CfE Kinematics - BMcMULLEN

- Speed is the distance travelled by a vehicle, person or object per second.
- Speed will vary continuously throughout a journey, so we tend to talk about two different types of speed:

1. Average speed
2. Instantaneous speed

1 Average speed

The average speed is measured over a large distance or a large period of time.

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

distance travelled: metres (m) OR kilometres (km)

Average speed: metres per second (ms^{-1}) OR kilometres per hour (kmh^{-1})

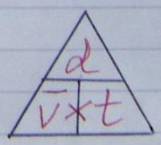
time taken: seconds (s) OR hours (h)

$$\bar{v} = \frac{d}{t}$$

$\bar{v}$ = Average Speed (ms^{-1})

d = distance travelled (m)

t = time taken (s)



1. $d = \bar{v} \times t$
2. $\bar{v} = \frac{d}{t}$
3. $t = \frac{d}{\bar{v}}$

$\bar{v}$ ⇒ Average speed only.

How to measure average speed

Apparatus: stopwatch, trolley, chalk and measuring tape.

Procedure:

- mark two points on a floor surface with chalk.

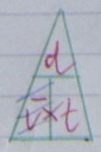
Points A and B

- Push a trolley through the two marked points on the floor surface.
- Start the stopwatch when the trolley passes through point A on the floor.
- Stop the stopwatch when the trolley passes through point B.

* Average Speed = $\frac{\text{measured distance from A to B}}{\text{measured time from A to B}}$ *

Q Ex 1: Calculate the average speed of a car that travels 800m in 40s.

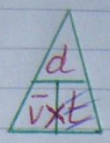
A $d = 800m$
$\bar{v} = ?$
$t = 40s$



$\bar{v} = \frac{d}{t} = \frac{800}{40} = 20ms^{-1}$

Q Ex2: How long would it take a lorry to travel 60km if it has an average speed of 15 Kmh^{-1} (15 kilometres per hour).

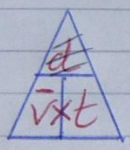
A $d = 60km$
$\bar{v} = 15Kmh^{-1}$
$t = ?$



$t = \frac{d}{\bar{v}} = \frac{60}{15} = 4h$

Q Ex3: How far will an athlete run if they have an average speed of 8 ms^{-1} for 50seconds.

A $d = ?$
$\bar{v} = 8ms^{-1}$
$t = 50s$



$d = \bar{v}t = 8 \times 50 = 400m$

2 Instantaneous Speed

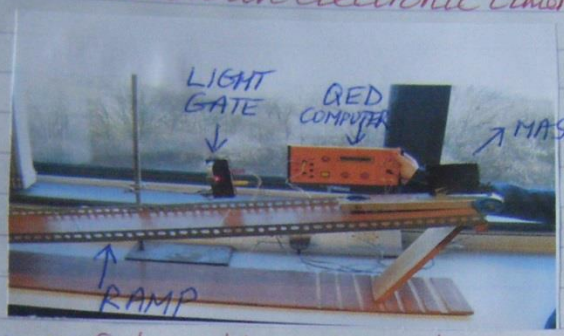
The instantaneous speed is measured over a very small distance or a very small period of time.

Instantaneous Speed	=	distance travelled / time taken

Instantaneous speed can only be measured electronically to achieve precise results. This is due to human reaction time when the experimenter is using the stopwatch to record the time. The human reaction time could be larger than the time that is actually being recorded!!

How to measure Instantaneous Speed

Apparatus: A ramp, trolley, mask(card), a ruler and a light gate with an electronic timer (QED Computer)



Procedure:

- Set up the apparatus as shown above.
- Measure the length of the mask with a ruler.
- Release the trolley from rest from the top of the ramp.
- When the front end of the mask on top of the trolley breaks the light beam the timer will start.
- When the back end of the mask on top of the trolley passes through the light beam the timer will stop.
- The instantaneous speed of the trolley is measured at the light gate where.

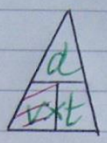
$$\text{Instantaneous Speed} = \frac{\text{length of mask}}{\text{time that the light beam is broken for.}}$$

Ex3

A trolley with a mask of 10cm in length passes through a light gate set up on a ramp with an electronic timer.

Q Calculate the instantaneous speed of the trolley as it passes through the light beam in 0·40seconds.

A $d = 10cm = 0.1m$
$v = ?$
$t = 0.40s.$



$v = \frac{d}{t} = \frac{0.1}{0.40}$

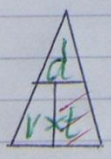
$\Rightarrow v = 0.25ms^{-1}$

Ex4

A trolley with a mask of length 5cm has an instantaneous speed of $0.40ms^{-1}$ recorded when it passes through a light gate with a QED computer attached.

Q Calculate the time that was recorded as the trolley mask breaks the light beam.

A $d = 5cm = 0.05m$
$v = 0.40ms^{-1}$
$t = ?$



$t = \frac{d}{v} = \frac{0.05}{0.40}$

$\Rightarrow t = 0.125seconds.$

* d = Length of trolley mask or card
t = time that the trolley mask breaks the light beam for.
v = Instantaneous speed of trolley *

Acceleration

Acceleration is defined precisely as the change in velocity per unit of time. (ie per second or per hour)

At this stage we usually use the term speed instead of velocity.

* (We will see the difference between the terms speed and velocity when we look at scalars and vectors, where speed → scalar quantity and velocity → vector quantity.) *

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

OR

$$\text{acceleration} = \frac{\text{Change in speed}}{\text{time taken}}$$

In letter form these formula are written as:

* $a = \frac{v-u}{t}$ OR $v = u + at$ *

u = Initial Speed / Velocity (ms^{-1})
v = Final Speed / Velocity (ms^{-1})
a = Acceleration (ms^{-2})
t = time taken (s).

** COMMON MISTAKE ⇒ ACCELERATION IN ms^{-1} X **

EX5

Q A car increases its speed from $8ms^{-1}$ $12ms^{-1}$ in 16seconds.

Calculate the acceleration of the car.

A $u = 8ms^{-1}$
$v = 12ms^{-1}$
$a = ?$
$t = 16s.$

$a = \frac{v-u}{t} = \frac{12-8}{16} = \frac{4}{16} = \underline{0.25ms^{-2}}$

EX6

A truck reduces its speed from $14ms^{-1}$ to $9ms^{-1}$ in 10seconds.

Q a) Calculate the acceleration of the truck
b) What does the negative answer for acceleration signify in terms of the trucks motion?

A a) $u = 14ms^{-1}$
$v = 9ms^{-1}$
$a = ?$
$t = 10seconds$

$a = \frac{v-u}{t} = \frac{9-14}{10} = \frac{-5}{10}$

$\Rightarrow \underline{a = -0.5ms^{-2}}$

b) The negative answer for acceleration signifies that the truck is decelerating ie slowing down.

ie -ve acceleration $\Rightarrow$ a deceleration

Ex8

Q A bus travelling at $8ms^{-1}$ accelerates at $0.6ms^{-2}$ for 7 seconds.

Calculate the speed of the bus after 7 seconds.

A $u = 8ms^{-1}$
$V = ?$
$a = 0.6ms^{-2}$
$t = 7s.$

$V = u + at$

$\Rightarrow V = 8 + 0.6 \times 7 = 8 + 4.2$

$\Rightarrow \underline{V = 12.2ms^{-1}}$

Ex9

Q A van accelerates at $-0.4ms^{-2}$ for 12 seconds until it reaches a speed of $9.6ms^{-1}$.

a) Calculate the initial speed of the van.
b) Describe the motion of the van.

A a) $u = ?$
$V = 9.6ms^{-1}$
$a = -0.4ms^{-2}$
$t = 12s.$

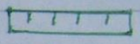
$V = u + at$
$\Rightarrow 9.6 = u + (-0.4) \times 12$
$\Rightarrow 9.6 = u - 4.8$
$\Rightarrow 9.6 + 4.8 = u$
$\Rightarrow \underline{u = 14.4ms^{-1}}$

b) The negative acceleration shows that the van is decelerating.

How to measure acceleration

Apparatus: A trolley, a ramp, a light gate and a QED computer. A ruler is also required and a double mask.

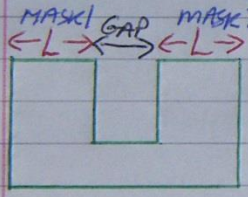
DOUBLE MASK



RULER.

Procedure:

- Set up the apparatus as shown above.



- measure the lengths of each part of the double mask and the gap in between with a ruler.
- Release the trolley from the top of the ramp and then it will pass through the light gate.

MASK 1 • Initial speed $u = \frac{\text{length of mask 1}}{\text{Time mask 1 breaks light beam}}$

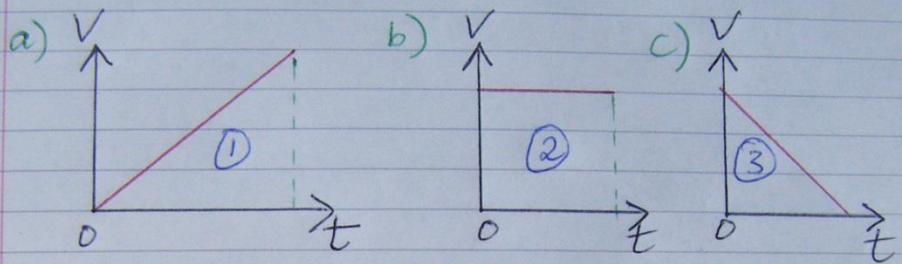
MASK 2 • Final speed $v = \frac{\text{length of mask 2}}{\text{Time mask 2 breaks light beam}}$

GAP • Gives the time for the equation t.

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

Speed - time Graphs

* The area under a speed-time graph is a measure of the total distance travelled. *



a) Constant acceleration

b) Constant Speed

c) Constant negative acceleration
ie constant deceleration.

The areas shown in the three graphs above are all regularly shaped ie rectangles or triangles.

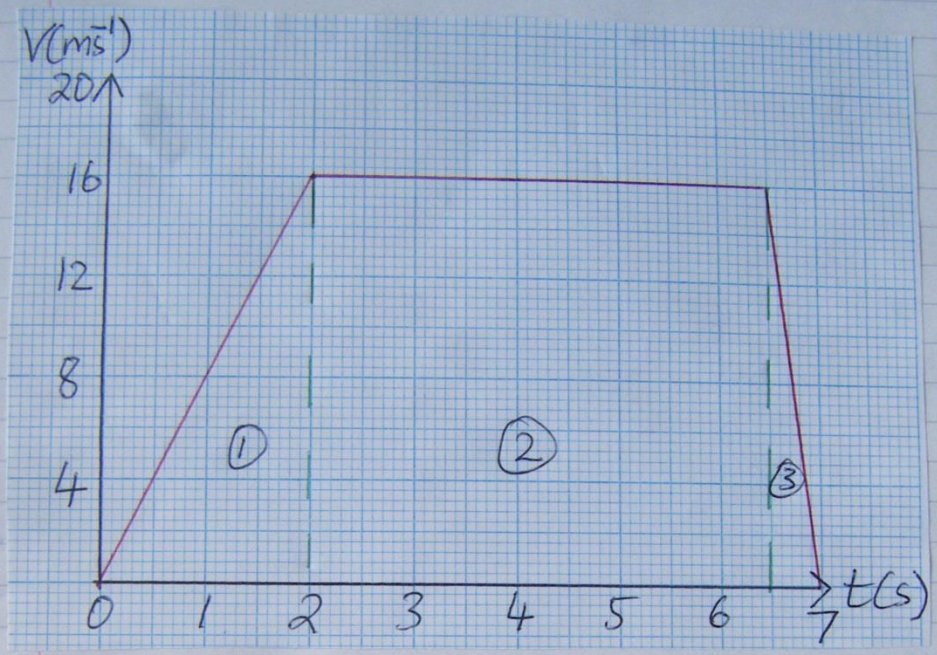
Where : area of a triangle = $\frac{1}{2}$ base x height

area of a rectangle = length x breadth

* We would normally talk about areas being measured in m^2 however with Speed time graphs the areas are measured in metres.

** Why? Speed x time = $ms^{-1} \times s = m$ **

Ex10



Q From the speed-time graph above:

a) Describe the motion of the object from i) 0→2s ii) 2→6·5s iii) 6·5→7s.

b) Calculate or find the acceleration of the object from:
i) 0→2s ii) 2→6·5s iii) 6·5→7s.

c) Calculate the total distance travelled by the object over the 7s.

d) Calculate the average speed of the object over the 7s.

A a) i) $0 \to 2s \Rightarrow$ Constant acceleration

ii) $2 \to 6.5s \Rightarrow$ constant speed

iii) $6.5 \to 7s \Rightarrow$ Constant negative accel^n = ie Constant deceleration

b) i) $u = 0$, $v = 16ms^{-1}$, $a = ?$, $t = 2s$.

$a = \frac{v-u}{t} = \frac{16-0}{2} = \underline{8ms^{-2}}$

ii) Constant speed $\Rightarrow a = 0$

iii) $u = 16ms^{-1}$, $v = 0$, $a = ?$, $t = 0.5s$

$a = \frac{v-u}{t} = \frac{0-16}{0.5} = \underline{-32ms^{-2}}$

* ie deceleration $= 32ms^{-2}$ *

c) Total distance travelled = Area ① + Area ② + Area ③

Area ① $= \triangle = \frac{1}{2} \times 2 \times 16 = \underline{16m}$.

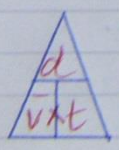
Area ② $= \square = (6.5-2) \times 16 = 4.5 \times 16 = \underline{72m}$

Area ③ $= \triangle = \frac{1}{2} \times 0.5 \times 16 = \underline{4m}$

Total distance travelled $= 16m + 72m + 4m = \underline{92m}$

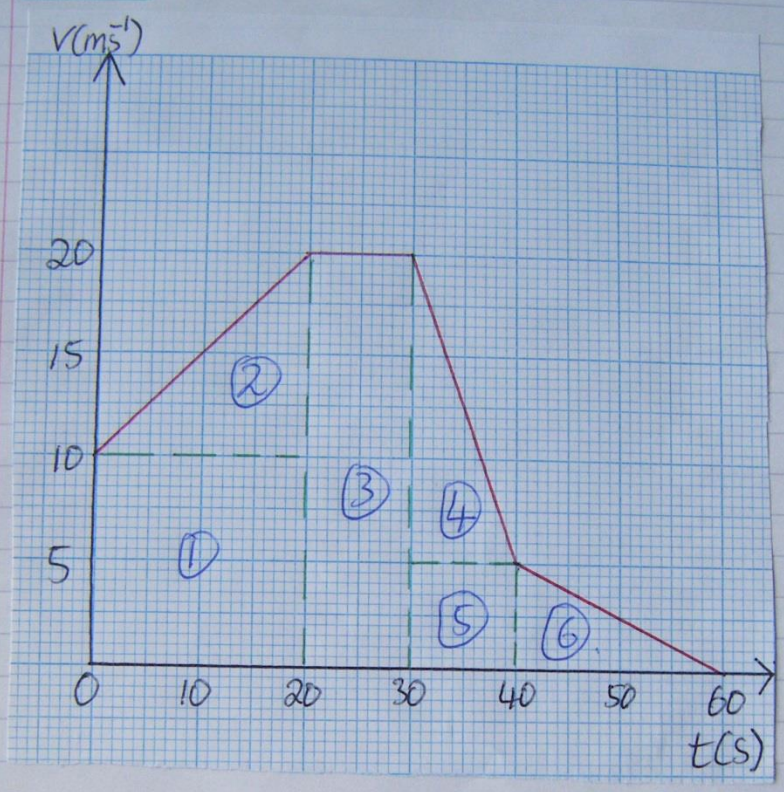
d) Average speed $= \frac{\text{distance}}{\text{time}} = \frac{92}{7} = \underline{13.1ms^{-1}}$

ie



$\bar{v} = \frac{d}{t}$

Ex11



Q From the speed-time graph above:

a) Calculate the accelerations over the four time intervals.

b) Calculate the total distance travelled over the 60s.

c) Calculate the average speed of the object over the first 30s.

A a) i) $0 \to 20s$, $u = 10ms^{-1}$, $v = 20ms^{-1}$, $a = ?$, $t = 20s$

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

$\Rightarrow a = \frac{20-10}{20} = \frac{10}{20}$

$\Rightarrow a = 0.5ms^{-2}$

ii) $20 \to 30s$, $a = 0$ as this involves a constant speed.

iii) $30 \to 40s$, $u = 20ms^{-1}$, $v = 5ms^{-1}$, $a = ?$, $t = 10s$.

$a = \frac{v-u}{t} = \frac{5-20}{10}$

$\Rightarrow a = \frac{-15}{10} = -1.5ms^{-2}$

iv) $40 \to 60s$, $u = 5ms^{-1}$, $v = 0ms^{-1}$, $a = ?$, $t = 20s$

$a = \frac{v-u}{t} = \frac{0-5}{20}$

$\Rightarrow a = -0.25ms^{-2}$

b) Total distance travelled = Area ① + Area ② + Area ③ + Area ④ + Area ⑤ + Area ⑥.

Area ① = □ = $20 \times 10 = 200m$

Area ② = △ = $\frac{1}{2} \times 20 \times 10 = 100m$

Area ③ = □ = $10 \times 20 = 200m$

Area ④ = △ = $\frac{1}{2} \times 10 \times 15 = 75m$

Area ⑤ = □ = $10 \times 5 = 50m$

Area ⑥ = △ = $\frac{1}{2} \times 20 \times 5 = 50m$

∴ Total distance travelled = $200m + 100m + 200m + 75m + 50m + 50m$

$= 675m$

c) Total distance over the first 30s = Area ① + Area ② + Area ③
= 200m + 100m + 200m
= 500m

Average Speed = distance travelled / time taken = 500/30 = 16.7ms^{-1}

Ex12

Q A cyclist travels along a straight road, and increases speed from 2ms^{-1} to 5ms^{-1} in 15 seconds.
Calculate or find:
a) The acceleration of the cyclist.
b) The average speed of the cylist
c) The distance travelled by the cyclist over the 15seconds.

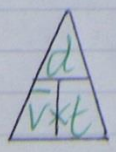
A a) $u = 2ms^{-1}$
$v = 5ms^{-1}$
$a = ?$
$t = 15s.$

$a = \frac{v-u}{t} = \frac{5-2}{15} = \frac{3}{15} = 0.2ms^{-2}$

b) $\bar{v} = \frac{u+v}{2} = \frac{2+5}{2} = \frac{7}{2} = 3.5ms^{-1}$

(The average of the initial and final speeds)

c) $d = ?$
$\bar{v} = 3.5ms^{-1}$
$t = 15s.$



$d = \bar{v} \times t = 3.5 \times 15$
$\Rightarrow d = 52.5m$