LINEAR MOTION

- DISTANCE
- SPEED AND VELOCITY
- ACCELERATION

Specification

Forces and motion

Movement and position

plot and interpret distance-time graphs

know and use the relationship:

average speed = distance moved / time taken

describe experiments to investigate the motion of everyday objects such as toy cars or tennis balls

know and use the relationship:

acceleration = change in velocity / time taken $a = (v - u) / t$

plot and interpret velocity-time graphs

determine acceleration from the gradient of a velocity-time graph

determine the distance travelled from the area between a velocity-time graph and the time axis.

Average Speed

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

In physics speed is usually measured in:

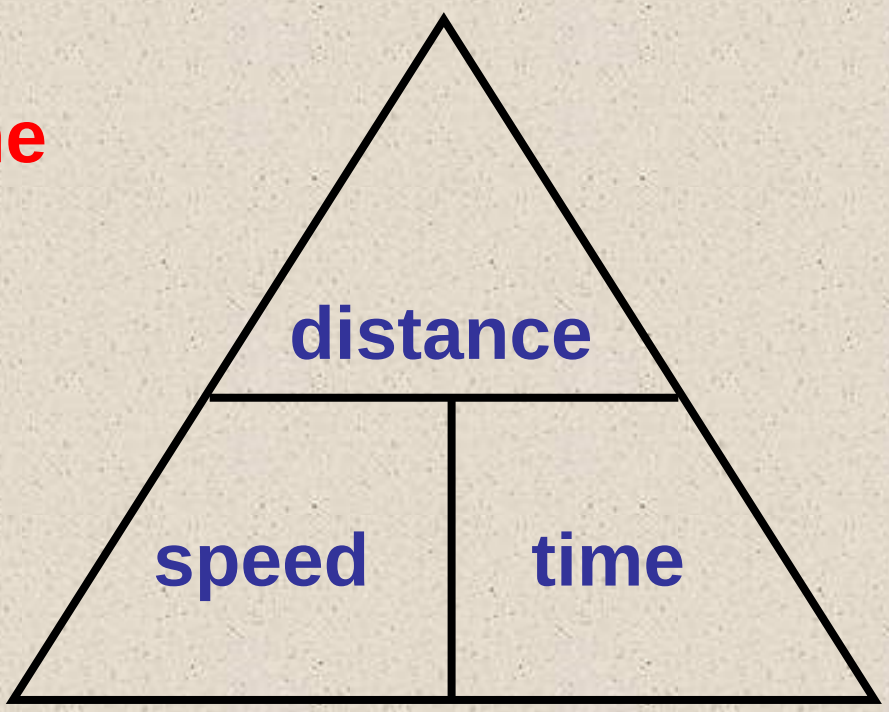
metres per second (m/s)

also:

distance = speed x time

and:

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



Speed Conversions

1 kilometre per hour (km/h)

= 1000 metres per hour

but 1 hour = 3600 seconds

therefore 1 km/h = 1000m ÷ 3600 s

1 km/h = 0.28 m/s

and 1 m/s = 3.6 km/h

Also: **100 km/h = approx 63 m.p.h**

Question 1

Calculate the average speed of a car that covers 500m in 20s.

average speed = distance / time

= 500m / 20s

= 25 m/s *(about 60 mph)*

Question 2

Sound waves travel at about 340m/s through air. How far will a sound wave travel in one minute?

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Sound waves travel at about 340m/s through air. How far will a sound wave travel in one minute?

distance = speed x time

= 340 m/s x 1 minute

= 340 m/s x 60 seconds

= 20 400 m

(20.4 km)

Complete

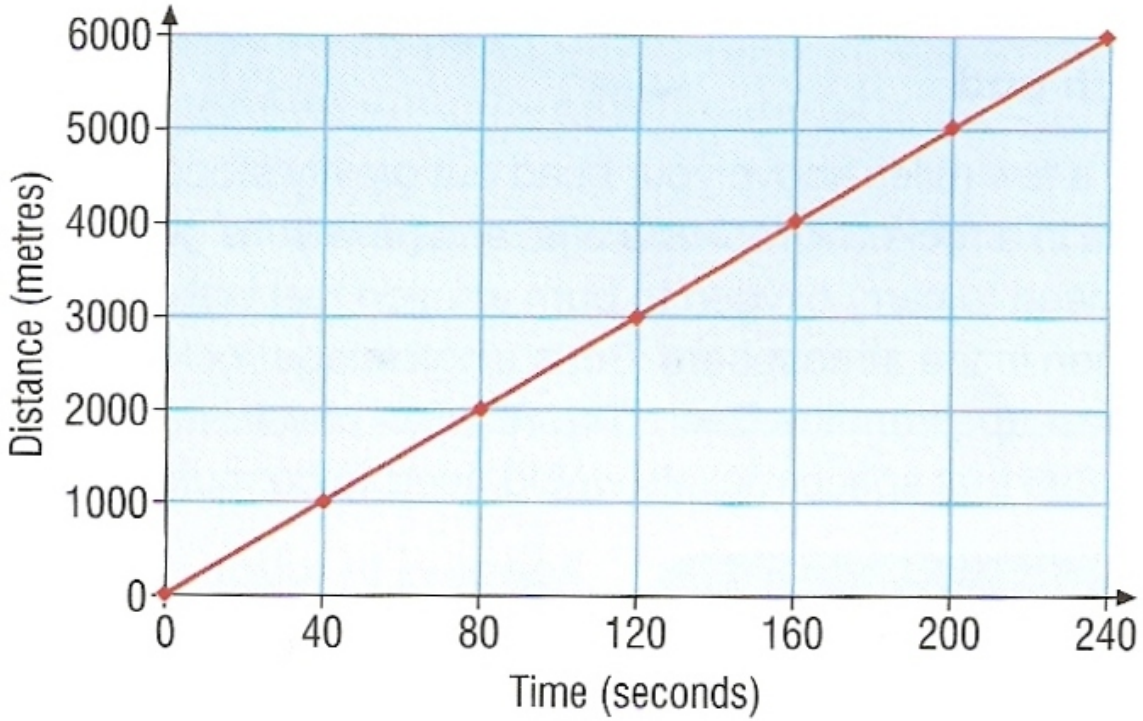
distance	time	average speed
60 m	3 s	m/s
m	35 s	40 m/s
300 m	s	1500 m/s
80 km	2 h	km/h
150 x 10^{6} km	Min s	3.0 x 10^{8} m/s
1 km	s	330 m/s

Complete

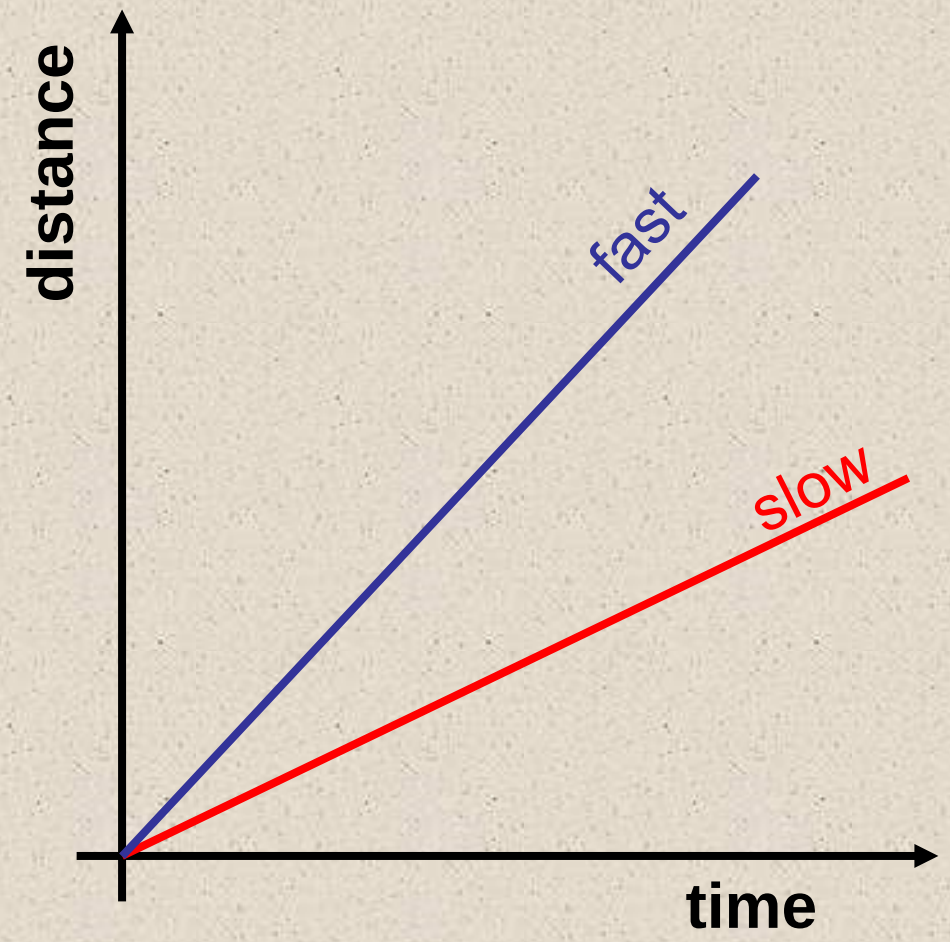
distance	time	average speed
60 m	3 s	20 m/s
1400 m	35 s	40 m/s
300 m	0.20 s	1500 m/s
80 km	2 h	40 km/h
150×10^{6} km	8 min 20 s	3.0×10^{8} m/s
1 km	3.03 s	330 m/s

Distance-time graphs

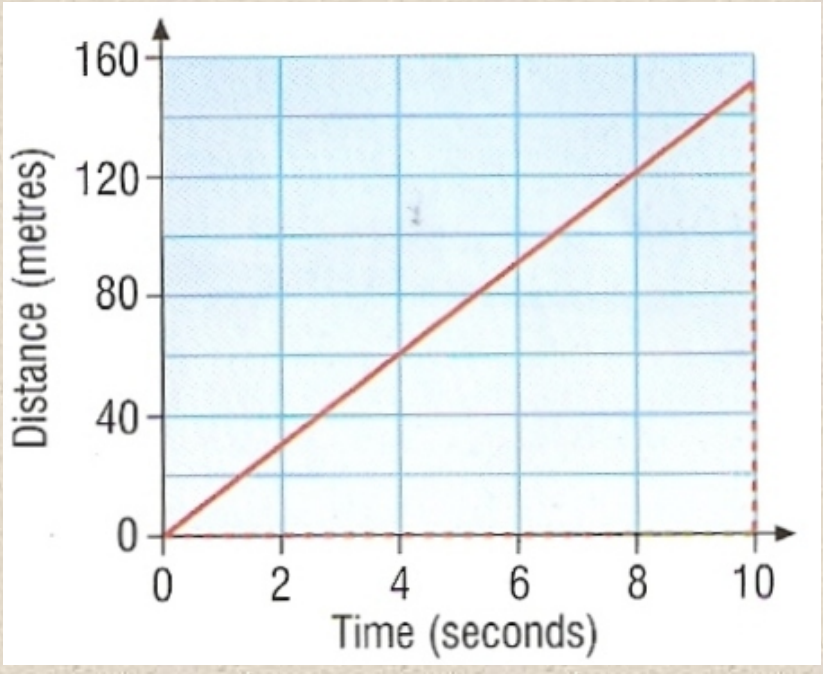
Distance (metres, m)	0	1000	2000	3000	4000	5000	6000
Time (seconds, s)	0	40	80	120	160	200	240



The **slope or gradient** of a distance-time graph increases with **speed.**



The **slope or gradient** of a distance-time graph is equal to the **speed.**



In the graph opposite:

slope = 150m / 10s

= 15 m/s

= speed

Question 1

Sketch on the same set of axes distance-time graphs for:

(a) a car moving at a steady speed,

(b) a bus moving at a steady speed greater than the car,

(c) a lorry increasing in speed from rest.

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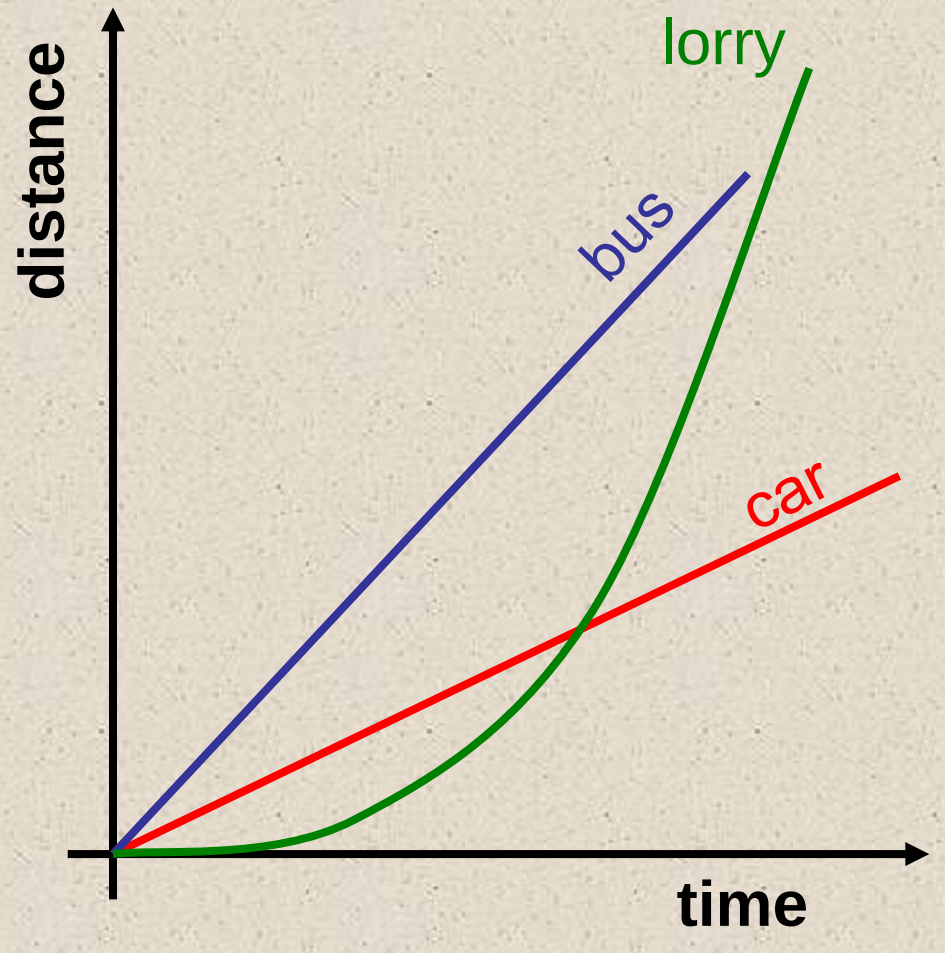
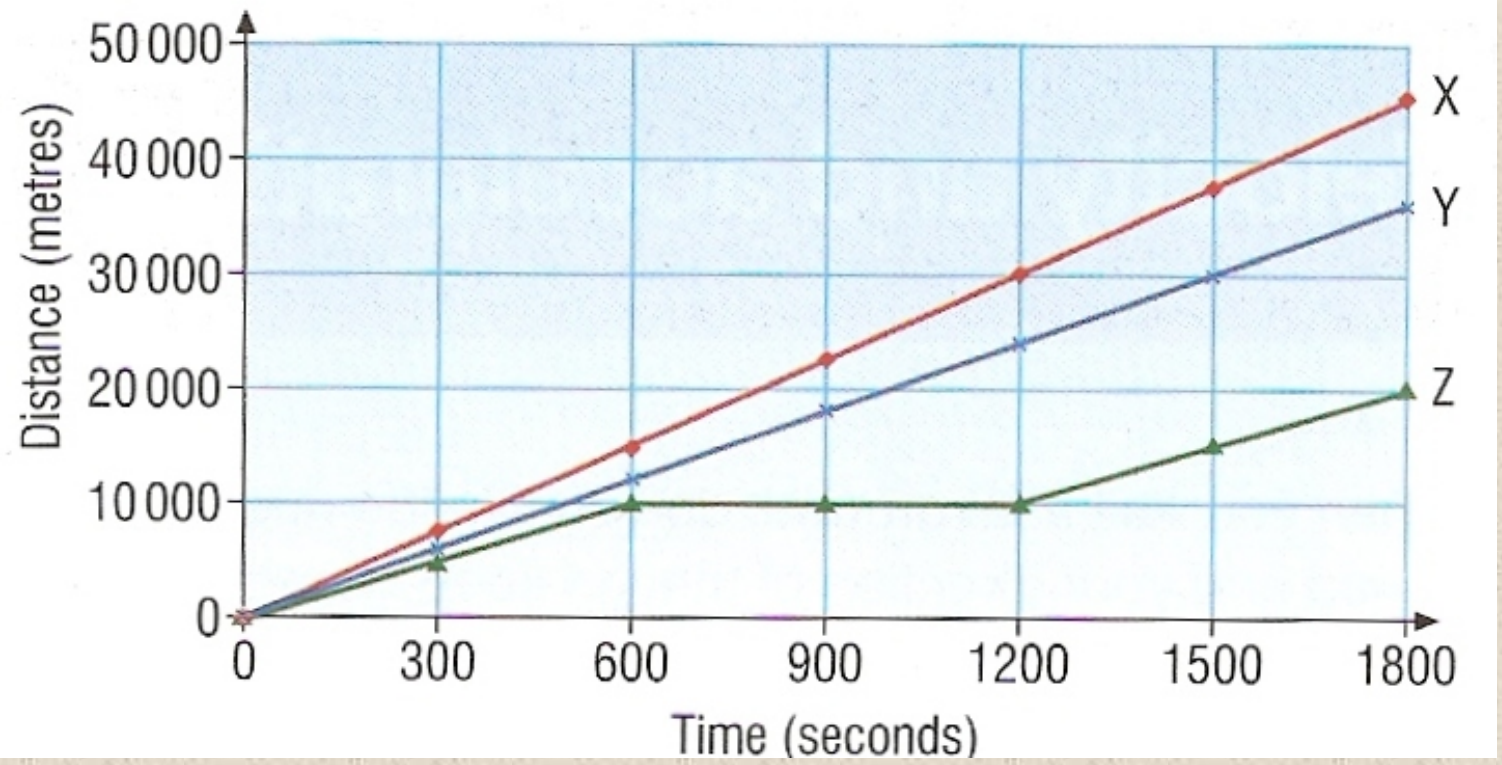


Question 2

Describe the motion of the three lorries X, Y and Z shown in the graph below.



Lorry X:

Moving quickest

speed = 45000m / 1800s = **25 m/s**

Lorry Y:

speed = 36000m / 1800s = **20 m/s**

Lorry Z:

Moving slowest

0 to 600s; speed = 10000m / 600s = **16.7 m/s**

600 to 1200s; **stationary**

1200 to 1800s; speed = **16.7 m/s**

average speed = 20000m / 1800s = 11.1 m/s

Choose appropriate words to fill in the gaps below:

Speed is equal to _____ divided by time and can be measured in _____ per second.

A speed of 20 m/s is the same as _____ km/h which is approximately equal to _____ mph.

The _____ of a distance against time graph can be used to calculate _____. The greater the gradient of the line the _____ is the speed. The line will be _____ when the speed is zero.

WORD SELECTION:

slope speed distance horizontal

40 higher 72 metres

Choose appropriate words to fill in the gaps below:

Speed is equal to _____ divided by time and can be measured in _____ per second.

A speed of 20 m/s is the same as _____ km/h which is approximately equal to _____ mph.

The _____ of a distance against time graph can be used to calculate _____. The greater the gradient of the line the _____ is the speed. The line will be _____ when the speed is zero.

distance
metres
72
40
slope
speed
higher
horizontal

WORD SELECTION:

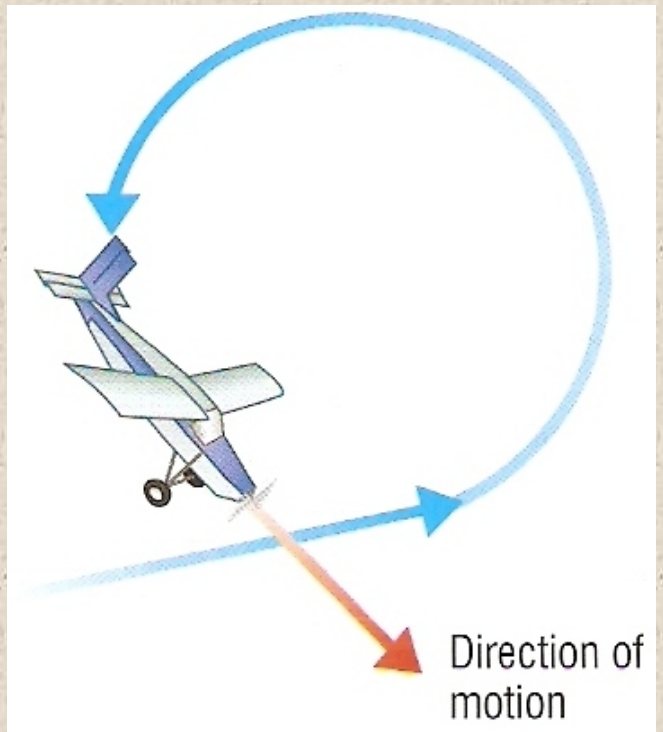
slope speed distance horizontal

40 higher 72 metres

Velocity

The velocity of a body is its speed in a given direction.

The airplane opposite may loop at a constant speed but its velocity changes as its direction of motion changes.



Question

A stone dropped off the top of a cliff falls down by 20m in 2s. Calculate its average velocity (a) downwards and (b) horizontally.

(a) average speed downwards = 20m / 2s

= 10m/s

Therefore velocity downwards = 10 m/s

(b) average speed horizontally = 0m / 2s

= 0m/s

Therefore velocity horizontally = 0 m/s

Acceleration

acceleration = velocity change / time taken

$$a = (v - u) / t$$

a = acceleration in **metres per second squared (m/s^2)**

v = final velocity in **m/s**

u = initial velocity in **m/s**

t = time taken in **seconds (s)**

Why is acceleration measured in m/s² ?

acceleration = velocity change / time taken

velocity change is measured in m/s

time taken is measured in s

therefore acceleration = m/s ÷ s

= m/s²

Other notes:

1. Speed and velocity:

Often, but not always, speed can be used in the equation.

2. Change in velocity:

= final velocity – initial velocity

= *v - u*

3. Deceleration:

This is where the speed is decreasing with time.

4. Circular motion at a constant speed:

Acceleration is occurring because the direction of motion is continually changing and hence so is velocity.

Question 1

Complete the table below for an airplane accelerating at 8m/s^2.

time (s)	0	1	2	3	4
velocity (m/s)	0	8			

Question 2

Calculate the acceleration of a car that changes in velocity from 5m/s to 25m/s in 4 seconds.

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a = (v – u) / t

= (25m/s – 5m/s) / 4s

= 20 / 4

acceleration = 5 m/s^2

Question 3

Calculate the final velocity of a train that accelerates at 0.3m/s^2 for 60 seconds from an initial velocity of 5m/s.

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a = (v – u) / t

becomes: ***(v – u) = a x t***

= 0.3m/s^2 x 60s

= 18m/s

therefore final train velocity = 5m/s + 18m/s

= 23 m/s

Question 4

Calculate the deceleration of a car that slows down from 18m/s to rest in 3 seconds.

Question 4

Calculate the deceleration of a car that slows down from 18m/s to rest in 3 seconds.

a = (v – u) / t

= (0m/s – 18m/s) / 3s

= -18 / 3 (notice minus sign)

acceleration = - 6 m/s^2

and so deceleration = 6 m/s^2

Note: Deceleration is the negative of acceleration.

Choose appropriate words to fill in the gaps below:

Velocity is speed measured in a particular _____.

A person walking northwards will have _____ velocity in a westwards direction.

Acceleration is equal to _____ change divided by the time taken. Acceleration is measured in metres per second _____.

Deceleration occurs when a body is _____ down. It is possible for a body to be accelerating even when its _____ is not changing provided its direction is, for example: a body moving in a _____.

WORD SELECTION:

speed zero slowing direction squared circle velocity

Choose appropriate words to fill in the gaps below:

Velocity is speed measured in a particular _____direction_____.

A person walking northwards will have ____zero____ velocity in a westwards direction.

Acceleration is equal to ____velocity____ change divided by the time taken. Acceleration is measured in metres per second ____squared____.

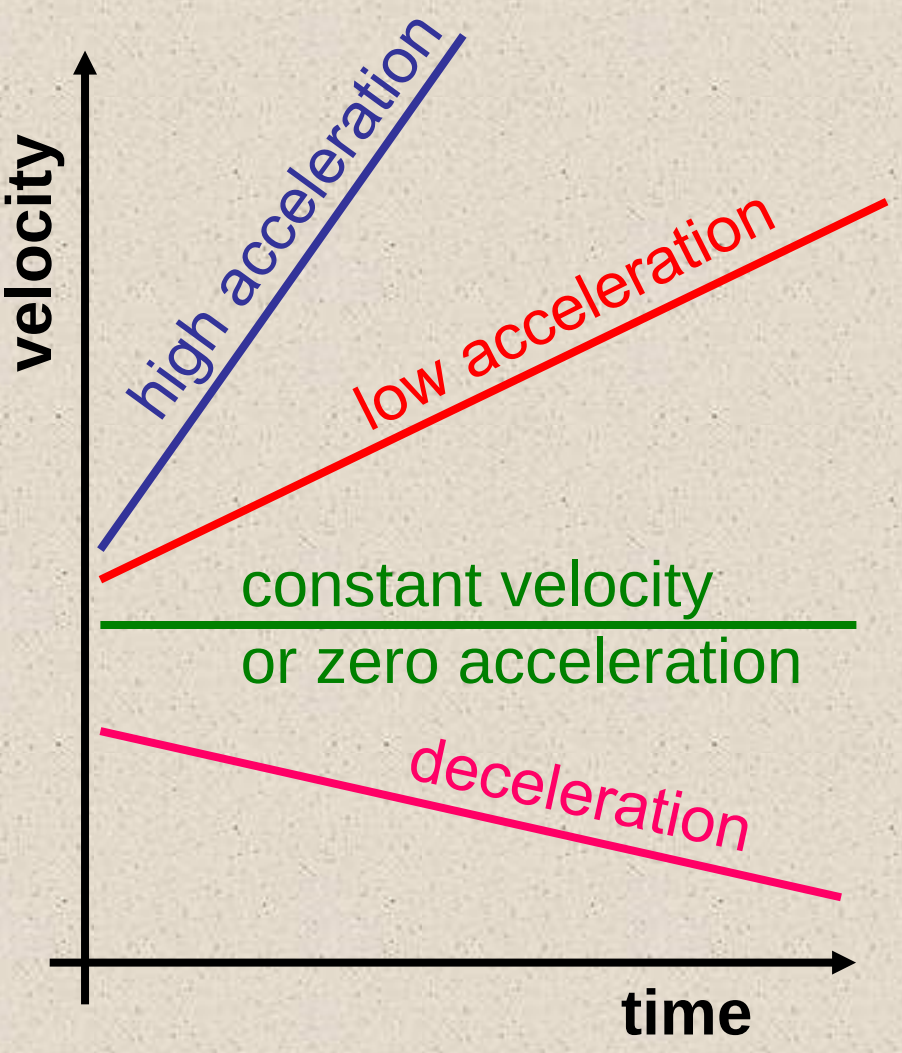
Deceleration occurs when a body is ____slowing____ down. It is possible for a body to be accelerating even when its ____speed____ is not changing provided its direction is, for example: a body moving in a ____circle____.

WORD SELECTION:

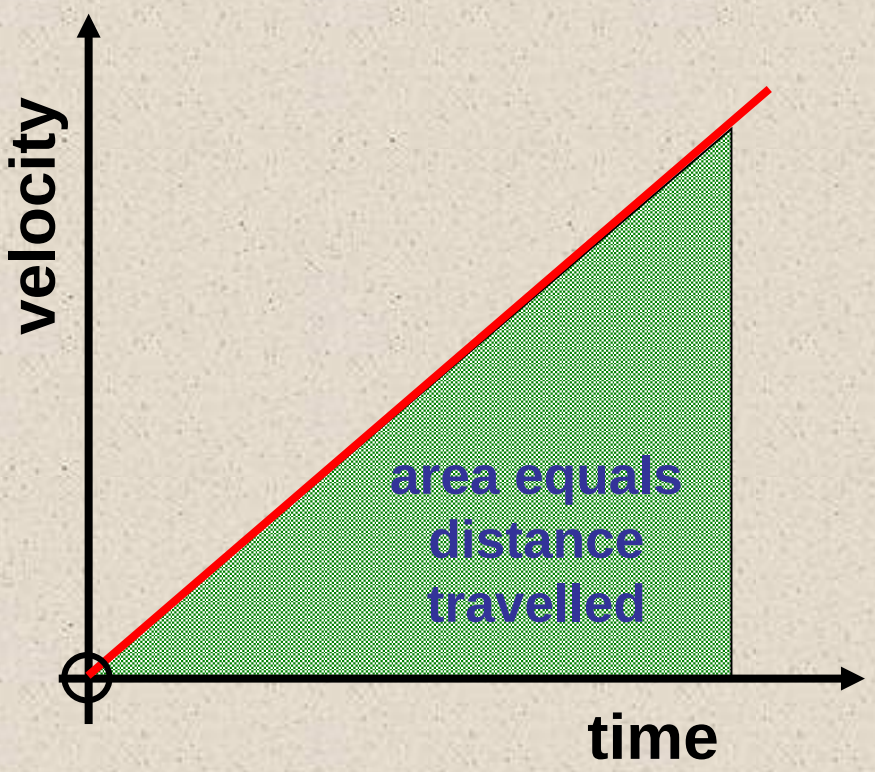
speed zero slowing direction squared circle velocity

Velocity-time graphs

The slope of a velocity-time graph represents acceleration.

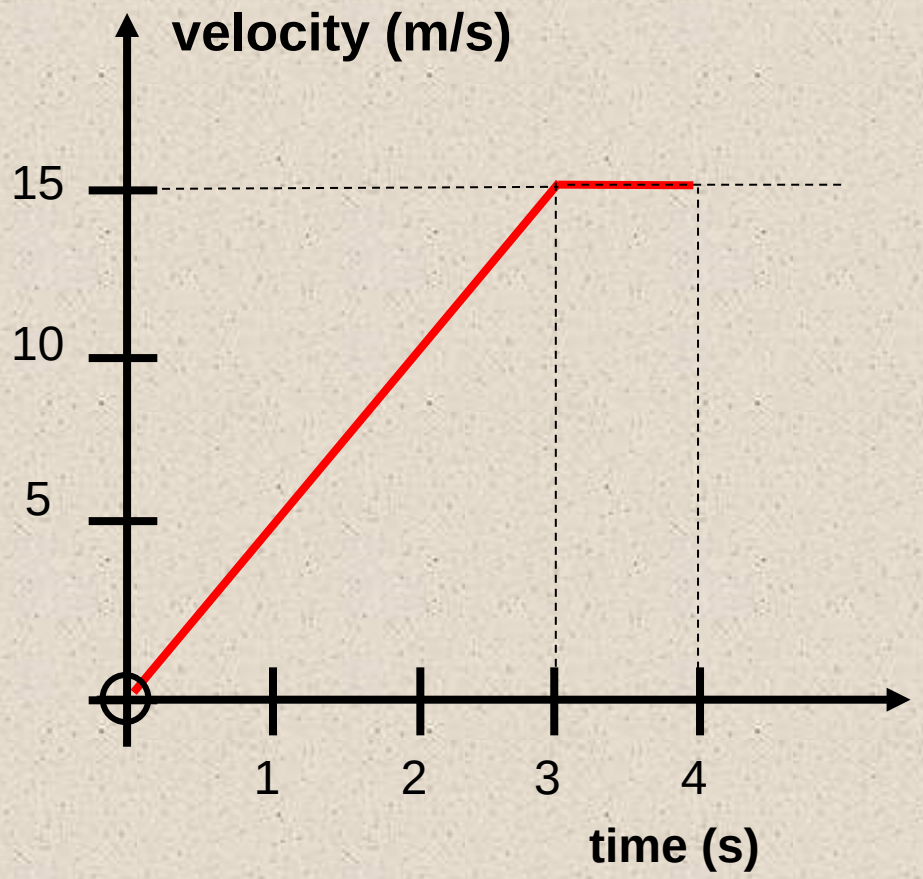


The area under a velocity-time graph represents distance travelled.



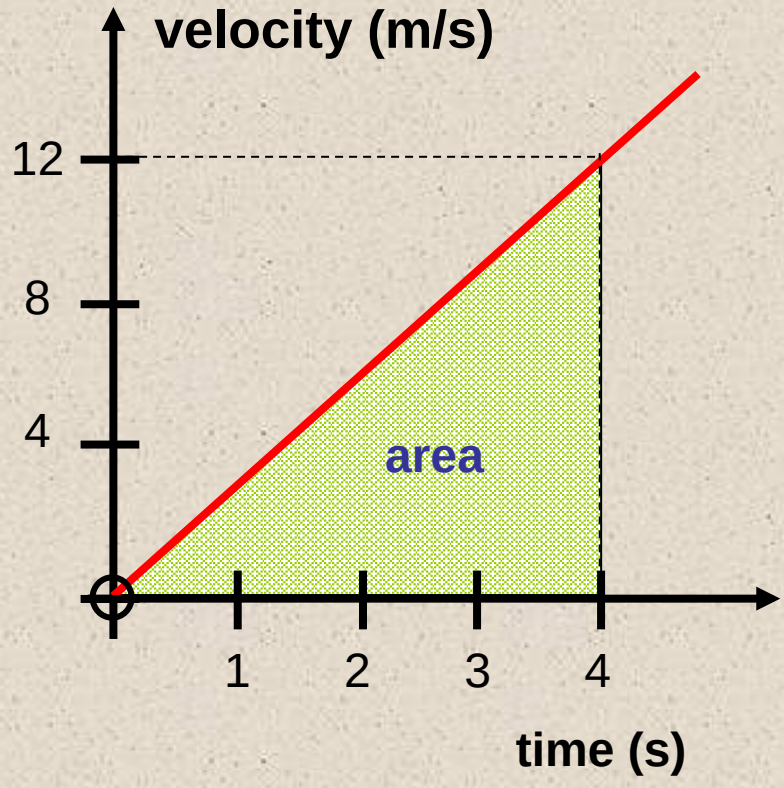
Question 1

Sketch the velocity time graph of a car accelerating from rest to 15m/s in 3 seconds and then remaining at a constant speed for one more second.



Question 2

Calculate the acceleration and the distance travelled after 4 seconds from using the graph opposite.



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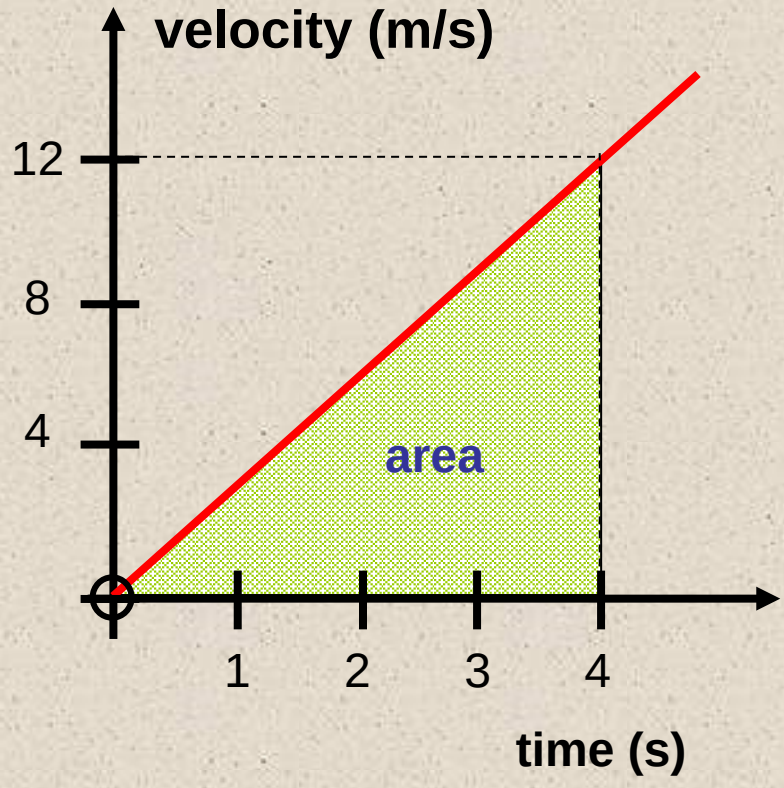


acceleration = gradient

= y-step ÷ x-step

= (12 - 0)m/s ÷ (4 – 0)s

= 12 / 4

acceleration = 3 m/s^2

distance = area under the graph

= area of triangle

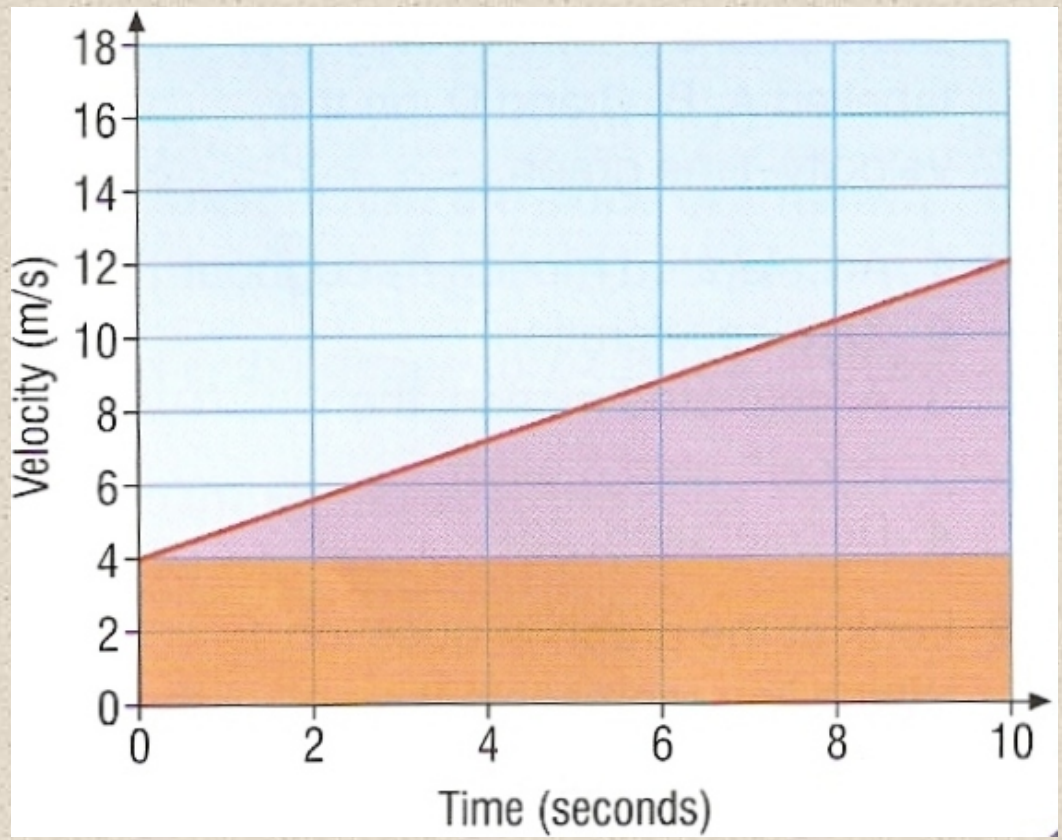
= ½ x base x height

= ½ x 4s x 12m/s

distance travelled = 24m

Question 3

Calculate the acceleration and distance travelled using the graph shown below.



Acceleration:

Acceleration equals the slope of the graph

= y-step ÷ x-step

= (16 - 4)m/s ÷ (10s)

= 12 / 10

Acceleration = 1.2 m/s^2

Distance travelled:

This equals the area below the graph

= area of rectangle + area of triangle

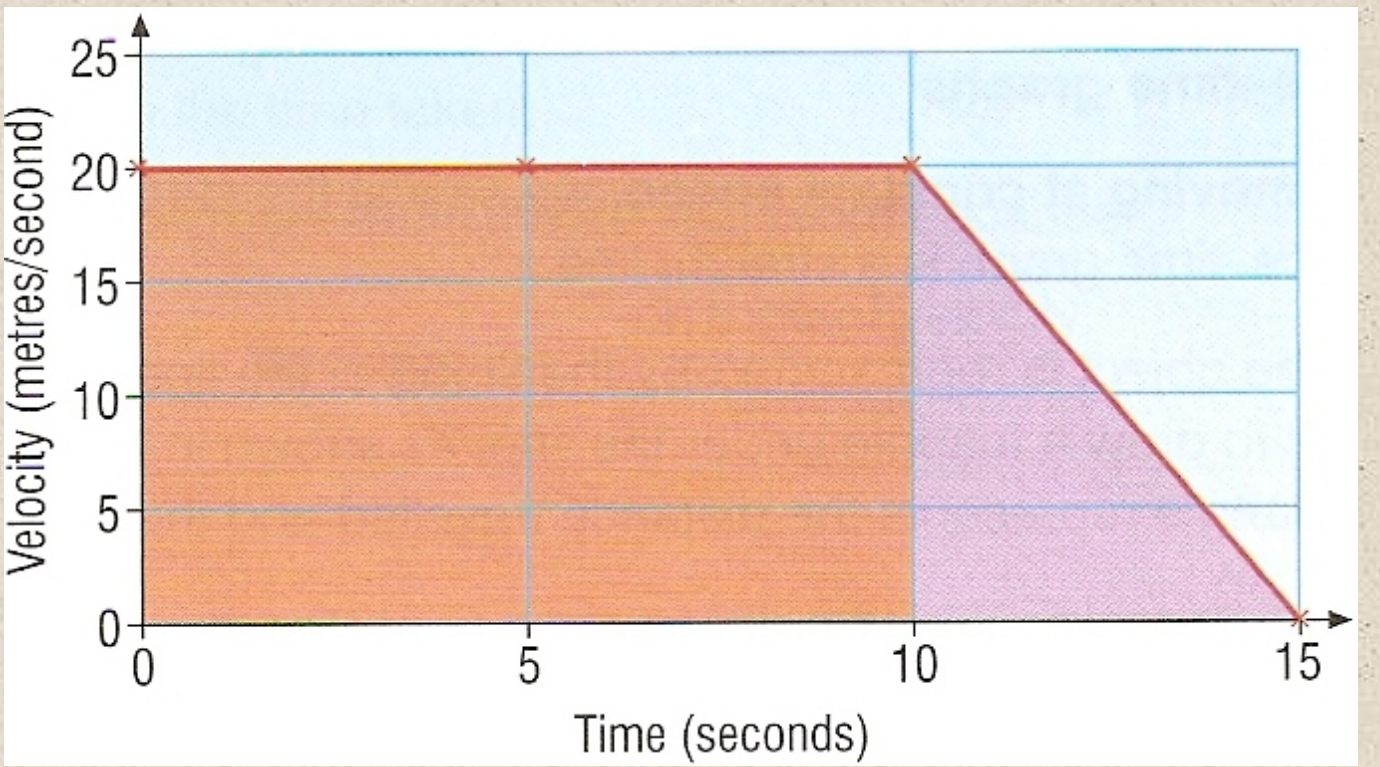
= (10s x 4m/s) + (½ x 10s x (12 – 4)m/s)

= 40m + 40m

Distance travelled = 80m

Question 4

Calculate the distance travelled over 15 seconds and the deceleration during the final five seconds using the graph below.



Distance travelled:

This equals the area below the graph

= area of rectangle + area of triangle

= (10s x 20m/s) + (½ x 5s x 20m/s)

= 200m + 50m

Distance travelled = 250m

Deceleration:

Acceleration equals the slope of the graph

= y-step ÷ x-step

= (- 20m/s) ÷ (5s)

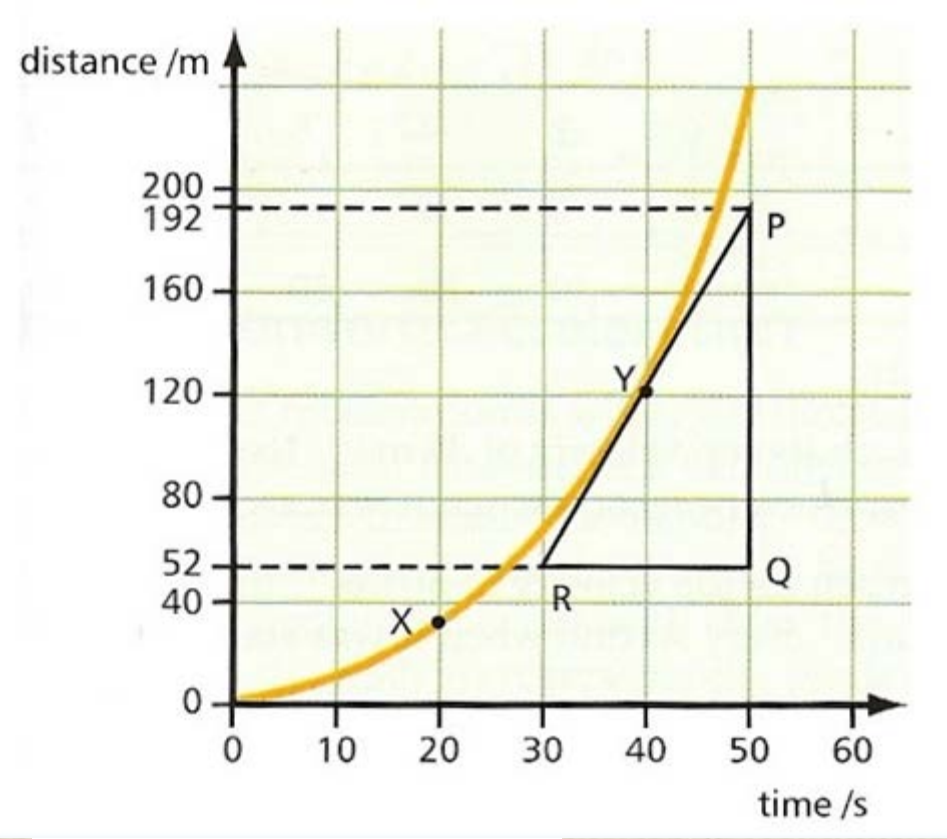
= - 4 m/s^2

but deceleration = negative of acceleration

Deceleration = 4 m/s^2

Distance-time graphs

The **gradient** of a distance-time graph is equal to the **speed**



$$\text{Speed at Y} = \frac{PQ}{QR}$$

$$= \frac{192-52}{20}$$

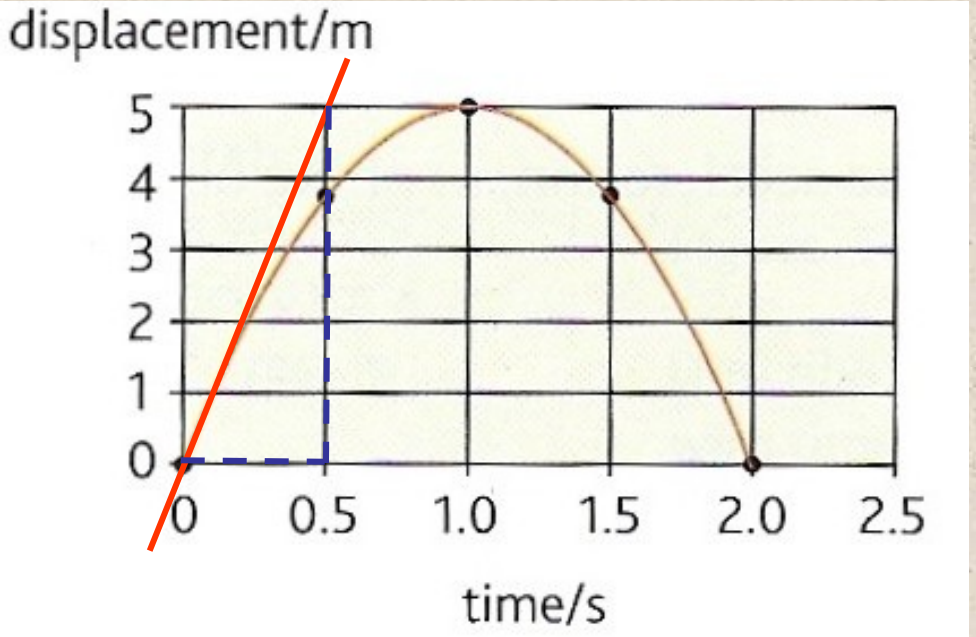
$$= 7\ \text{m s}^{-1}$$

Displacement-time graphs

The **gradient** of a displacement-time graph is equal to the **velocity**

The graph opposite shows how the displacement of an object thrown upwards varies in time.

Note how the gradient falls from a high positive value to zero (at maximum height) to a large negative value.



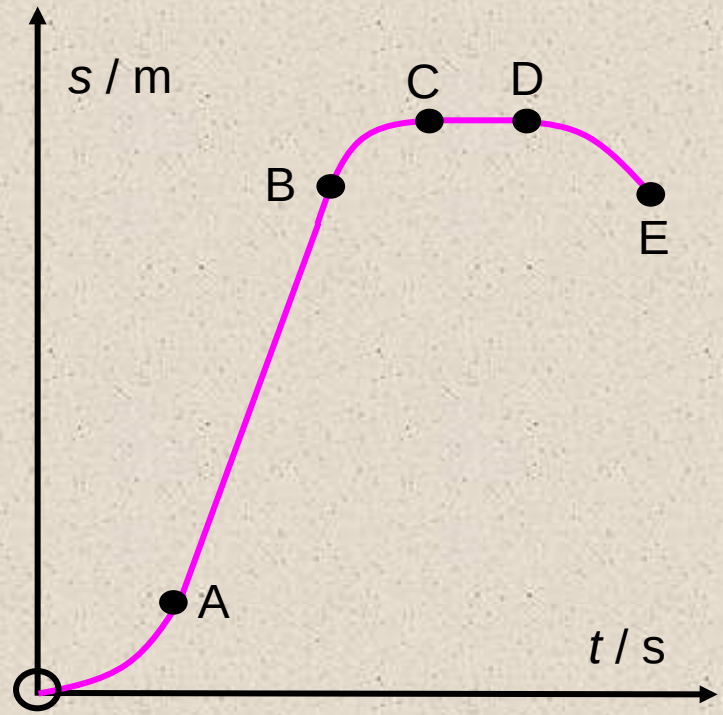
Estimate the initial velocity of the object.

Initial gradient = (5 – 0)m / (0.5 – 0)s = 10 ms^{-1}

Initial velocity = 10 ms^{-1}

Question

Describe the motion shown by the displacement-time graph below:



O → A: acceleration from rest

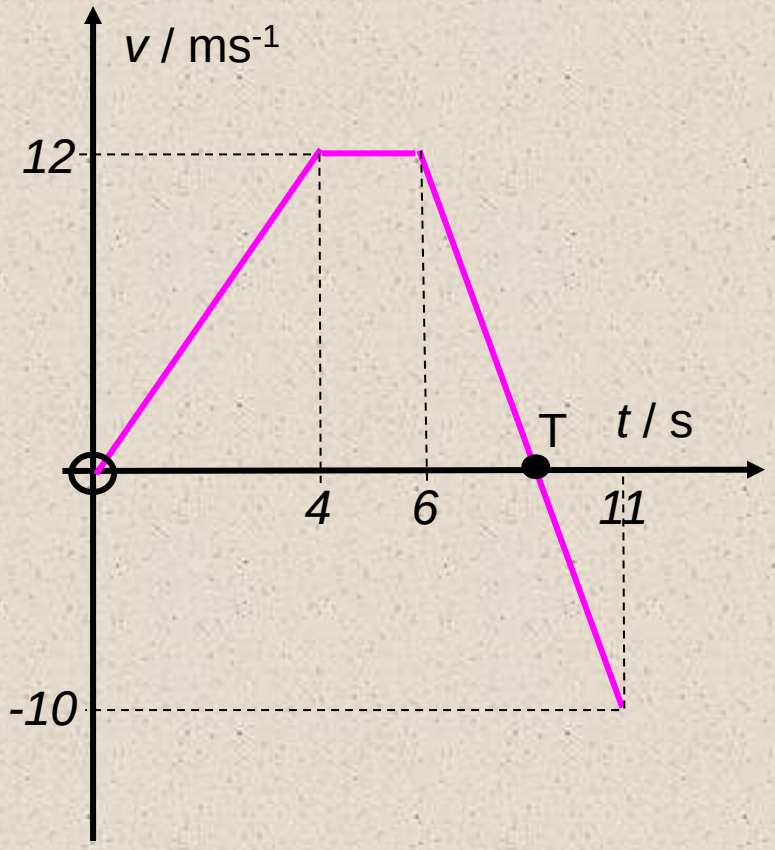
A → B: constant velocity

B → C: deceleration to rest

C → D: rest (no motion)

D → E: acceleration from rest back towards the starting point

Question 2



The graph shows the velocity-time graph of a car. Calculate or state:

(a) the acceleration of the car during the first 4 seconds.

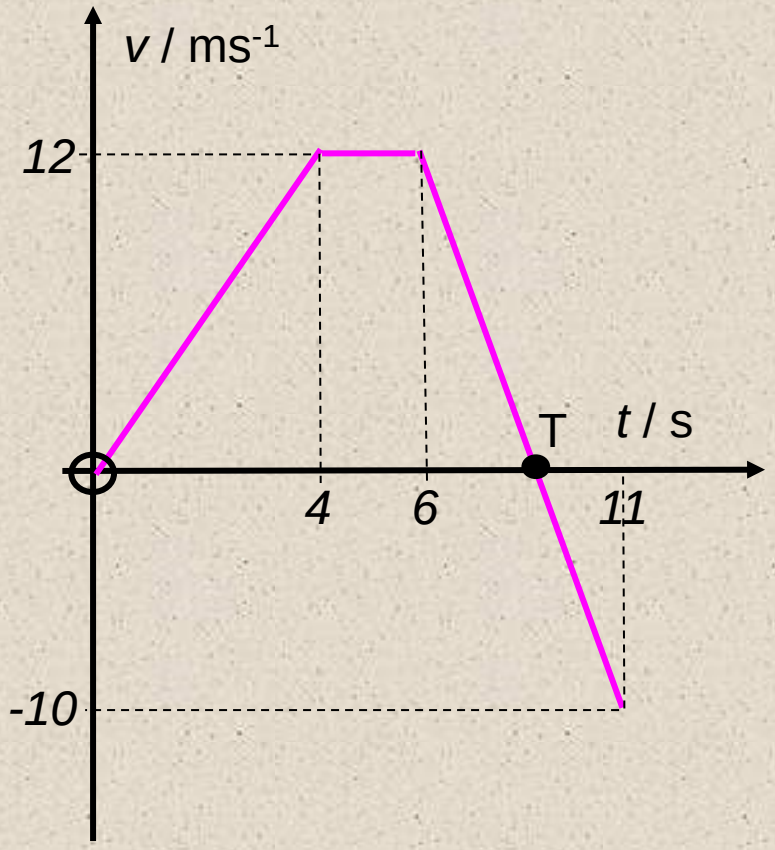
(b) the displacement of the car after 6 seconds.

*(c) time **T**.*

(d) the displacement after 11 seconds.

(e) the average velocity of the car over 11 seconds.

Question 2



a) the acceleration of the car during the first 4 seconds.

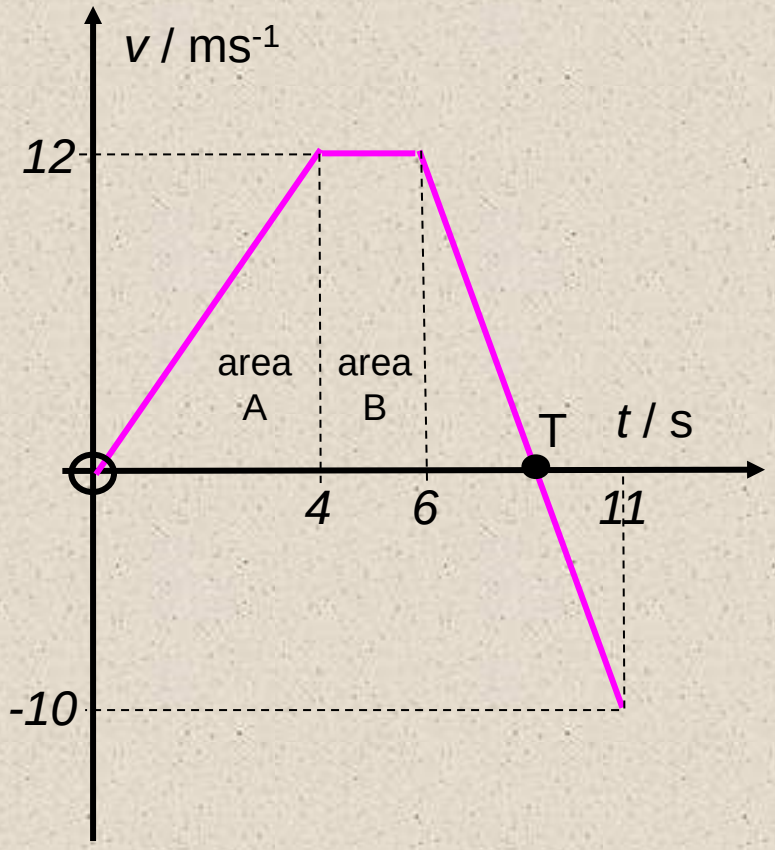
acceleration = gradient

= (12 - 0)ms^{-1} / (4 – 0)s

= 12 / 4

acceleration = 3 ms^{-2}

Question 2



(b) the displacement of the car after 6 seconds.

displacement = area

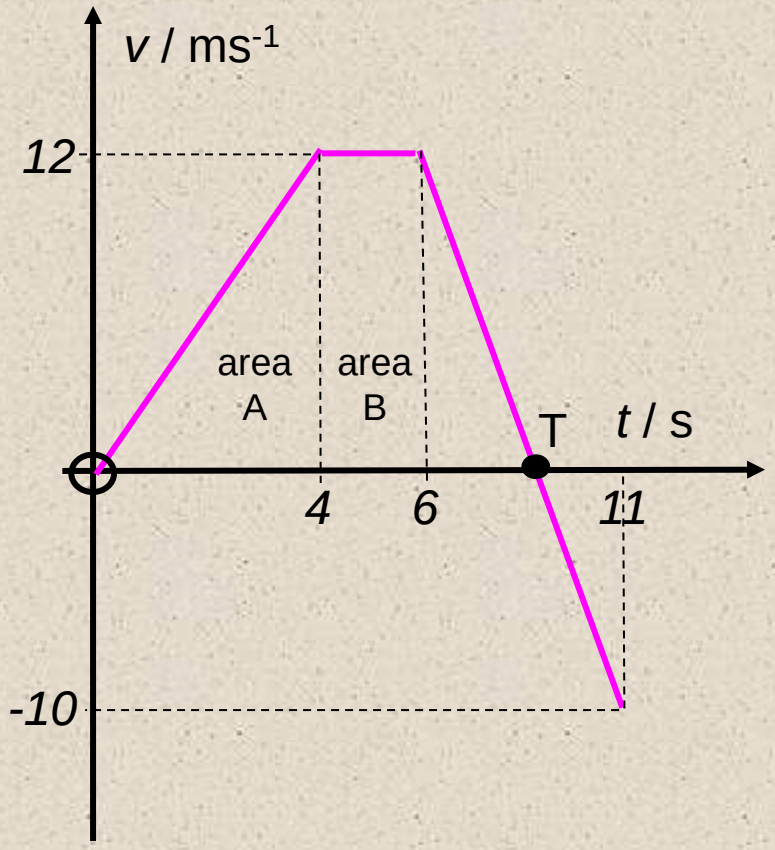
= area A + area B

= ½ (12 x 4) + (12 x 2)

= 24 + 24

displacement = 48 m

Question 2



*(c) time **T**.*

By similar triangles:

(T - 6):(11 - T) = 12:10

i.e. (T - 6) / (11 - T) = 12 / 10

(T - 6) / (11 - T) = 1.20

(T - 6) = 1.20 (11 – T)

T - 6 = 13.2 – 1.2T

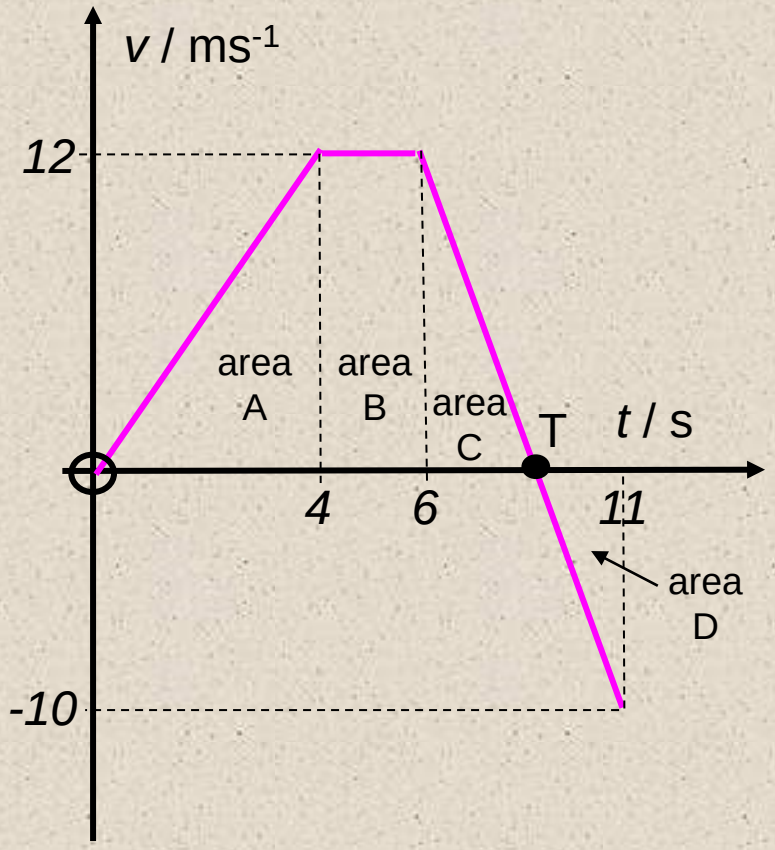
2.2T = 19.2

T = 19.2 / 2.2

T = 8.73 seconds

Note: **T** can also be found by scale drawing or by using the equations of uniform acceleration (see later).

Question 2



(d) the displacement after 11 seconds.

displacement = area

= area A + area B + area C – area D

= 24 + 24 + ½ (12 x 2.73) – ½ (10 x 2.27)

= 24 + 24 + 16.38 – 11.35

= 53.03

displacement = 53.0 m

The equations of uniform acceleration

v = FINAL velocity

u = INITIAL velocity

a = acceleration

t = time for the velocity change

s = displacement during the velocity change

$$v = u + at$$

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

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

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

THESE EQUATIONS ONLY APPLY WHEN THE ACCELERATION REMAINS CONSTANT

Question 2

Calculate the stopping distance of a car that is decelerated at 2.5 ms $^{-2}$ from an initial velocity of 20 ms $^{-1}$.

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

$0 = 20^2 + (2 \times -2.5 \times s)$

$0 = 400 + -5s$

$-400 = -5s$

$-400 / -5 = s$

stopping distance = 80 m

Question 3

A stone is dropped from the edge of a cliff. If it accelerates downwards at 9.81 ms $^{-2}$ and reaches the bottom after 1.5s calculate the height of the cliff.

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A stone is dropped from the edge of a cliff. If it accelerates downwards at 9.81 ms $^{-2}$ and reaches the bottom after 1.5s calculate the height of the cliff.

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

$$s = (0 \times 1.5) + \tfrac{1}{2} (9.81 \times (1.5)^2)$$

$$s = \tfrac{1}{2} (9.81 \times 2.25)$$

cliff height = 11.0 m

Question 4

Calculate the time taken for a car to accelerate uniformly from 5 ms^{-1} to 12 ms^{-1} over a distance of 30m.

Question 4

Calculate the time taken for a car to accelerate uniformly from 5 ms $^{-1}$ to 12 ms $^{-1}$ over a distance of 30m.

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

$30 = \frac{1}{2}(5 + 12) \times t$

$30 = 8.5 \times t$

$30 \div 8.5 = t$

time = 3.53 s