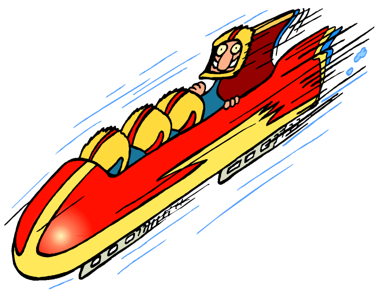
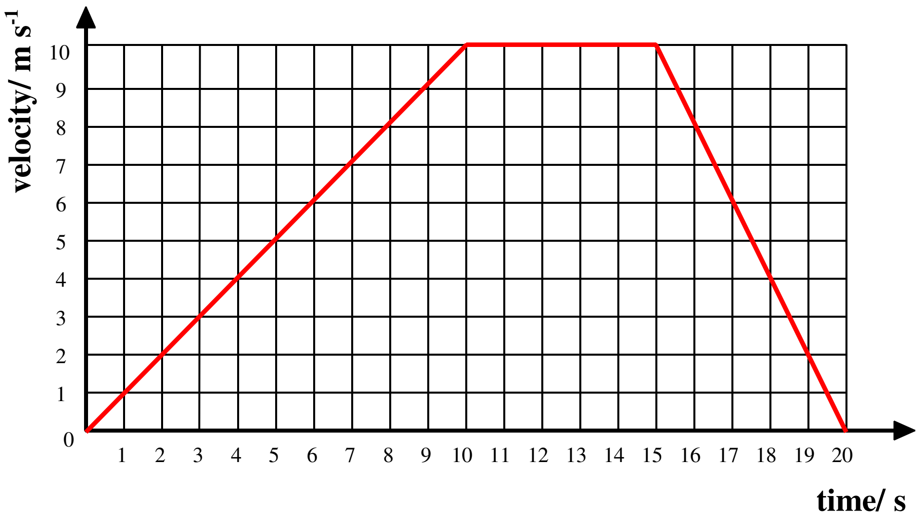
National 5 Physics

"DYNAMICS"

'Acceleration'



'Velocity-Time Graphs'



Name: ______________________________

This section of the "Dynamics" unit introduces the concept of 'acceleration' - its definition, how it is calculated, how it is measured experimentally and how it is represented on a velocity-time graph.

The use of a velocity-time graph to determine the 'displacement' of an object is also explained.

By the end of this section, you should be able to:

☐ state that if the velocity of an object is increasing, the object is accelerating and that if the velocity of an object is decreasing, the object is decelerating.

☐ state that the acceleration or deceleration (negative acceleration) of an object is the change in velocity of the object over a given time

☐ describe an experiment to measure the acceleration of an object

☐ carry out calculations involving 'acceleration', 'final velocity' (or 'speed'), 'initial velocity' (or 'speed')' and 'time' using the formula

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

☐ draw or sketch 'velocity-time graphs' (or 'speed-time graphs') using provided data

☐ interpret a 'velocity-time graph' to describe the motion of an object

☐ determine the 'acceleration' (or 'deceleration') of an object from its 'velocity-time graph'

☐ state that the 'acceleration' of an object is equal to the gradient of the straight line on the 'velocity-time graph' representing its motion

☐ determine the 'displacement' of an object from its 'velocity-time graph'

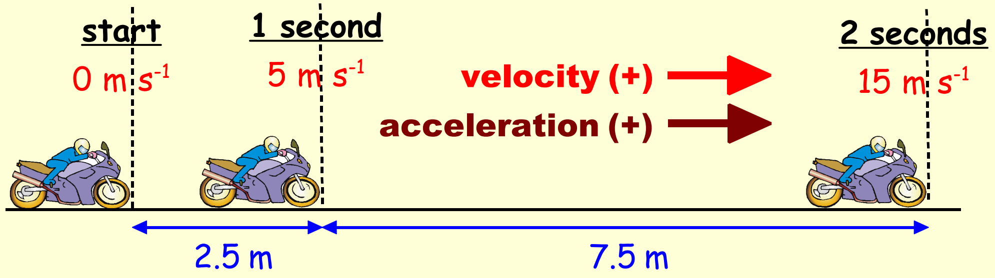
☐ state that the 'displacement' of an object is equal to the area area under 'velocity-time graph' representing its motion

Acceleration and Deceleration (Negative Acceleration)

This diagram shows a motorbike **accelerating** in a straight line to the right from a **stationary start** (**rest, 0 m s^{-1}**) to a **velocity** of **15 m s^{-1} to the right**.

After each second:

- its **velocity** has **increased**
- it has travelled **further** than it travelled the second before

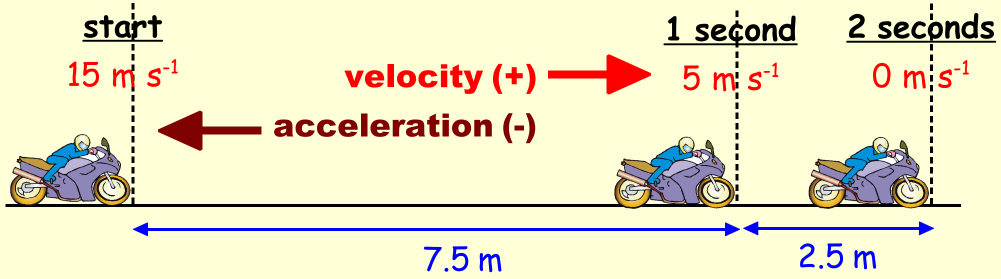


This diagram shows a motorbike **decelerating** in a straight line to the right from a **velocity** of **15 m s^{-1} to the right** to **rest** (**0 m s^{-1}**).

After each second:

- its **velocity** has **decreased**
- it has travelled **less far** than it travelled the second before

The "correct" term for 'deceleration' is 'negative acceleration'.



- When an object's **velocity** **increases** with time, the object is **a** _ _ _ _ _ _ _ _ _ _ _ _.
- When an object's **velocity** **decreases** with time, the object is **d** _ _ _ _ _ _ _ _ _ _ _ _.

velocity and acceleration in same direction

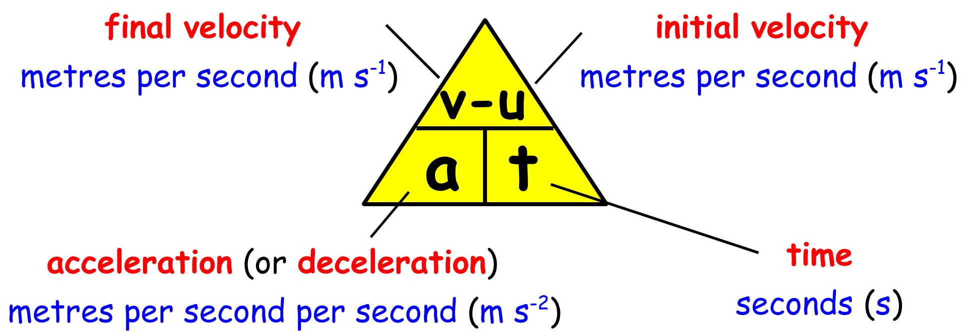
velocity and acceleration in opposite directions

The **acceleration** (**a**) or **deceleration** (**negative acceleration**) of an object is its **change in velocity** over a **given time**.

Acceleration or **deceleration** (**negative acceleration**) is a **vector** quantity - it has a **magnitude** (**size**) ***and*** a **direction**.

$$\text{acceleration (or deceleration)} = \frac{\text{change in velocity}}{\text{time taken}}$$

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



Measuring Acceleration

To measure the **acceleration** (**a**) of a moving object (for example, a trolley running down a slope), **electronic timing** is required.

Two light gates are connected to an electronic timer/computer.

A mask (thick card) is fixed on top of the trolley. No light can pass through the mask, so when it passes through a light gate, no light reaches the light detector of the light gate. This activates the electronic timer/computer.

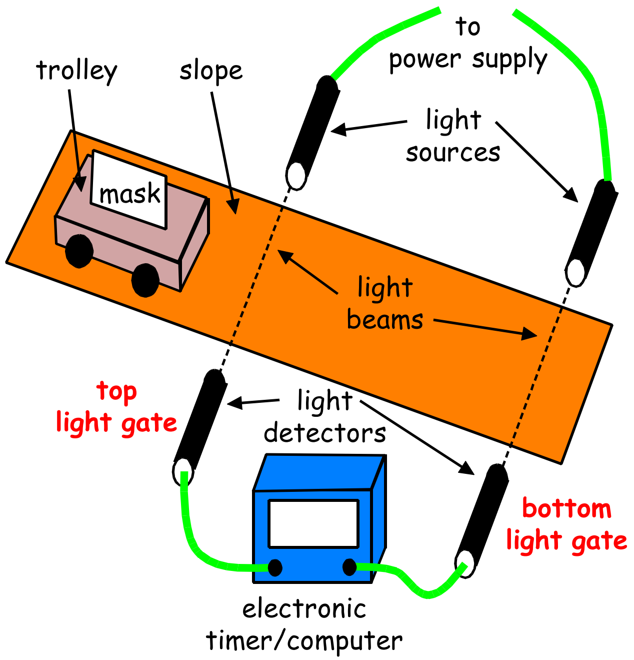
The length of the mask is entered into the electronic timer/computer.

When the mask on the trolley passes through the light beam of the top light gate, the electronic timer/computer measures the time this takes, then calculates the value for the velocity of the mask passing through the top light gate (u).

When the mask on the trolley passes through the light beam of the bottom light gate, the electronic timer/computer measures the time this takes, then calculates the value for the velocity of the mask passing through the bottom light gate (v).

The electronic timer/computer also records the time it takes for the mask to travel from the top light gate to the bottom light gate.

The acceleration of the trolley running down the slope is then calculated by the electronic timer/computer, as shown below:



$$\text{initial velocity (u)} = \frac{\text{length of mask}}{\text{time for mask to pass through top light gate}}$$

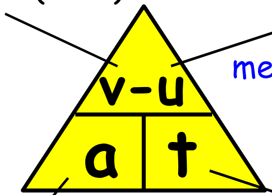
$$\text{final velocity (v)} = \frac{\text{length of mask}}{\text{time for mask to pass through bottom light gate}}$$

$$\text{acceleration (a)} = \frac{\text{final velocity (v) - initial velocity (u)}}{\text{time for mask to travel from top to bottom light gate}}$$

Acceleration Calculations

final velocity
metres per second ($m\ s^{-1}$)

initial velocity
metres per second ($m\ s^{-1}$)



acceleration (or **deceleration**)
metres per second per second ($m\ s^{-2}$)

time
seconds (s)

v-u =

a =

t =

Sample Calculations

Acceleration

Calculate the **acceleration** of a walker who increases their velocity from **1 $m\ s^{-1}$** to **3 $m\ s^{-1}$** **to the right** in a time of **4 s**.

- $v = 3\ m\ s^{-1}$
- $u = 1\ m\ s^{-1}$
- $t = 4\ s$
- $a = ?$

$$a = \frac{v - u}{t} = \frac{3 - 1}{4}$$

$$= \frac{2}{4}$$

$$= \underline{0.5\ m\ s^{-2}}$$

to the right

Deceleration

Calculate the **deceleration** of a cyclist who decreases their velocity from **7 $m\ s^{-1}$** to **1 $m\ s^{-1}$** **to the right** in a time of **3 s**.

- $v = 1\ m\ s^{-1}$
- $u = 7\ m\ s^{-1}$
- $t = 2\ s$
- $a = ?$

$$a = \frac{v - u}{t} = \frac{1 - 7}{3}$$

$$= \frac{-6}{3}$$

$$= \underline{-2\ m\ s^{-2}}$$

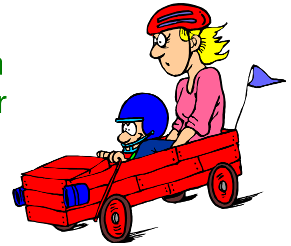
to the right

The - sign indicates "deceleration"

1) Farmer Jones' tractor starts from rest and increases its velocity to 8 $m\ s^{-1}$ to the right in 10 s.

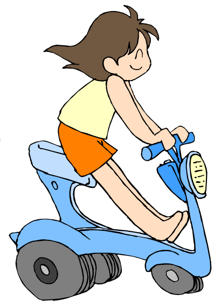
Calculate the **acceleration** of the tractor.

3) In their box-kart, Jill and her Mum increase their velocity from rest to 6 $m\ s^{-1}$ to the left in 12 s.



Calculate the **acceleration** of the go-kart.

2) On her motor scooter, Dominique takes 5 s to increase her velocity from 3 $m\ s^{-1}$ to the right to 13 $m\ s^{-1}$ to the right.

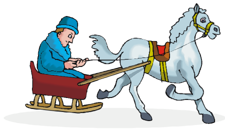


Calculate the **acceleration** of the motor scooter.

4) Mike's motorbike takes 5 s to increase in velocity from 10 $m\ s^{-1}$ to the left to 30 $m\ s^{-1}$ to the left.

Calculate the **acceleration** of the motorbike.

5) Sid's sleigh takes 20 s to decrease its velocity from 12 m s^{-1} to the right to 4 m s^{-1} to the right.



Calculate the **deceleration** of the sleigh.

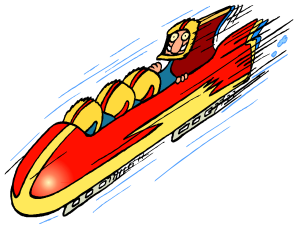
6) An arrow hits a stationary target with a velocity of 50 m s^{-1} to the right and comes to rest in 0.1 s.

Calculate the **deceleration** of the arrow once it hits the target.

7) In their golf cart, Tom and Sue decrease their velocity from 9 m s^{-1} to the left to 2 m s^{-1} to the left in a time of 5 s.

Calculate the **deceleration** of the golf cart.

8) As a bobsleigh crosses the finishing line of a race, its velocity decreases from 46 m s^{-1} to 24 m s^{-1} down the slope. This happens in a time of 0.4 s.



Calculate the **deceleration** of the bobsleigh during this time.

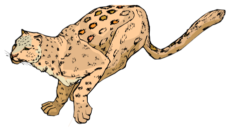
9) Barah's forklift truck accelerates at 0.25 m s^{-2} while increasing its velocity from rest to 5 m s^{-1} to the left.

Calculate the **time** this takes.

10) Sam somersaults across a gym floor. He starts from rest and increases his velocity to 2.4 m s^{-1} to the right, having accelerated at 0.3 m s^{-2}.

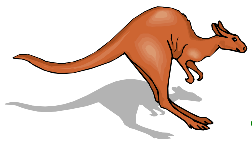
What **time** does this take?

11) Starting from rest, a cheetah accelerates to the left at 3.6 m s^{-2} for a time of 7.5 s.



Calculate the cheetah's **change in velocity** during this time.

12) Starting from rest, a red kangaroo accelerates to the right at 3 m s^{-2} for a time of 5.5 s.

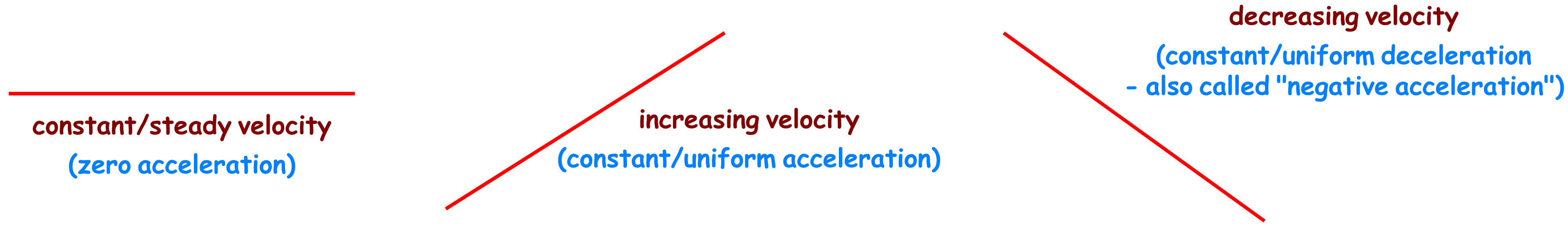


Calculate the kangaroo's **increase in velocity** over this time.

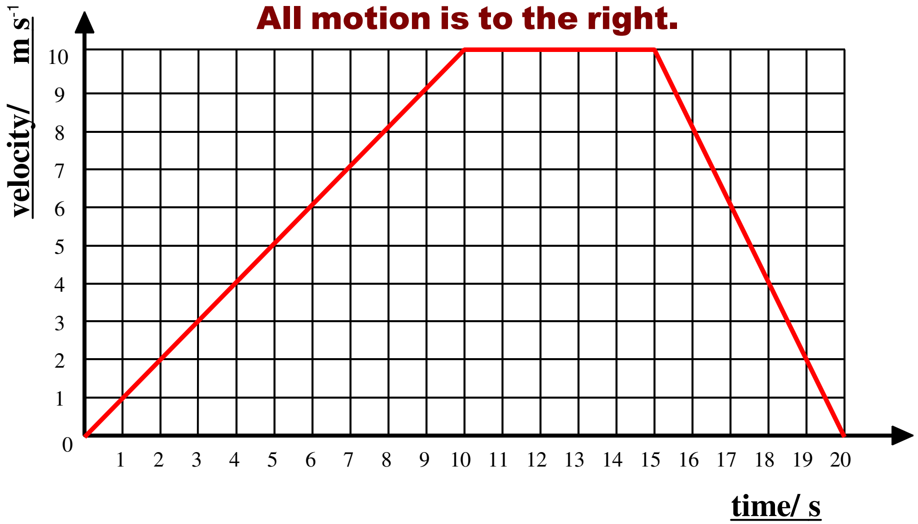
Velocity-Time Graphs

The motion of any object can be represented by a **line** drawn on a **velocity-time graph**.

The steepness (gradient) of the line represents the value for the object's **acceleration** - larger gradient means larger acceleration.



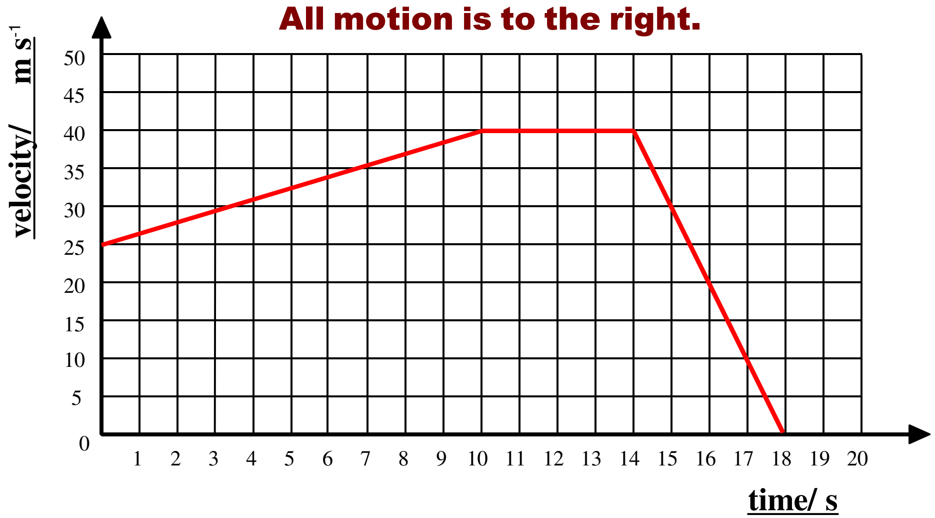
13) Describe the motion represented by the **line** on each **velocity-time graph**:



0 - 10 seconds: ____________ ____________ from ____ $m\ s^{-1}$ to ____ $m\ s^{-1}$.
(Constant/uniform ________________).

10 - 15 seconds: ___________ __________ of ____ $m\ s^{-1}$.

15 - 20 seconds: __________ ______________ from ____ $m\ s^{-1}$ to ____ $m\ s^{-1}$.
(Constant/uniform __________________).



0 - 10 seconds: ____________ ____________ from ____ $m\ s^{-1}$ to ____ $m\ s^{-1}$.
(Constant/uniform ________________).

10 - 14 seconds: ___________ __________ of ____ $m\ s^{-1}$.

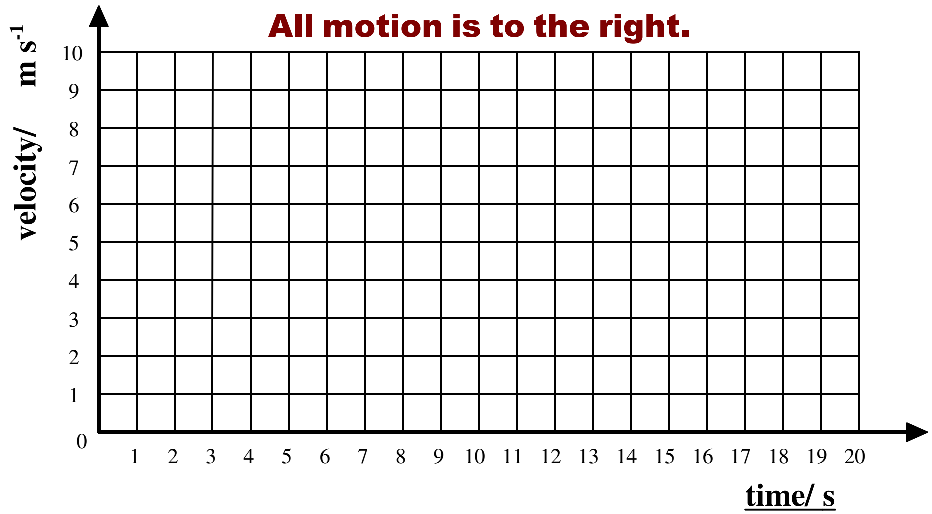
14 - 18 seconds: ____________ _____________ from ____ $m\ s^{-1}$ to ____ $m\ s^{-1}$.
(Constant/uniform __________________).

14) Draw the **line** on each **velocity-time graph** to represent the motion described:

0 - 5 seconds: Increasing velocity from rest (0 m s^{-1}) to 10 m s^{-1} to the right. (Constant/uniform acceleration).

5 - 15 seconds: Constant velocity of 10 m s^{-1} to the right.

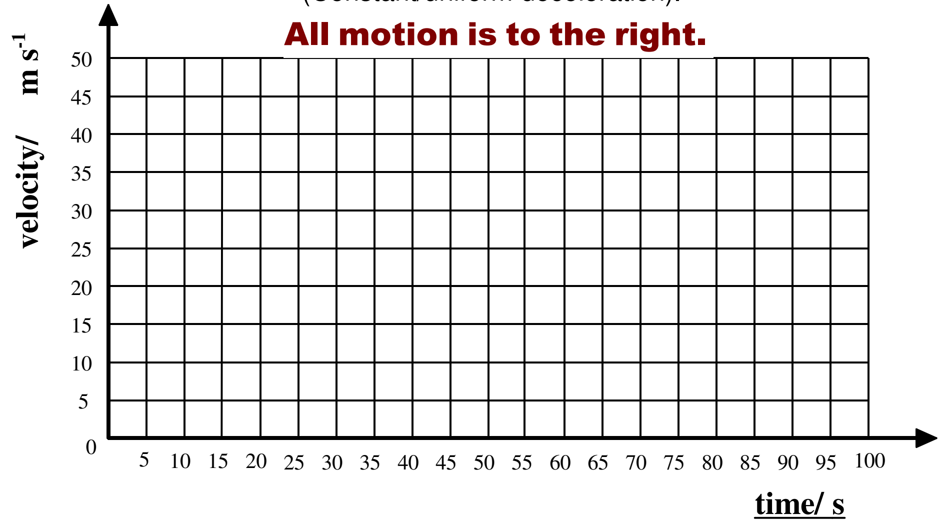
15 - 20 seconds: Decreasing velocity from 10 m s^{-1} to the right to rest (0 m s^{-1}). (Constant/uniform deceleration).



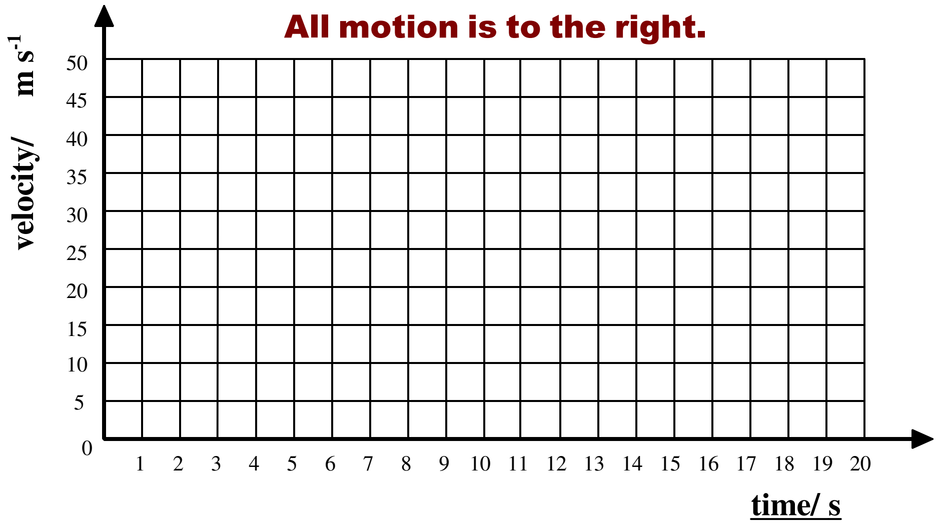
0 - 30 seconds: Increasing velocity from 25 m s^{-1} to 40 m s^{-1} to the right. (Constant/uniform acceleration).

30 - 60 seconds: Constant velocity of 40 m s^{-1} to the right.

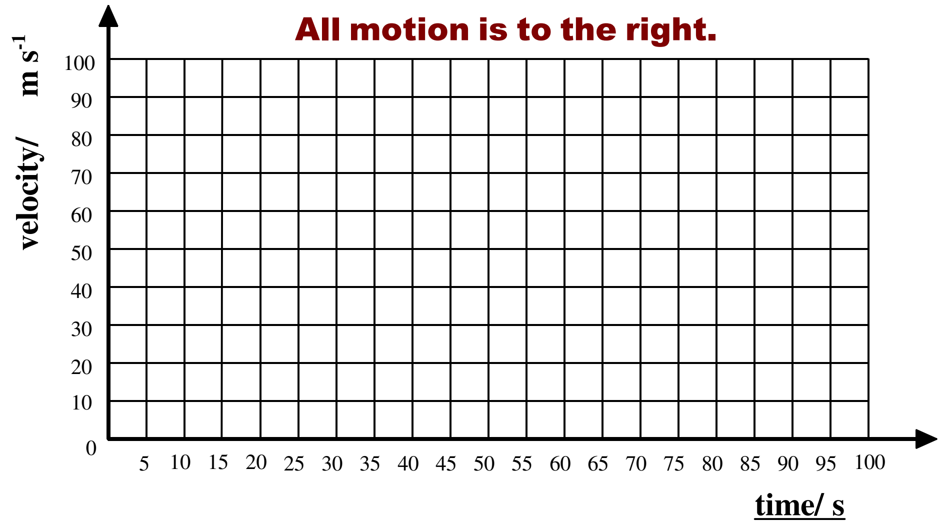
60 - 90 seconds: Decreasing velocity from 40 m s^{-1} to the right to rest (0 m s^{-1}). (Constant/uniform deceleration).



With uniform/constant acceleration, a motorcycle takes 8 s to increase its velocity from rest to 20 m s^{-1} to the right. The motorcycle continues to travel at this steady velocity for 4 s. It then increases its velocity to 45 m s^{-1} to the right (constant/uniform acceleration) in 7 s.



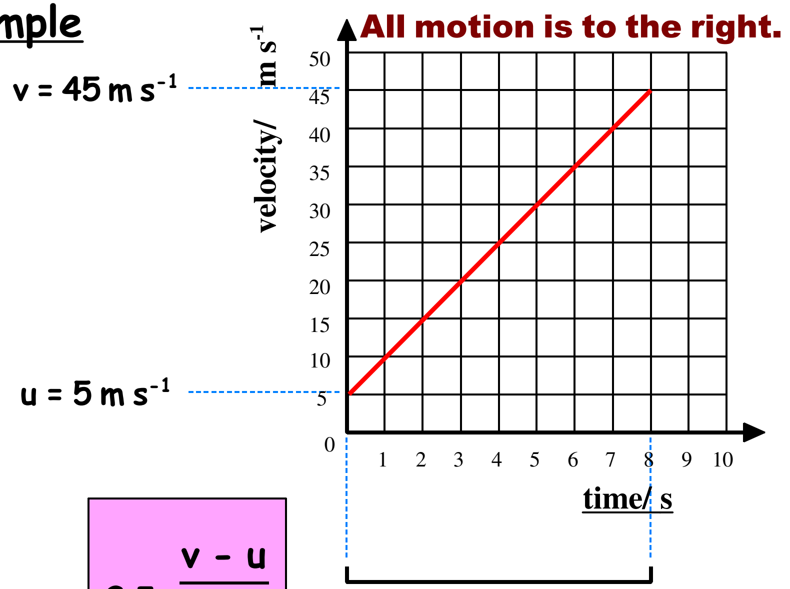
A helicopter, initially travelling at 80 m s^{-1} to the right, decelerates constantly/uniformly to a velocity of 60 m s^{-1} to the right in 25 s. For the next 50 s, it continues to travel at this steady velocity before decelerating constantly/uniformly to the right to rest in a further 25 s.



Calculating Acceleration (or Deceleration) From a Velocity-Time Graph

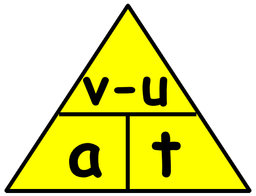
By taking **velocity** and **time** values from a **velocity-time graph**, we can calculate the **acceleration** or **deceleration** of the object that the graph represents.

For Example



time (t) = 8 - 0

= 8 s



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

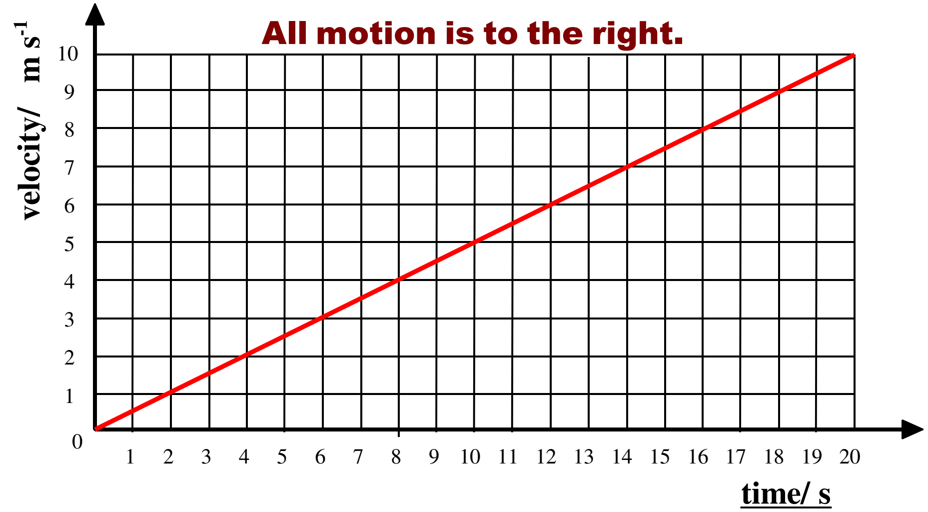
$$\text{acceleration (a)} = \frac{v - u}{t}$$

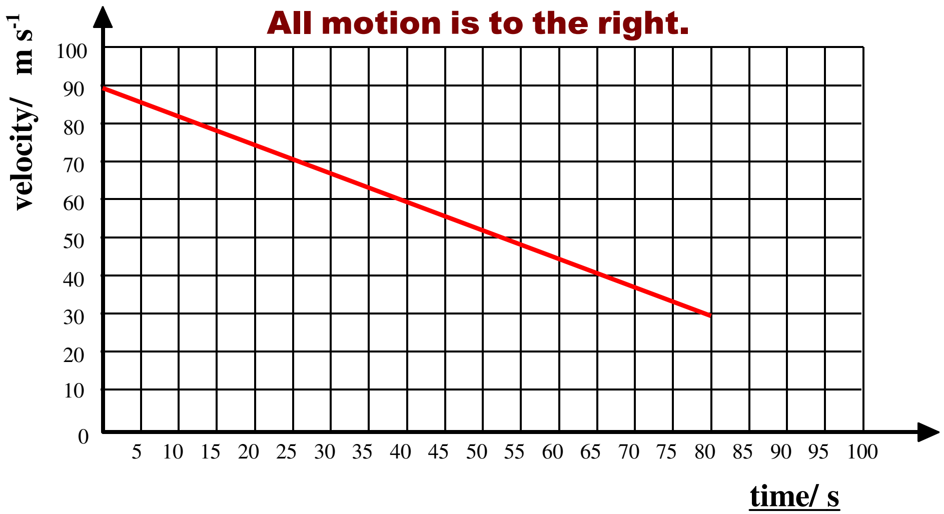
$$= \frac{45 - 5}{8}$$

$= 5\ m\ s^{-2}$ to the right

The gradient of a straight line on a velocity-time graph over a specific time interval is equal to the acceleration of the object represented by the graph during that time interval.

15) Calculate the **acceleration** or **deceleration** represented by the **line** on each **velocity-time graph**.





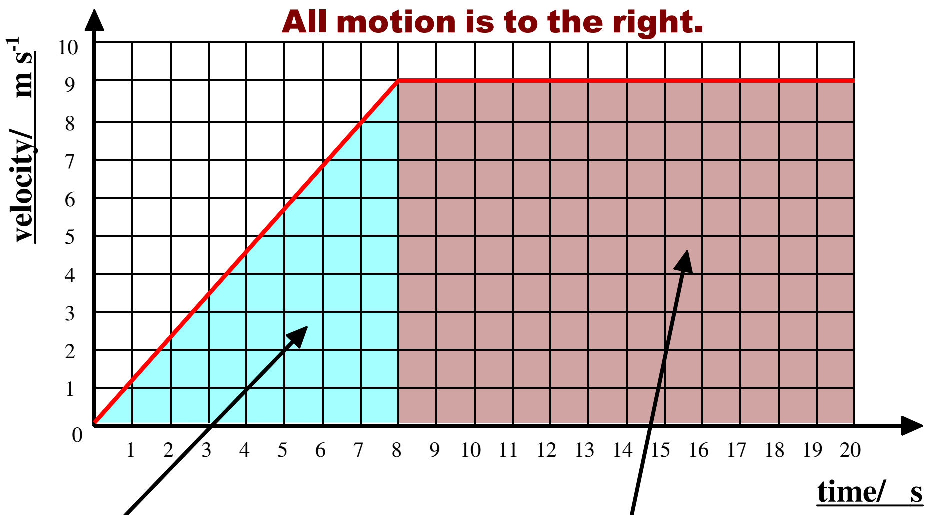
Calculating Displacement From a Velocity-Time Graph

The **area** under a **velocity-time graph** representing the motion of an object gives the **displacement** of the object.

For Example

This **velocity-time graph** represents the motion of a go-kart travelling in a straight line to the right for the first 20 s of its journey.

Determine the **displacement** of the go-kart after these 20 s.



Area of triangle = 1/2 x base x height
= 1/2 x 8 x 9
= 36

Area of rectangle = base x height
= 12 x 9
= 108

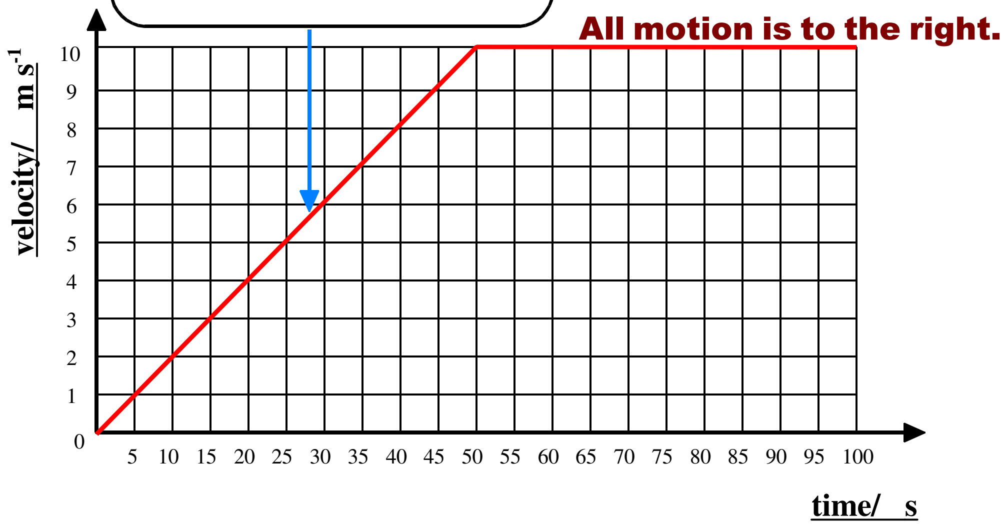
Displacement = Area under velocity-time graph
= 36 + 108
= 144 m to the right

Displacement and Acceleration Calculations

16) Each of the following **velocity-time graphs** represent the motion of a vehicle.

For each graph, calculate any **accelerations** and **decelerations** of the vehicle, plus the **displacement** of the vehicle.

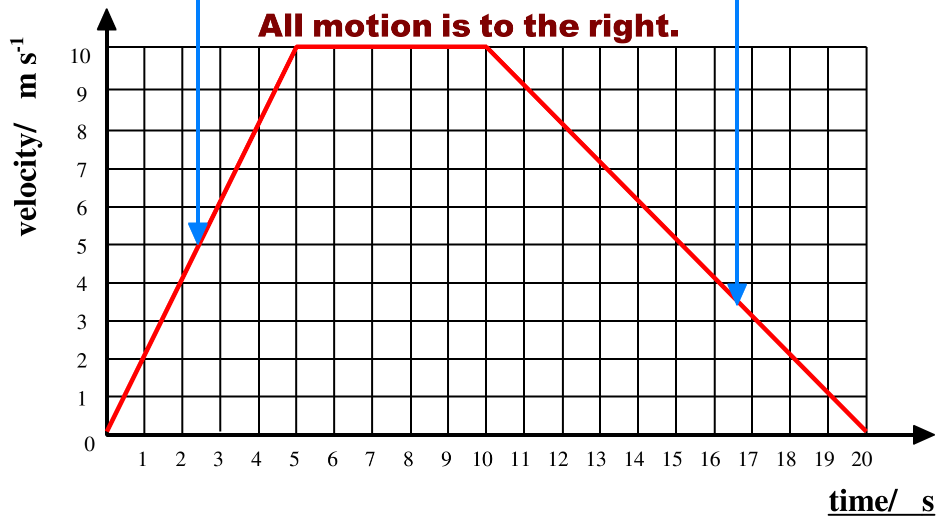
Acceleration Calculation



Displacement Calculation

Acceleration Calculation

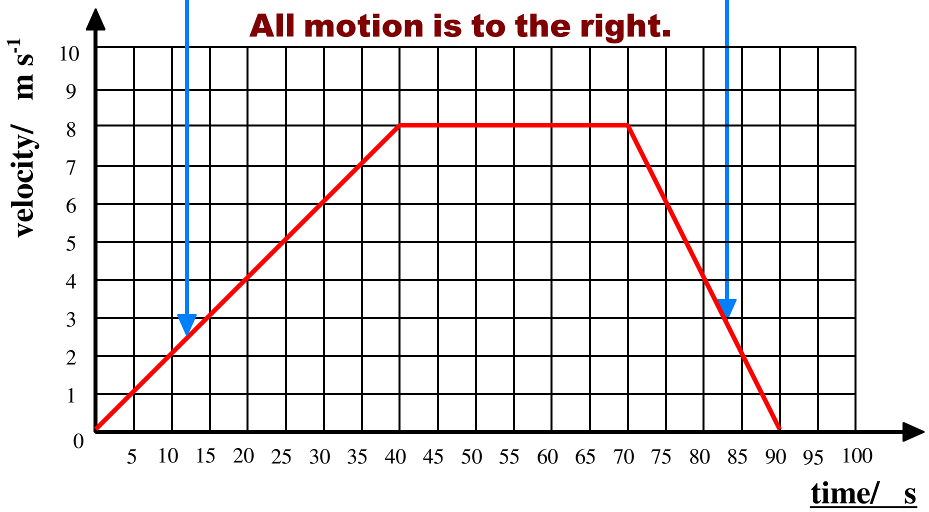
Deceleration Calculation



Displacement Calculation

Acceleration Calculation

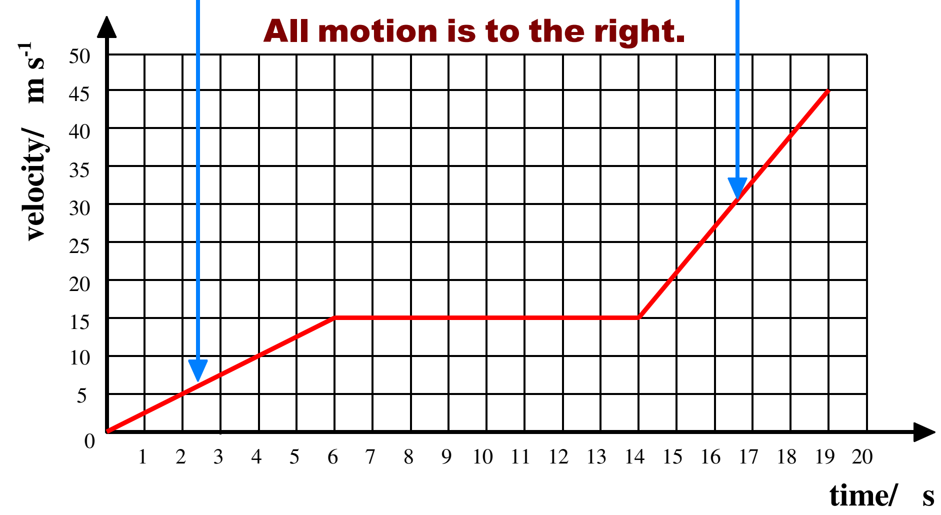
Deceleration Calculation



Displacement Calculation

Acceleration Calculation

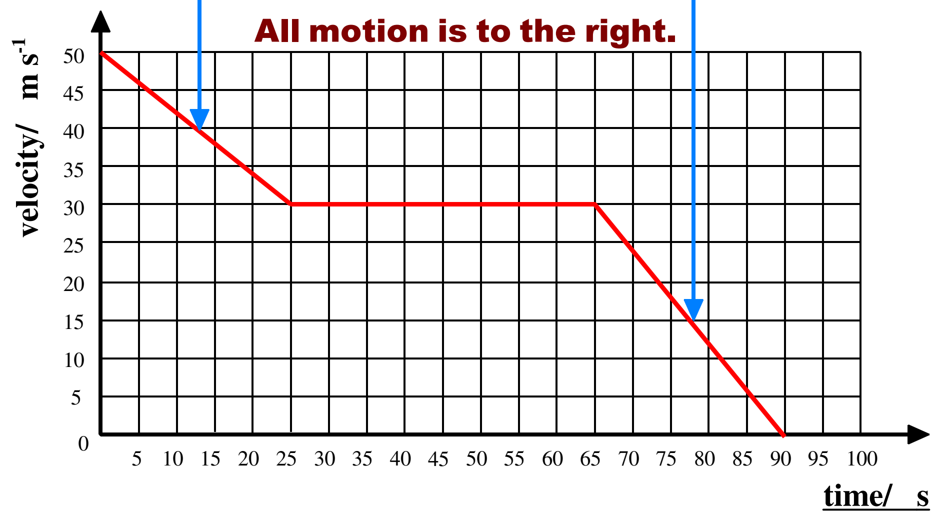
Acceleration Calculation



Displacement Calculation

Deceleration Calculation

Deceleration Calculation



Displacement Calculation

Velocity-Time Graphs - Objects Reversing Direction

Velocity is a vector quantity - it has both a magnitude (size) and a direction.

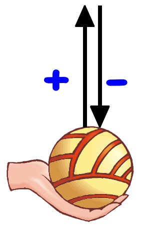
A velocity-time graph can be used to show the time at which a moving object ***reverses direction*** - at this time, the line on the velocity-time graph ***crosses the time axis***.

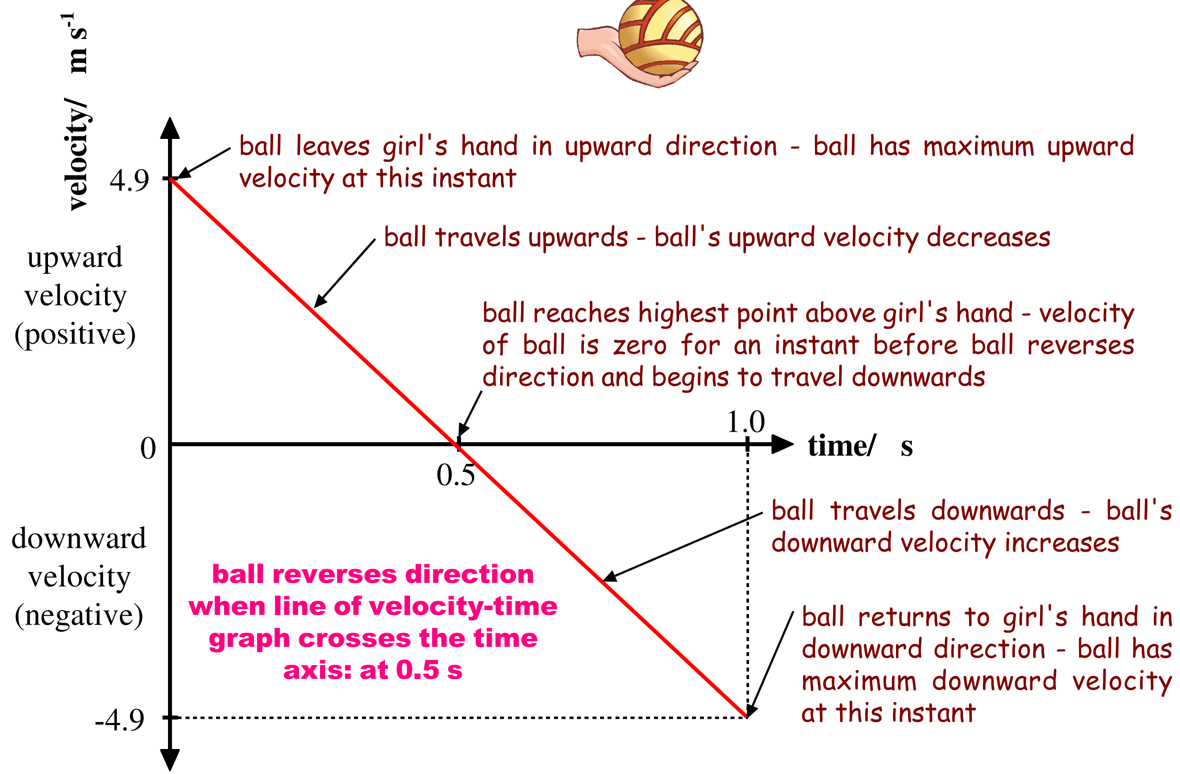
For example, the velocity-time graph shown below represents the motion of a ball thrown upwards from a girl's hand. The ball returns to the girl's hand.

To account for the vector nature of velocity:

upward velocity has been taken to be 'positive'

downward velocity has been taken to be 'negative'





The acceleration of the ball for each stage of its motion (upwards and downwards) can be calculated using values taken from the velocity-time graph.

Calculating Acceleration For Upward Motion

From velocity-time graph:

- initial upward velocity (u) = 4.9 m s^{-1}
- final upward velocity (v) = 0 m s^{-1}
- time taken = 0.5 - 0 = 0.5 s

$$a = \frac{v - u}{t} = \frac{0 - 4.9}{0.5} = -9.8 \text{ m s}^{-2}$$

Calculating Acceleration For Downward Motion

From velocity-time graph:

- initial downward velocity (u) = 0 m s^{-1}
- final downward velocity (v) = -4.9 m s^{-1}
- time taken = 1.0 - 0.5 = 0.5 s

$$a = \frac{v - u}{t} = \frac{-4.9 - 0}{0.5} = -9.8 \text{ m s}^{-2}$$

The total area under the velocity-time graph gives the total displacement of the ball over the time represented on the velocity-time graph.

Total displacement of ball	=	**Area of triangle above time axis**	+	**Area of triangle below time axis**
	=	**1/2 x base x height**	+	**1/2 x base x height**
	=	**(1/2 x 0.5 x 4.9)**	+	**(1/2 x 0.5 x -4.9)**
	=	**(1.2)**	+	**(-1.2)**
	=	**0 m**		

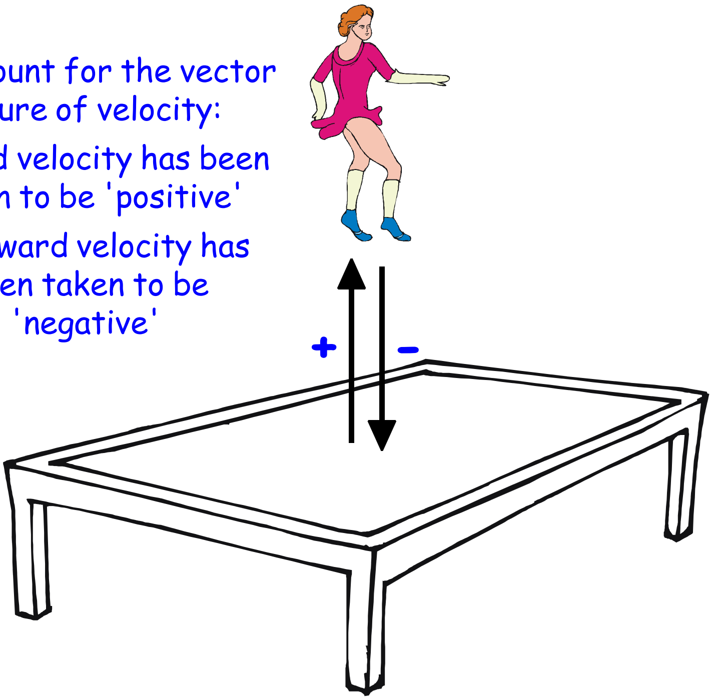
The total displacement of the ball is zero because it has returned to its starting position (the girl's hand).

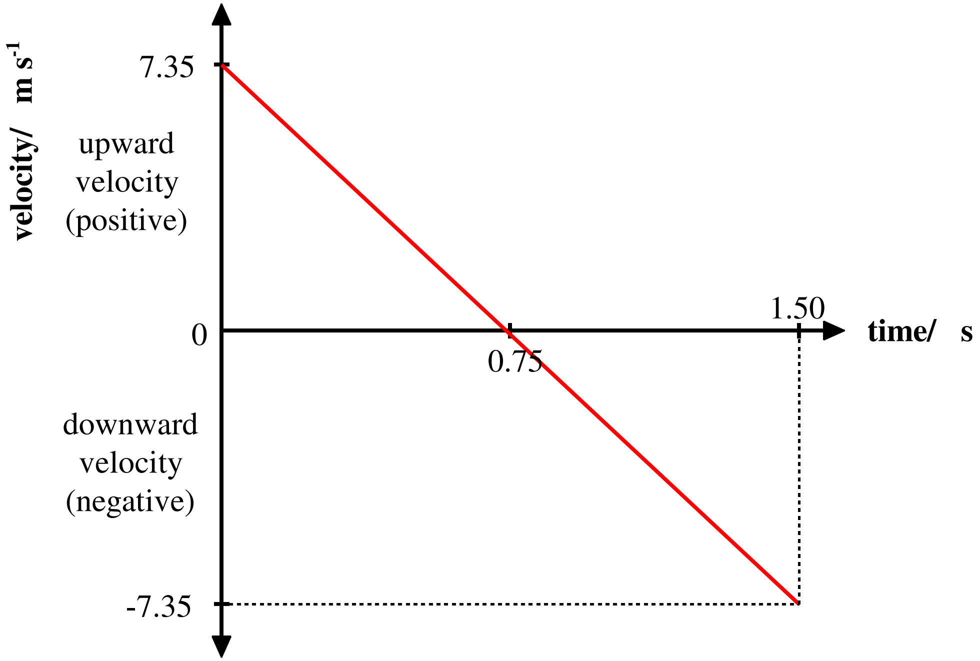
17) The velocity-time graph for one up-and-down motion of a girl on a trampoline is shown. The up-and-down motion takes a total time of 1.50 s.

To account for the vector nature of velocity:

upward velocity has been taken to be 'positive'

downward velocity has been taken to be 'negative'





(a) At what **time** after launching herself upwards from the trampoline does the girl **reach her maximum height**, **achieve a velocity of 0 m s^{-1}** and **reverse direction**? ____________________________

(b) Calculate the **acceleration** of the girl as she **travels upwards**.

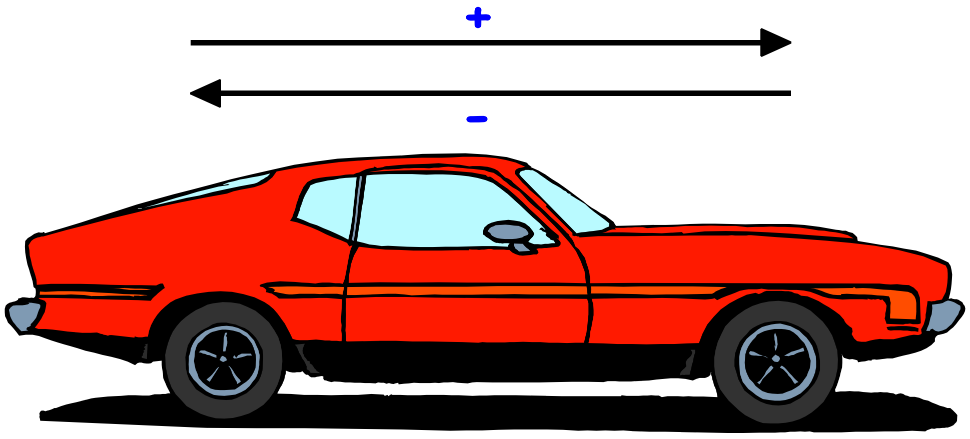
(c) Calculate the **acceleration** of the girl as she **travels downwards**.

(d) Use the graph to show that the **total upward displacement** of the girl (i.e., the maximum height she reaches) is **2.76 m**.

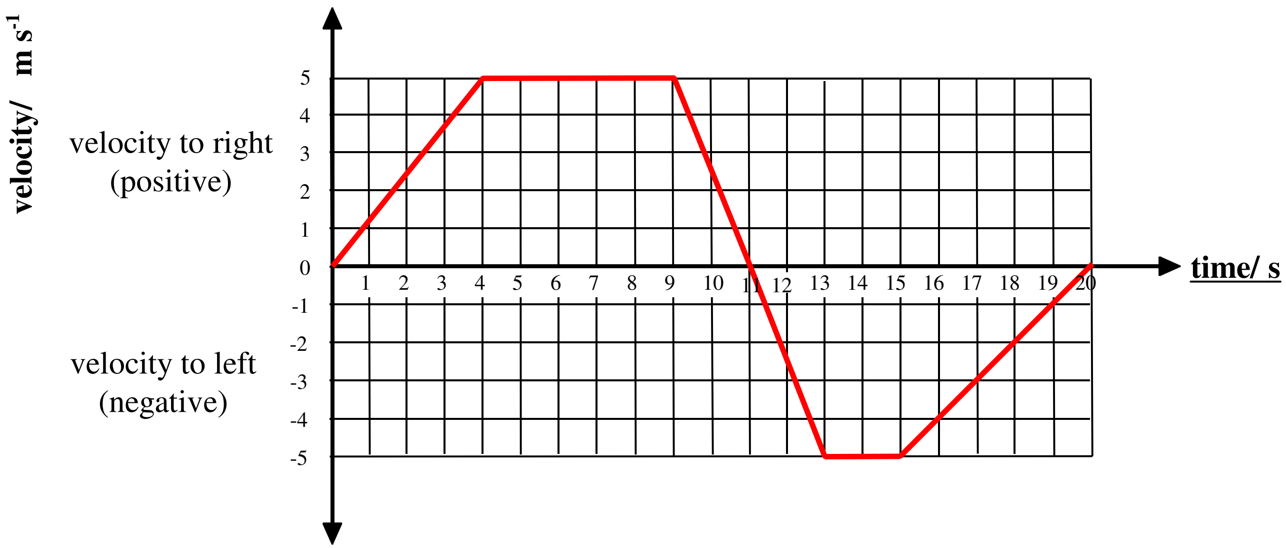
(e) Use the graph to show that the **total downward displacement** of the girl (i.e., the height she falls through) is **-2.76 m**.

(f) Show that the **total overall displacement** of the girl during the 1.5 s is **0 m**.

18) The velocity-time graph below represents the straight-line journey of a car over a 20.0 s time interval.



To account for the vector nature of velocity:
velocity to the right has been taken to be 'positive'
velocity to the left has been taken to be 'negative'



(a) The velocity of the car is **0 m s^{-1}** at **three times** during its 20.0 s journey.

What are these **three times**? ______________________

(b) During its 20.0 s journey, the car **reverses direction** once.

At what **time** does the car **reverse direction**? ______

(c) Use the graph to show that the **total displacement** of the car **to the right** is **40.0 m**.

(d) Use the graph to show that the **total displacement** of the car **to the left** is **-27.5 m**.

(e) Show that the **total overall displacement** of the car during the 20.0 s is **12.5 m** to the **right**.

Notes

Notes