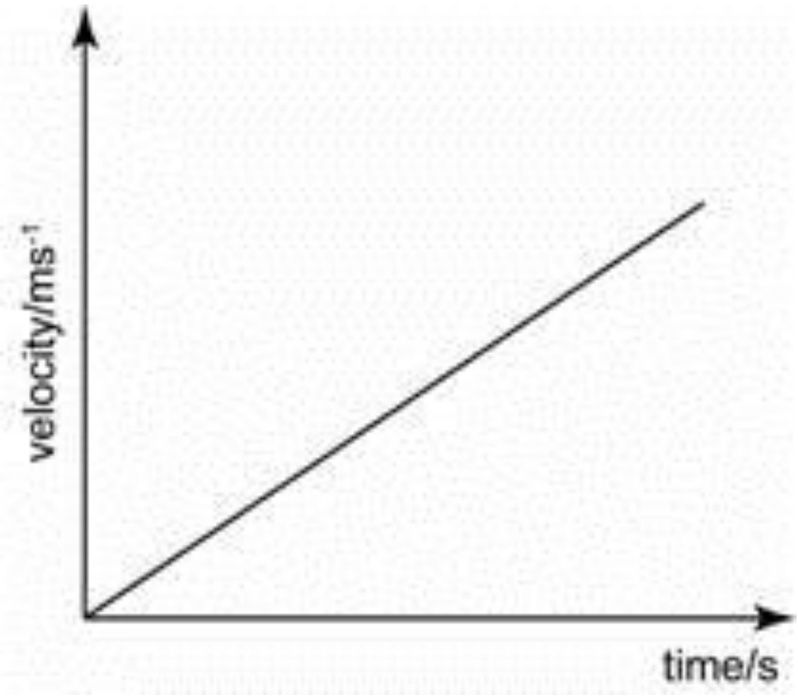


Analysing Velocity - Time Graph

- Uniform Velocity

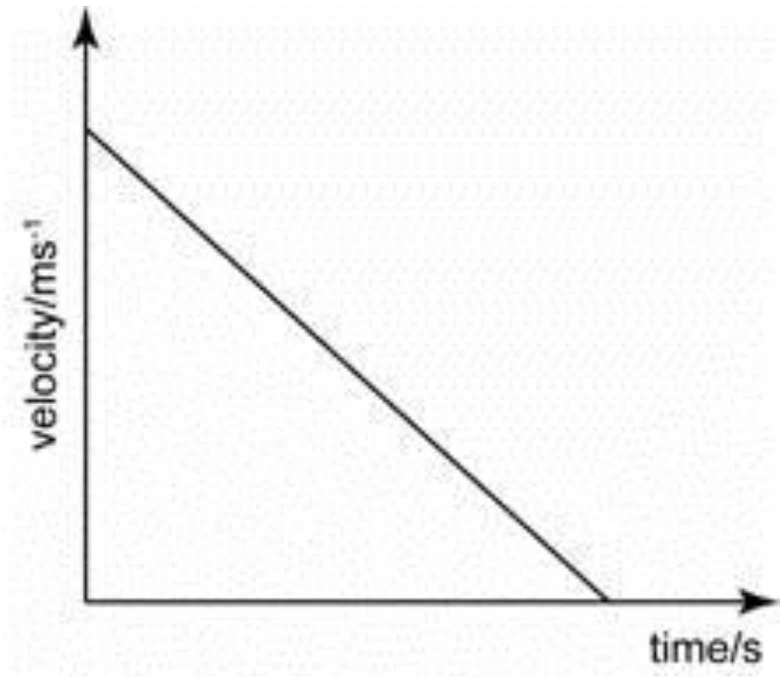


- Uniform Acceleration

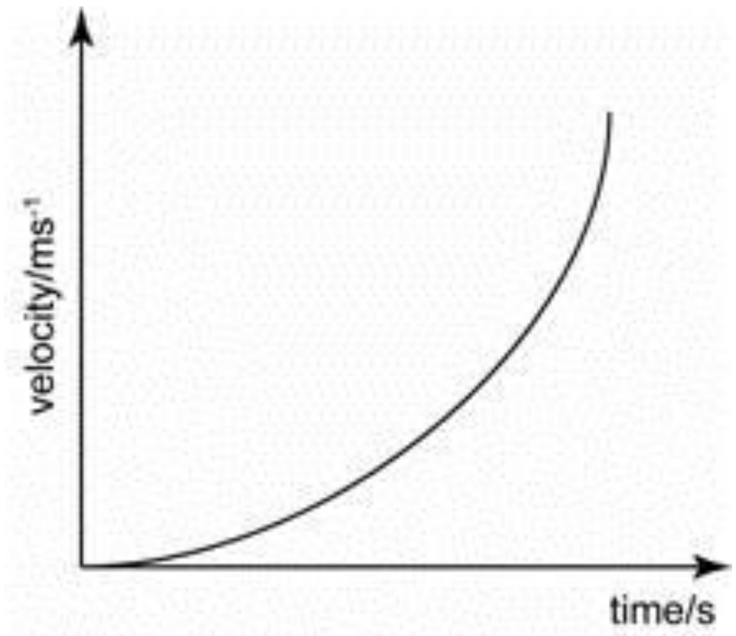


Analysing Velocity - Time Graph

- Uniform deceleration

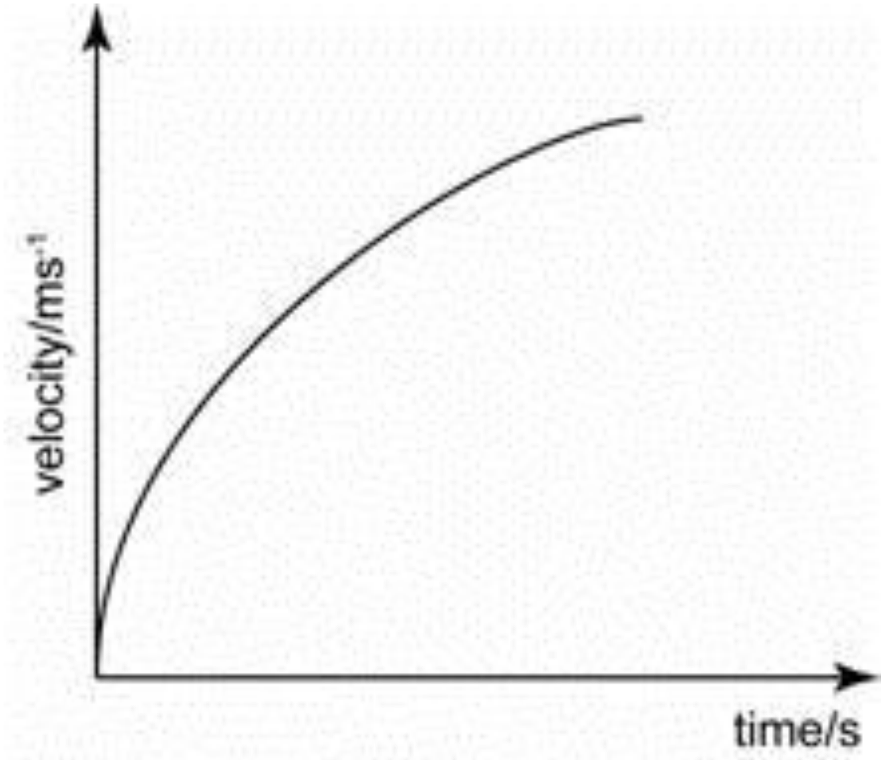


- Increasing acceleration



Analysing Velocity - Time Graph

Decreasing acceleration



How do you find the gradient of velocity-time graph?

- You need to select two points on the graph, for example (x_1,y_1) and (x_2,y_2).
- Once you have selected the points you put then into the equation $m=(y_2-y_1)/(x_2-x_1)$
- m = the gradient

- The gradient represents the acceleration.
- In other words, We take the vertical reading from the graph where the acceleration finishes and divide it by the horizontal reading where the acceleration finishes.

Example 1

Figure 2.14 shows the speed-time graph of a moving lift.

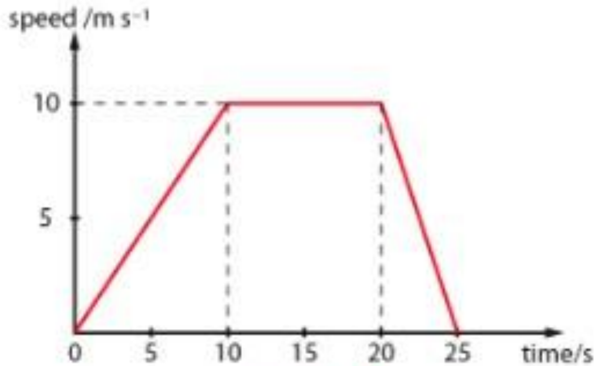


Figure 2.14

(a) What is the maximum speed of the lift?

(b) For how many seconds does the lift move?

(c) How much speed does the lift gain in the first 10 seconds? What is its acceleration?

(d) What is the deceleration of the lift in the last 5 seconds?

Solution

(a) The maximum speed of the lift is 10 m s^{-1}.

(b) The lift moves for 25 s.

(c) The lift gains 10 m s^{-1} in the first 10 s.

$$\text{Acceleration} = \frac{10-0}{10} = 1 \text{ m s}^{-2}$$

(d) $$\text{Acceleration} = \frac{0-10}{5} = -2 \text{ m s}^{-2}$$

Therefore the deceleration is 2 m s^{-2}.

Area under a speed-time graph

The figure below shows the speed-time graph of a car travelling with a uniform speed of 20 ms^{-1}. The distance travelled by the car is given by:

Distance = speed x time = 20 x 5

= 100 m

The same information of distance travelled can also be obtained by calculating the area under the speed-time graph.

The area under a speed-time graph gives the distance travelled.

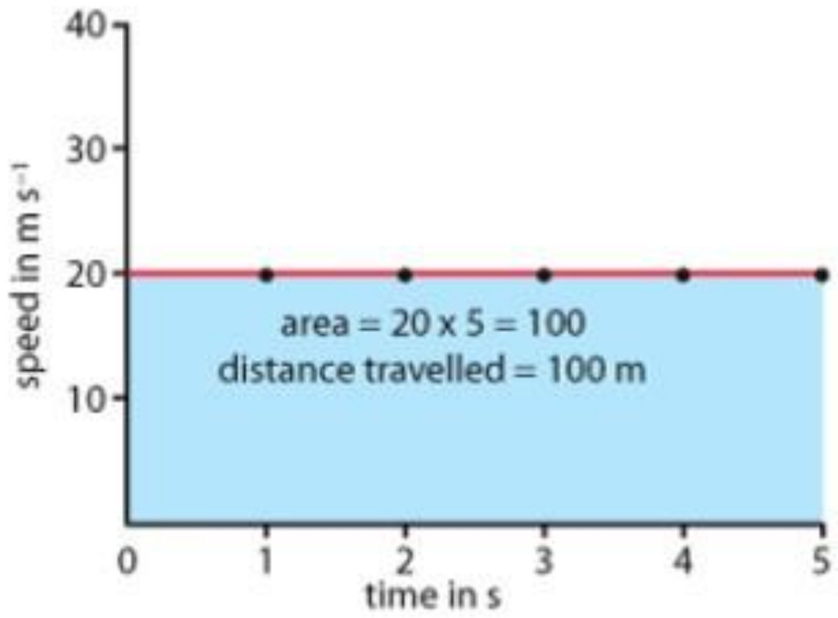


Figure 2.16

Example 3 - Question

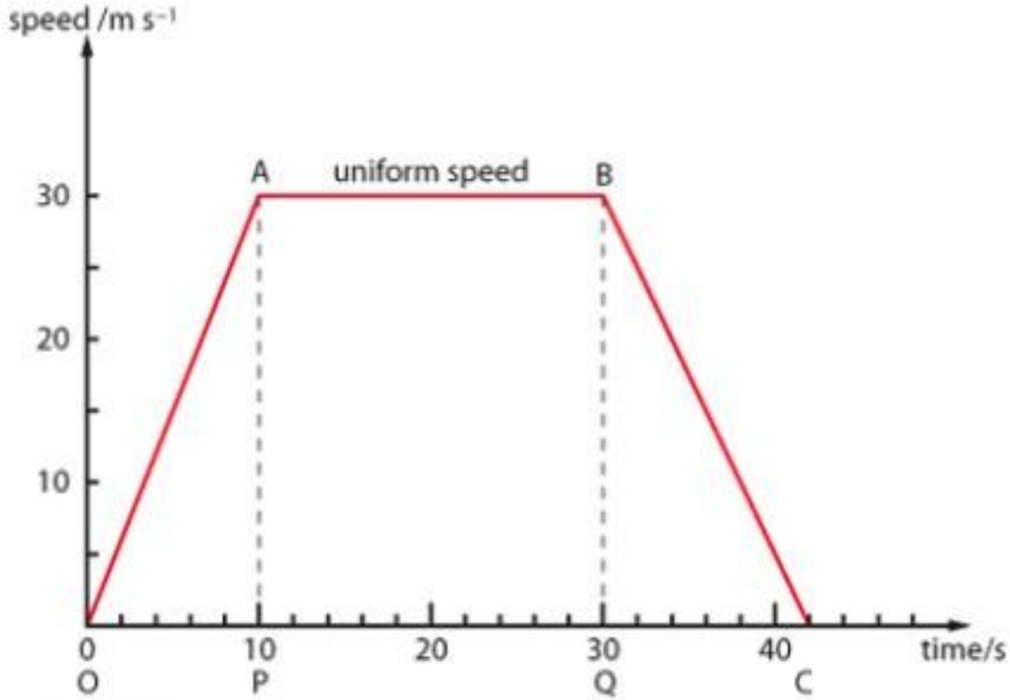


Figure 2.17 Speed-time graph of a car accelerating, moving with uniform speed and then decelerating

Figure 2.17 shows the speed-time graph of a car travelling along a straight road.

(a) What is the distance travelled during the first 10 s?

(b) What is the total distance travelled?

(c) What is the time taken for the whole journey?

(d) What is the average speed for the whole journey?

Example 3 - Solution

Solution

(a) During the first 10 s, distance travelled = area of triangle OAP

$$= \frac{1}{2} \times 10 \times 30$$

$$= 150 \text{ m}$$

(b) Total distance travelled = area of trapezium OABC

$$= \frac{1}{2} \times (20 + 42) \times 30$$

$$= 930 \text{ m}$$

(c) Time taken for the whole journey = 42 s

(d) Average speed for the whole journey $= \frac{\text{Total distance travelled}}{\text{Total time taken}}$

$$= \frac{930}{42}$$

$$= 22.1 \text{ m s}^{-1}$$

Uniformly accelerated motion

- **Free fall** is motion with no acceleration other than that provided by gravity.

In other words………

- **A free-falling object is an object which is falling under the sole influence of gravity.**
- **Any object which is being acted upon only be the force of gravity is said to be in a state of free fall.**

Free Fall

Any object which is moving and being acted upon only be the force of gravity is said to be "in a state of free fall.“

- all objects fall freely at $g = 9.81\ \text{m s}^{-2}$ when near the earth and air resistance is negligible.
- speed of a free-falling body increases by $9.8\ \text{m s}^{-1}$ every second or when a body is thrown up, its speed decreases by $9.8\ \text{m s}^{-1}$ every second.

Although the acceleration due to gravity is considered constant, it tends to vary slightly over the earth since the earth is not a perfect sphere.

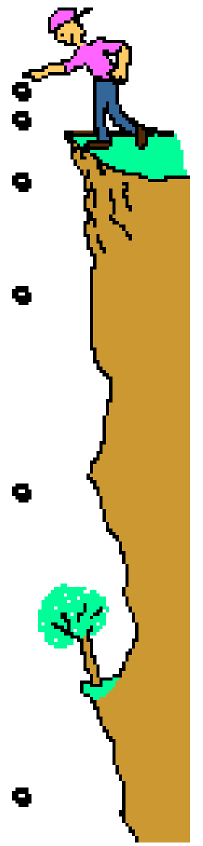
Examples

- Examples of objects in Free fall

➢ Throwing a ball into the air and the ball will rise first then start to fall in the absence of air resistance.

- Examples of objects not in Free fall

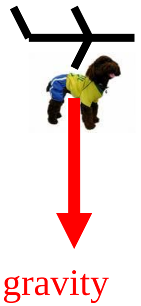
➢ Standing on the ground: the gravitational acceleration is counteracted by the normal force from the ground.



Questions to answer !

- **“Doesn't a more massive object accelerate at a greater rate than a less massive object?" "Wouldn't an elephant free-fall faster than a mouse?"**

Force of gravity means the dog accelerates

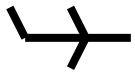


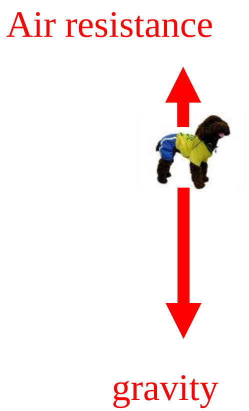
To start, the dog is falling slowly (it has not had time to speed up).

There is really only one force acting on the dog, the force of gravity.

The dog falls faster (accelerates) due to this force.

Gravity is still bigger than air resistance





As the dog falls faster, another force becomes bigger – air resistance.

The force of gravity on the dog of course stays the same

The force of gravity is still bigger than the air resistance, so the dog continues to accelerate (get faster)

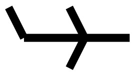
Gravity = air resistance
Terminal Velocity

As the dog falls faster and air resistance increases, eventually the air resistance becomes as big as (equal to) the force of gravity.

The dog stops getting faster (accelerating) and falls at constant speed.

This velocity is called the terminal Velocity

Terminal Speed



The dog will continue to fall at constant speed (called the terminal speed) until…………