Describing motion

G2 | Ji Yutong | 30/08/2022

Speed

Speed

Speed

What is motion? What is speed?

Speed

- **average** speed vs **instantaneous** speed

- Calculating **speed**:

Speed

average speed vs **instantaneous** speed

Calculating **speed**: $speed = \frac{distance}{time}$

$$v = \frac{s}{t} = \frac{\Delta s}{\Delta t} \xrightarrow{\text{rearrange}} t = \frac{s}{v}, \quad s = vt$$

Attention: s stands for distance!!

Unit:

Distance is not displacement!!

Speed

- **average** speed vs **instantaneous** speed

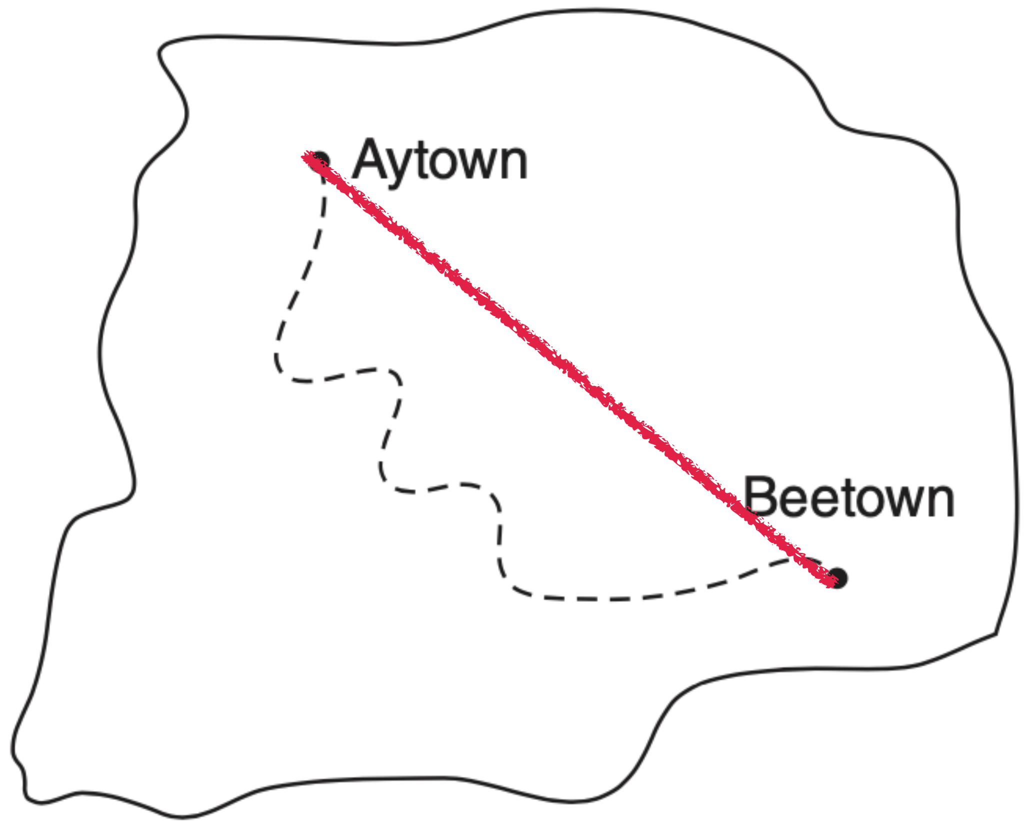
- Calculating **speed:** $speed = \frac{distance}{time}$

$$v = \frac{s}{t} = \frac{\Delta s}{\Delta t} \xrightarrow{\text{rearrange}} \begin{array}{l} t = \frac{s}{v} \\ s = vt \end{array}$$

Attention: s stands for distance!!

- Unit: m/s

Distance is not displacement!!



Speed vs velocity

→ **Speed** : only magnitude, ***scalar*** quantity

e.g. An aircraft has a **speed** of 200m/s.

→ **Velocity**: magnitude + direction, ***vector*** quantity

e.g. The aircraft has a **velocity** of 200m/s due north.

A car travels forwards along a straight horizontal road. Only the horizontal forces acting on it are shown.

The length of each arrow represents the size of each force.

How do these forces affect the motion of the car?

A The car moves at constant speed.

B The car moves backwards.

C The car slows down.

D The car’s forward speed increases.

Scalar vs vector

Scalar : only magnitude, e.g. temperature

Vector: magnitude + direction, e.g. weight

Exercise 2.e

Which of the following physical quantities are scalars? Which are vectors?

distance, speed, time, mass, energy, force, weight, velocity, acceleration, momentum, electric field strength, gravitational field strength

Vector addition

Exercise 2.f

An aircraft is flying **due north** with a **velocity** of 200 m/s. A side wind of velocity 50 m/s is blowing due east. What is the aircraft's **resultant velocity** (give the magnitude and direction)?

Vector addition

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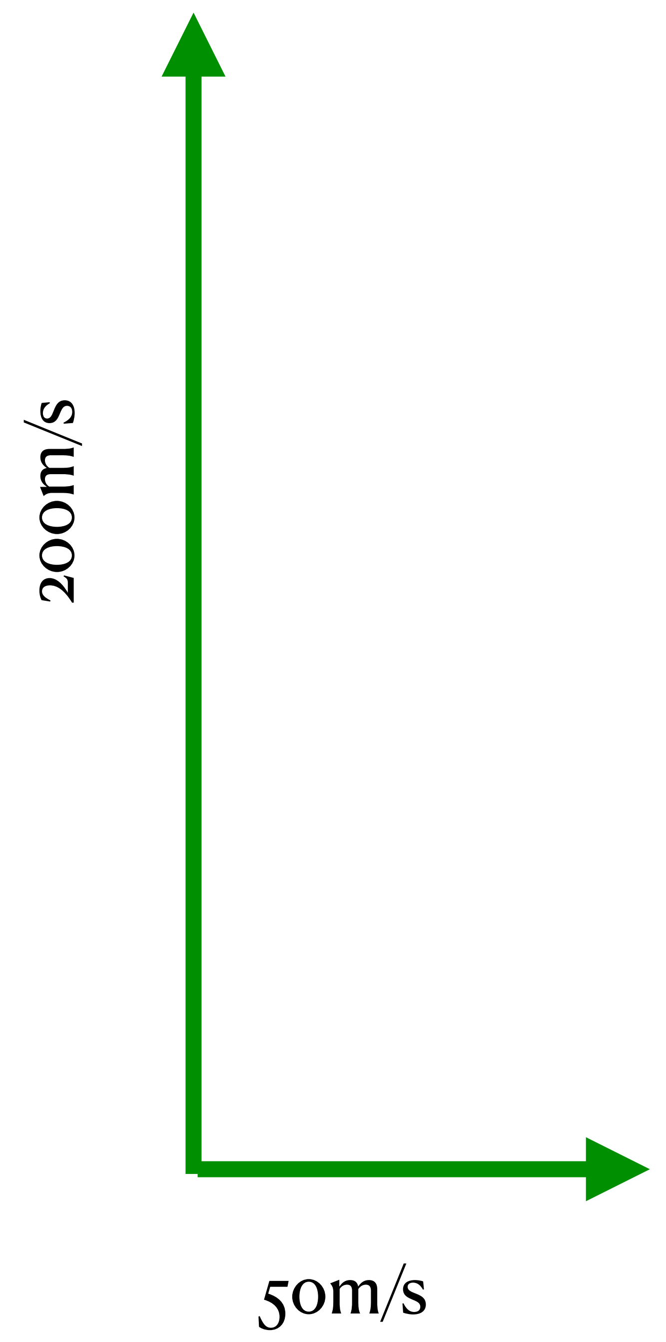

Vector addition

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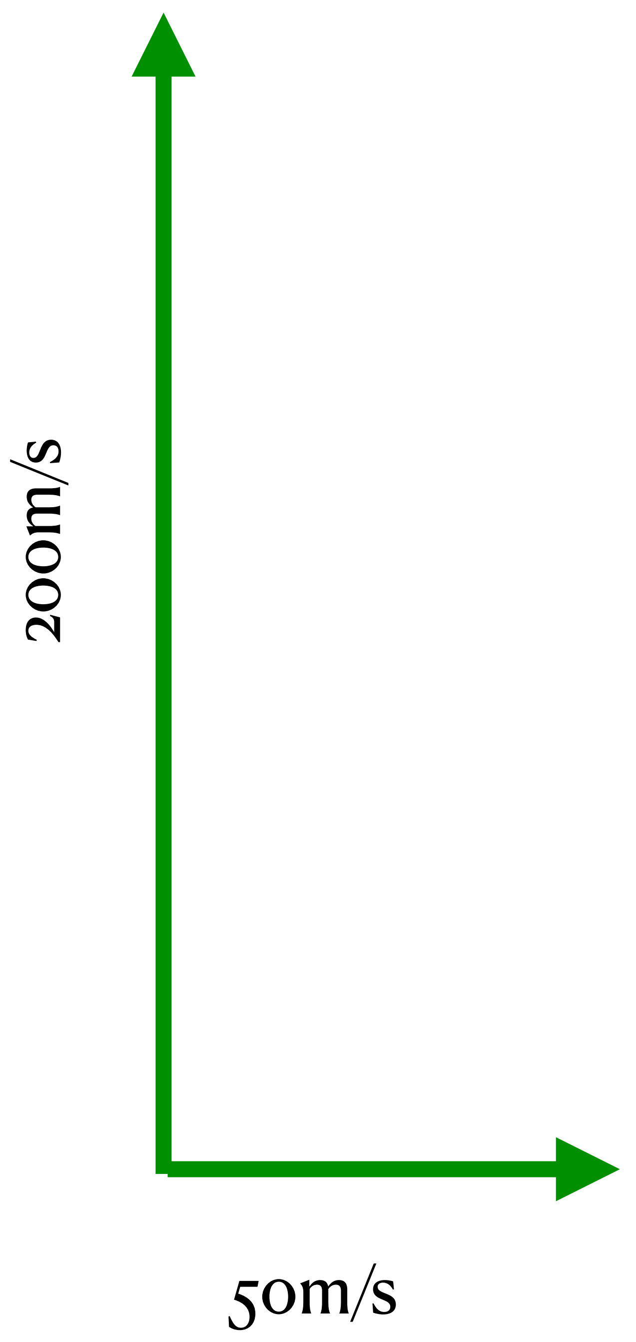
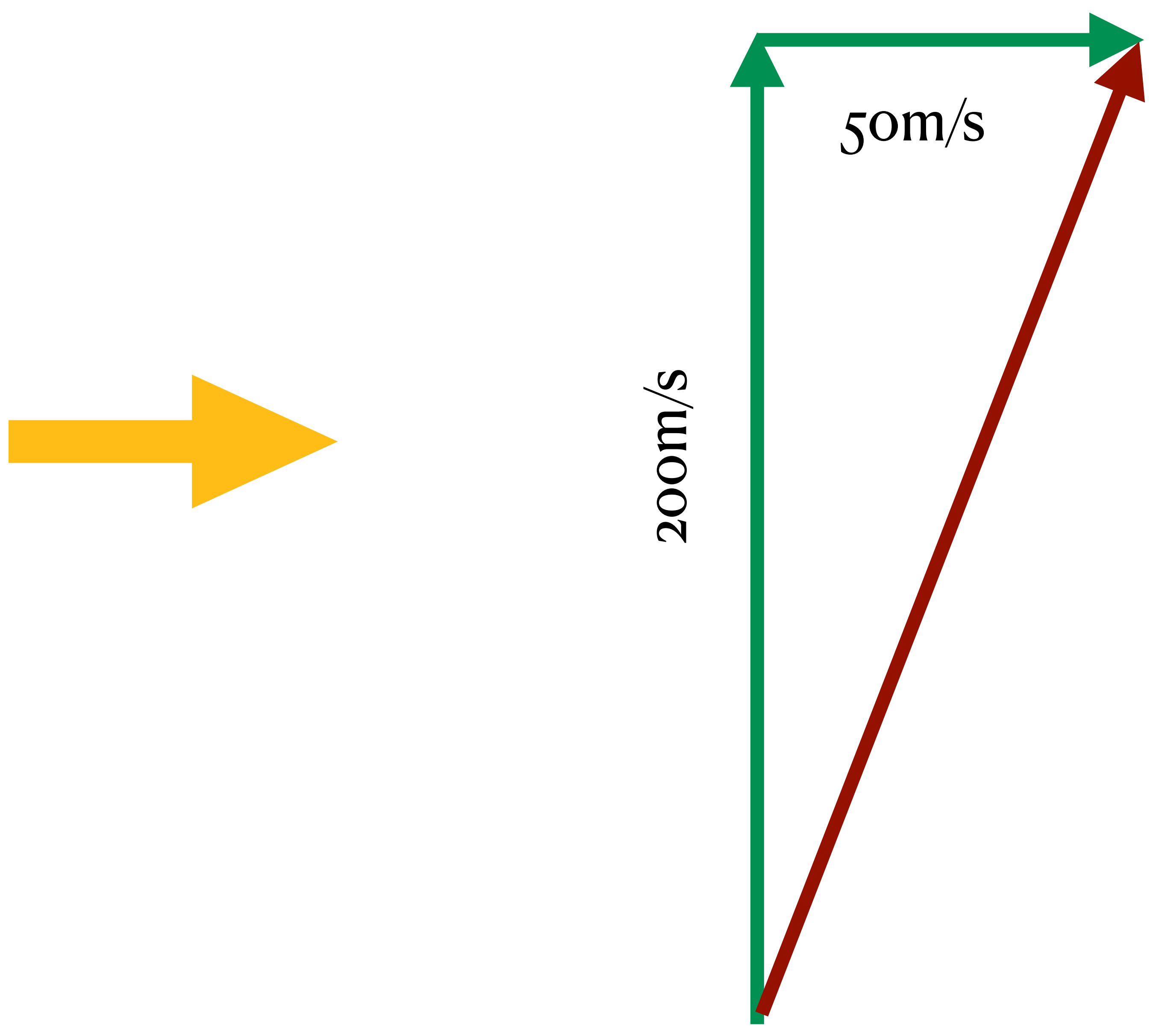
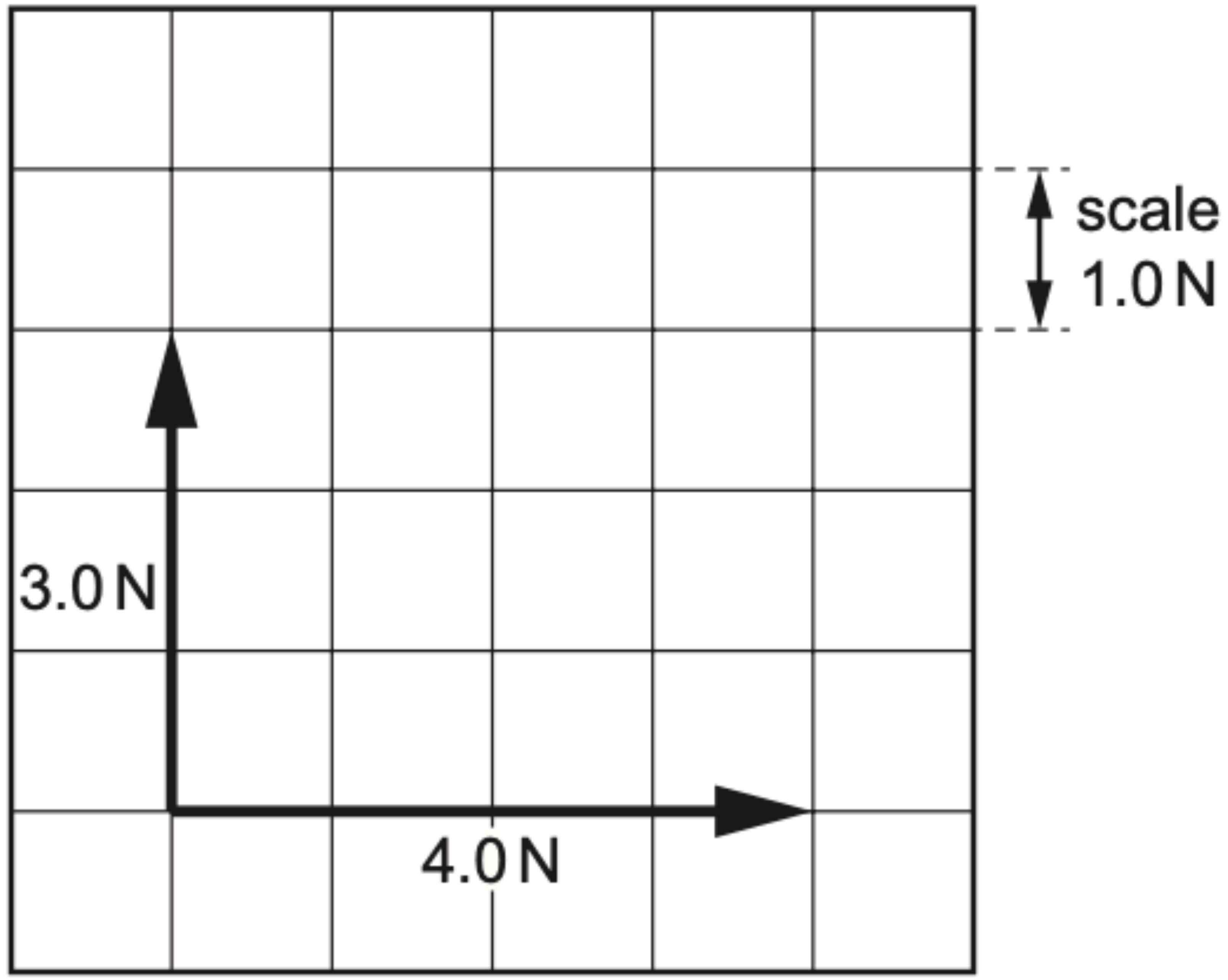




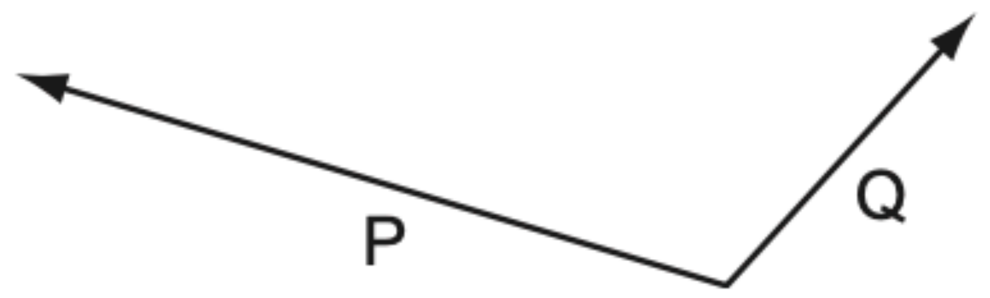
The diagram shows two forces acting at right angles to each other.



What is the resultant of the two forces?

A 1.0 N **B** 5.0 N **C** 7.0 N **D** 12.0 N

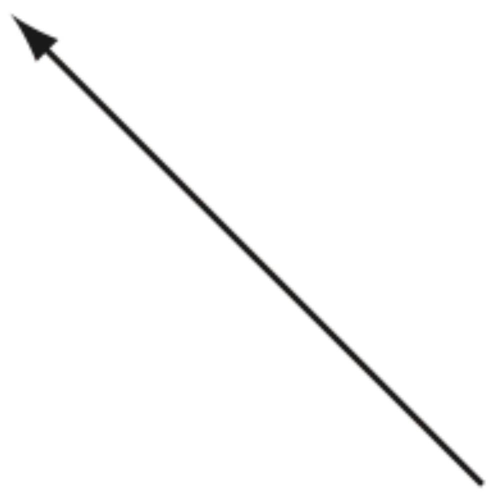
Two possible displacements of an object are represented by the vectors P and Q.



Which vector best represents the resultant displacement (P – Q) of the object?

A

B



C

D

(c) Fig. 4.2 shows two forces acting on an object.

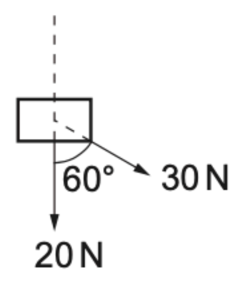


Fig. 4.2 (not to scale)

Draw a scale diagram to determine the resultant force acting on the object. State the scale you use.

scale ....

magnitude of resultant force = ...

direction of resultant relative to the direction of the 20 N force = ...
[4]

Which statement correctly describes the effects of placing a heavy load in a car?

A It is easier to accelerate the car and easier to bring the car to rest.

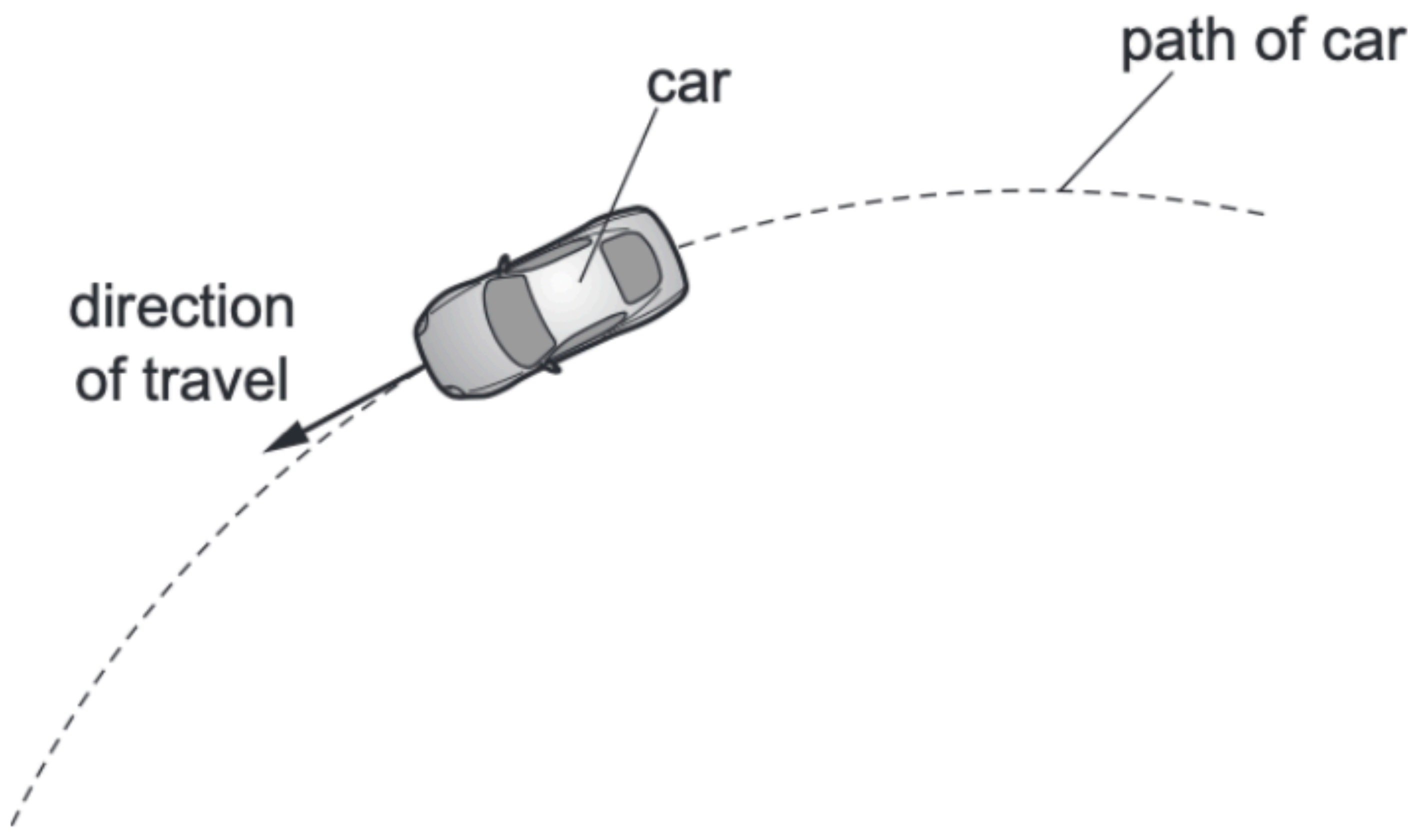
B It is easier to accelerate the car but more difficult to bring the car to rest.

C It is more difficult to accelerate the car and more difficult to bring the car to rest.

D It is more difficult to accelerate the car but easier to bring the car to rest.

A car moves in a circular path as it turns a corner on a horizontal road.

The car moves at constant speed.



Which description of the forces acting on the car is correct?

A All the forces are balanced as the car is moving at constant speed.

B The forces are unbalanced and the resultant force acts away from the centre of the circle.

C The forces are unbalanced and the resultant force acts towards the centre of the circle.

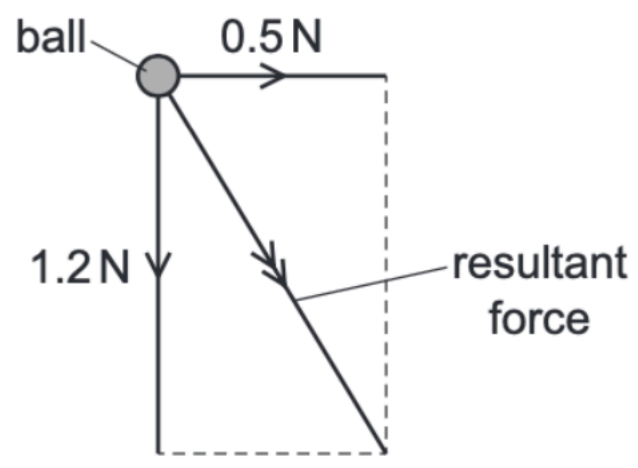
D The forces are unbalanced and the resultant force is in the direction of travel of the car.

A ball of weight 1.2 N drops through the air at terminal velocity.

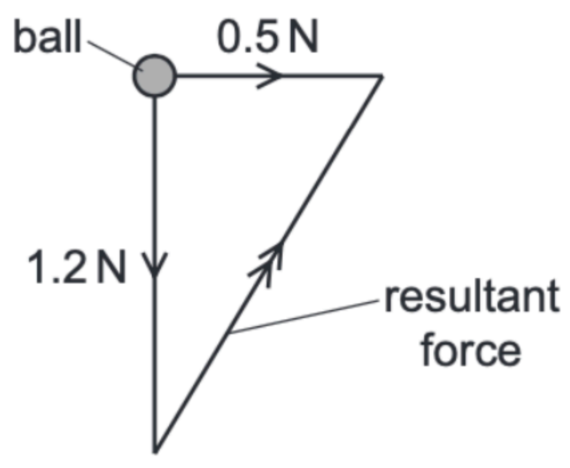
A sudden gust of wind exerts a horizontal force of 0.5 N on the ball from the left.

Which diagram shows the resultant force on the ball while the wind is blowing?

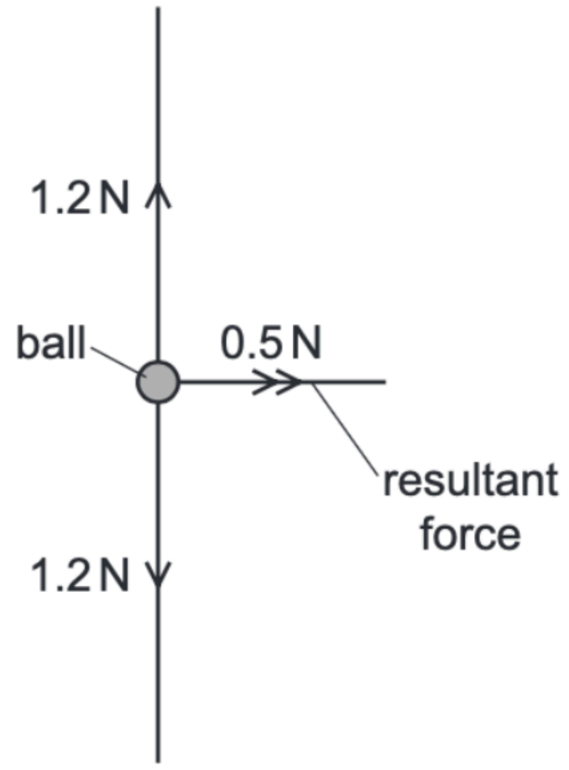
A



B



C



D

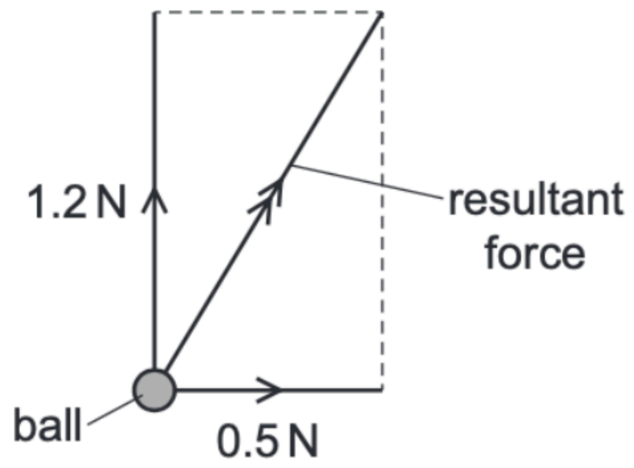


Fig. 2.1 shows a train.

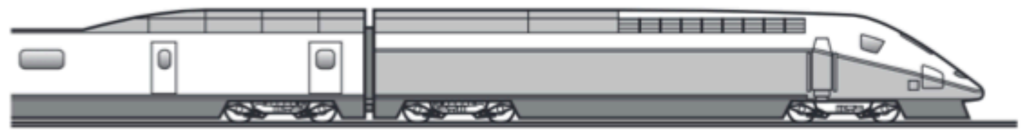


Fig. 2.1

The total mass of the train and its passengers is 750 000 kg. The train is travelling at a speed of 84 m/s. The driver applies the brakes and the train takes 80 s to slow down to a speed of 42 m/s.

(a) Calculate the impulse applied to the train as it slows down.

impulse = ... [3]

(b) Calculate the average resultant force applied to the train as it slows down.

force = ... [2]

(c) Suggest how the shape of the train helps it to travel at high speeds.

....

.... [1]

(d) The train took 80 s to reduce its speed from 84 m/s to 42 m/s. Explain why, with the same braking force, the train takes more than 80 s to reduce its speed from 42 m/s to zero.

....

.... [1]

(e) On a wet day, the train travels a greater distance before it stops along the same track. The train has the same speed of 84 m/s before the brakes are applied.

Suggest a reason for this.

....

.... [1]

[Total: 8]

An object is moving at +3.0 m/s.

A force acts on the object.

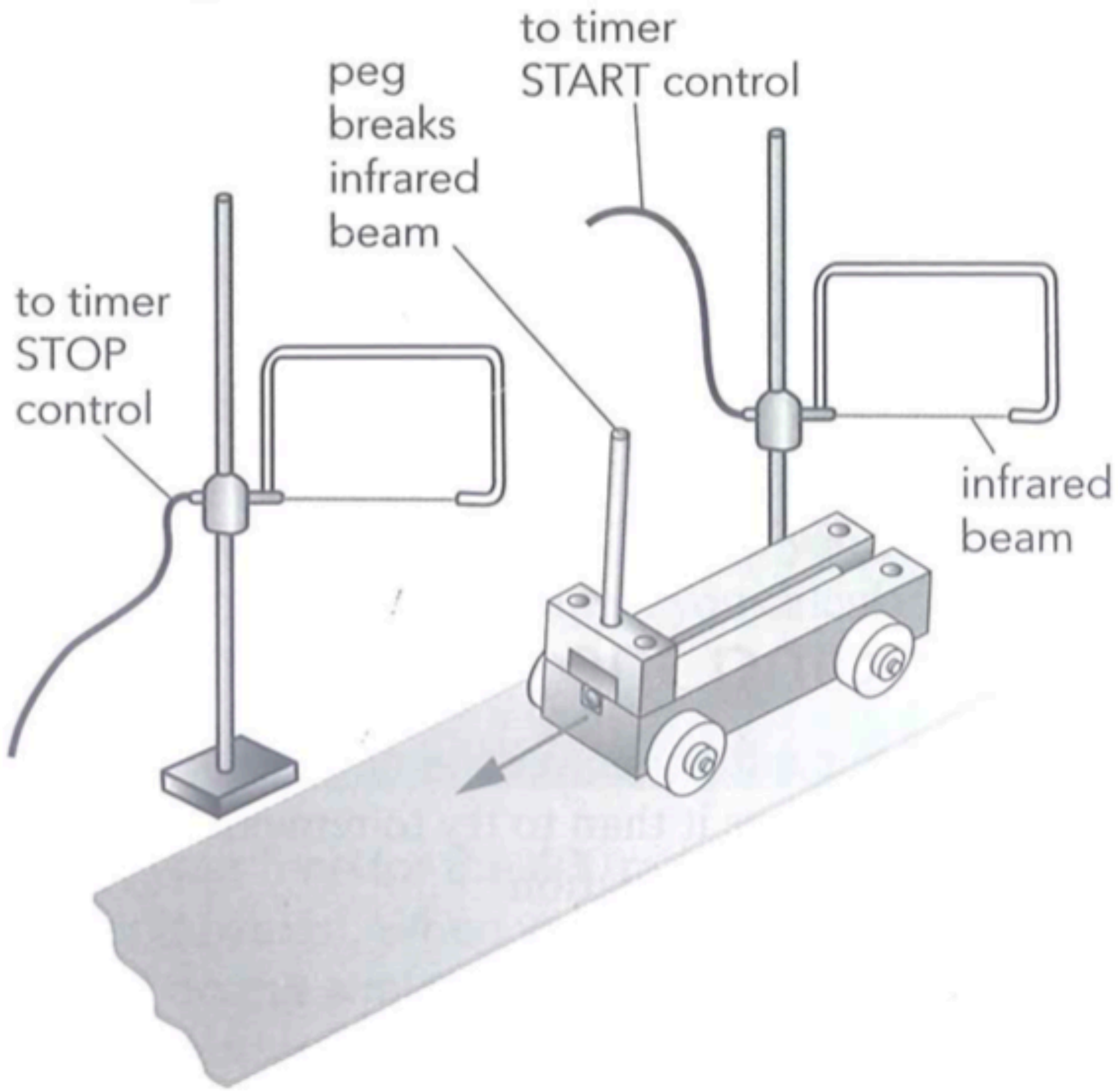
After a time, the object is moving at –4.0 m/s.

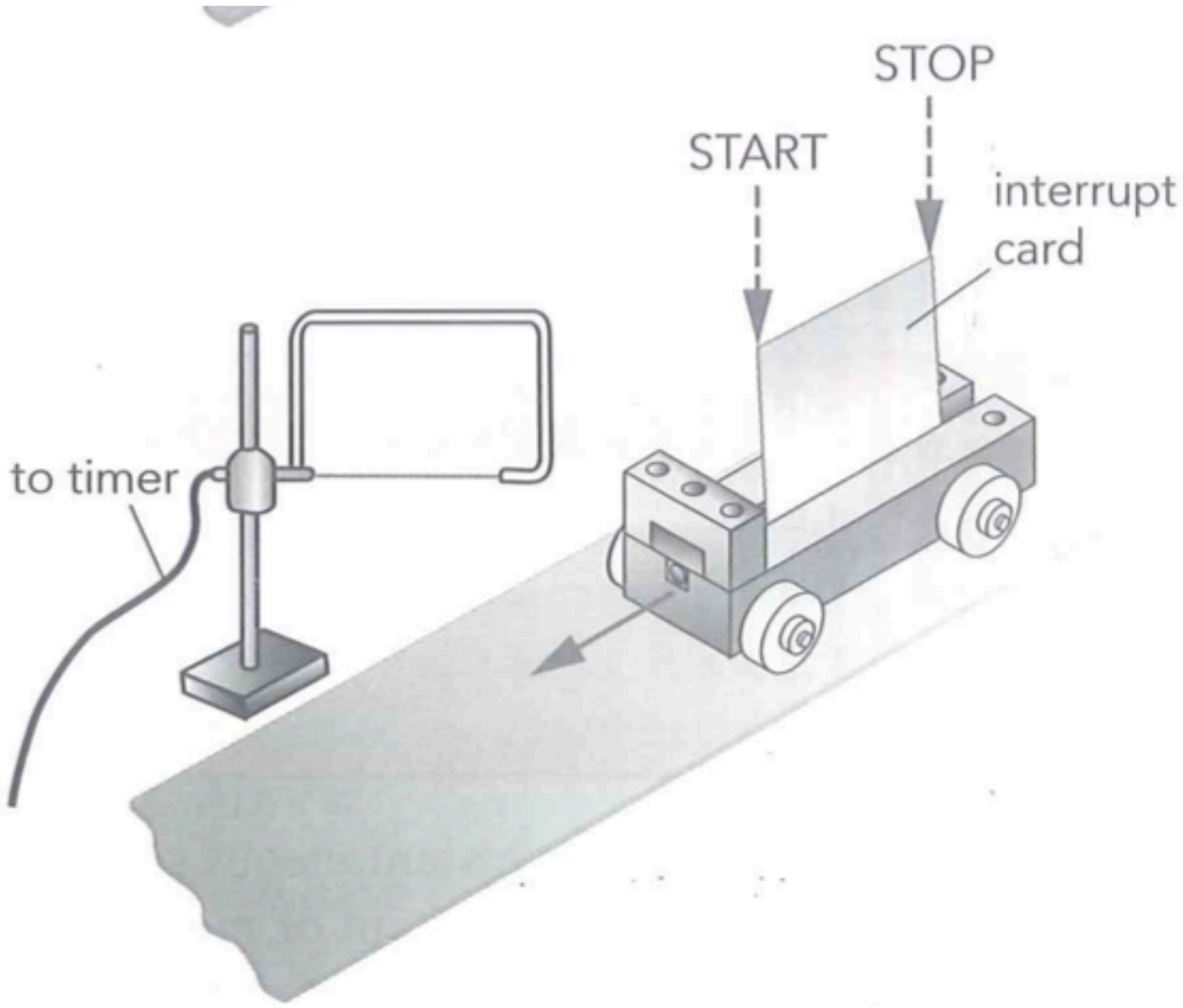
The mass of the object is 5.0 kg.

What is the change in momentum of the body?

A –35 kg m/s **B** –5.0 kg m/s **C** +5.0 kg m/s **D** +35 kg m/s

Experiment: determine speed in the laboratory



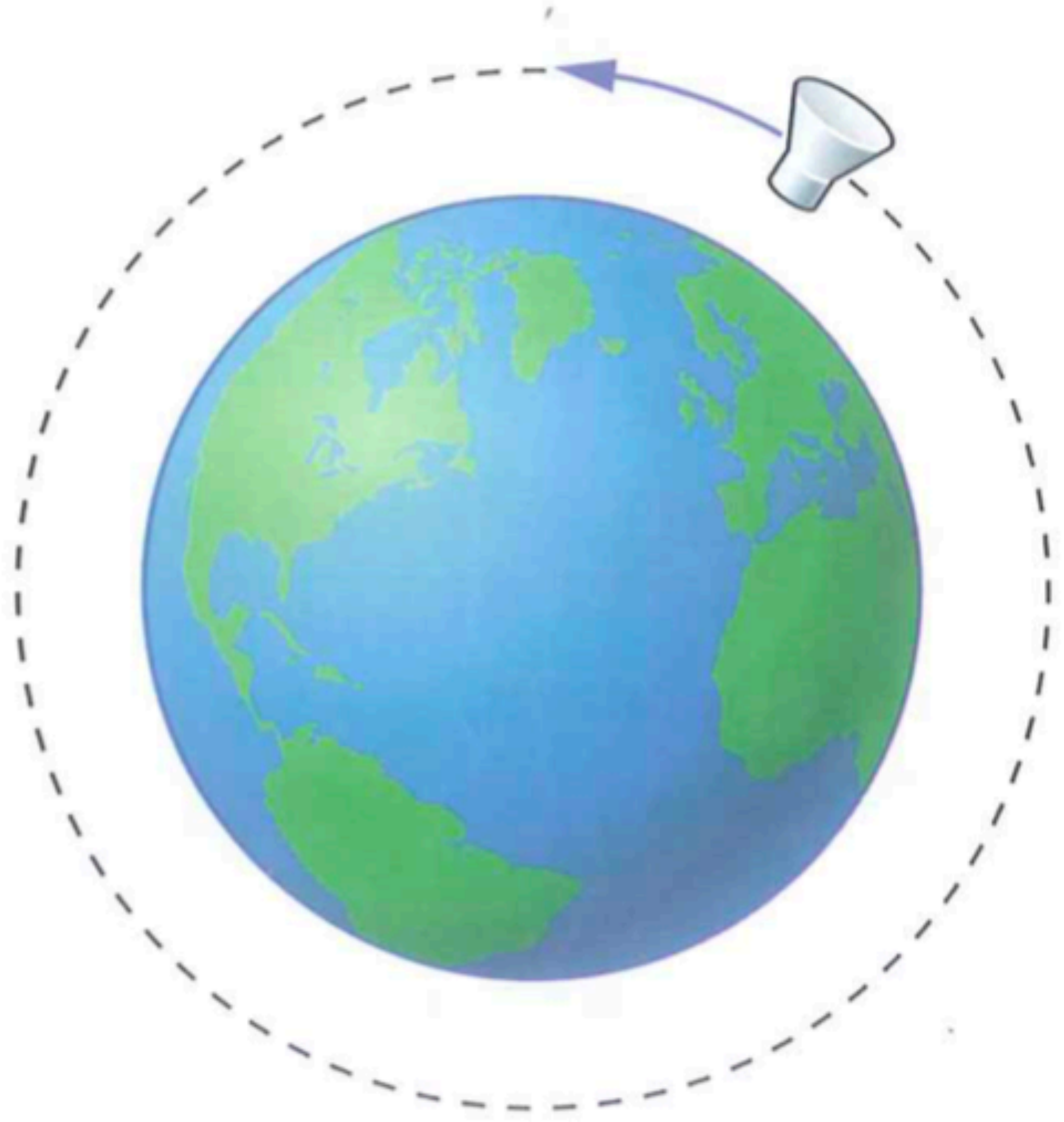


1. Using a peg + two **light gates**
2. Using a **interrupt card** + a light gate

Exercise

Exercise 2.a

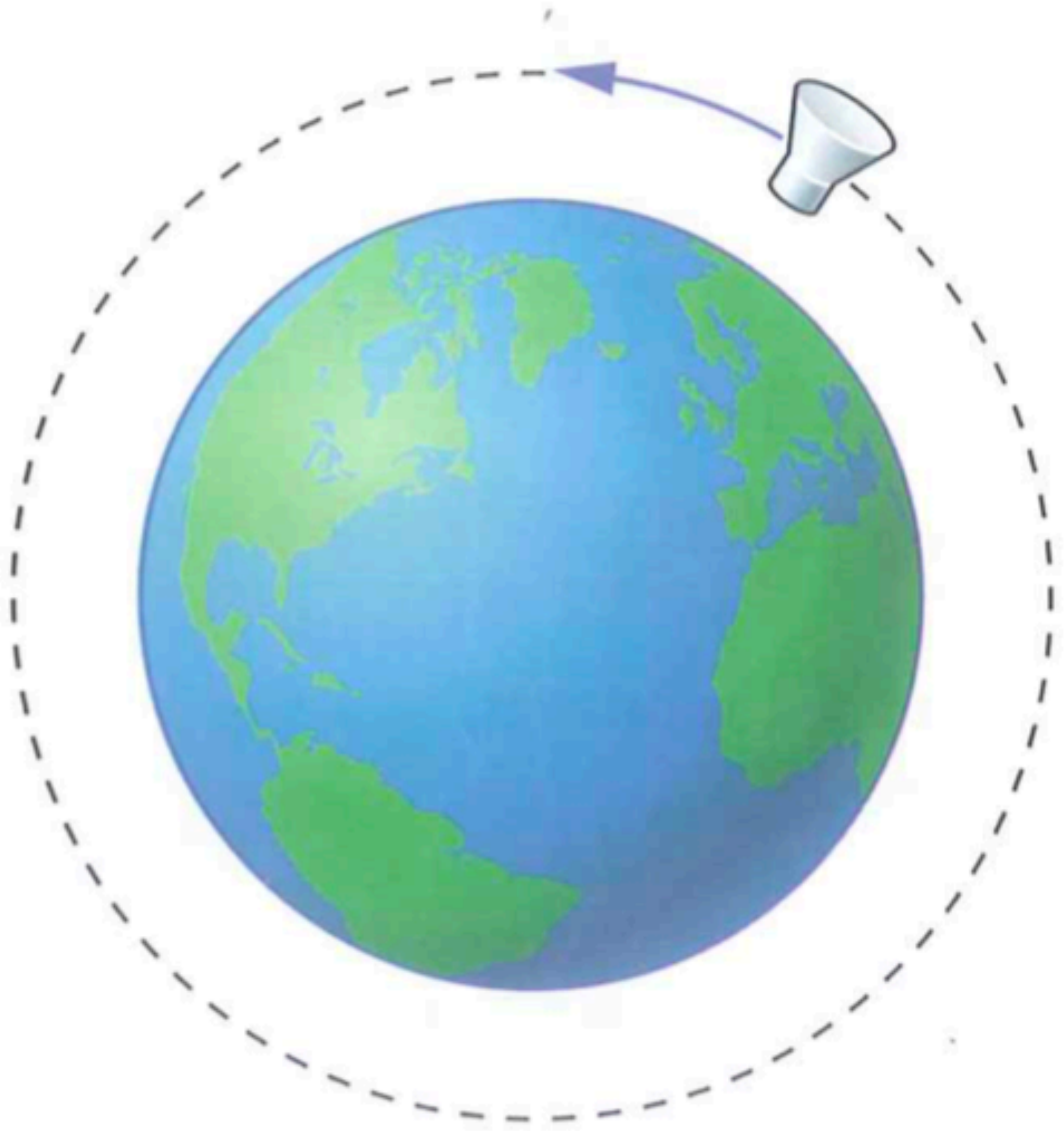
A spacecraft is orbiting the Earth at a **steady speed** of 8km/s. How long does it take to complete a single orbit?



Exercise

Exercise 2.a

A spacecraft is orbiting the Earth at a **steady speed** of 8km/s. How long does it take to complete a single orbit?



step 1.

speed $v = 8.0\ km/s$, distance $40000\ km$

time $t = ?$

step 2.

$$t = \frac{s}{v} = \frac{40000\ km}{8.0\ km/s} = 5000\ s$$

Check if units match!!

Exercise

Exercise 2.b

A car travels 600km in 5.5 hours, what is the speed of the car in **km/h and m/s**?

Exercise

Exercise 2.b

A car travels 600km in 5.5 hours, what is the speed of the car in **km/h and m/s**?

step 1.

distance $s = 600\ km$, time $t = 5.5\ h$

speed $v = ?$

step 2.

$$v = \frac{s}{t} = \frac{600\ km}{5.5\ h} \approx 109.09\ km/h$$

$$1\ km/h = \frac{1\ km}{1\ h} = \frac{1 \times 10^3\ m}{3600\ s} \approx 0.28 m/s$$

$$109.09\ km/h = 109.09 \times 1\ km/h = 109.09 \times 0.28\ m/s = 30.55\ m/s$$

Exercise

Exercise 2.c

Calculate how long does it takes for sunlight to reach us from the Sun? The Sun is about 144 million km away and the speed of light is around $3 \times 10^8\ m/s$

step 1.

step 2.

Exercise

Exercise 2.c

Calculate how long does it takes for sunlight to reach us from the Sun? The Sun is about 144 million km away and the speed of light is around $3 \times 10^8\ m/s$

step 1.

distance $s = 1.44 \times 10^8\ km = 1.44 \times 10^{11}\ m$, speed $v = 3 \times 10^8\ m/s$

time $t = ?$

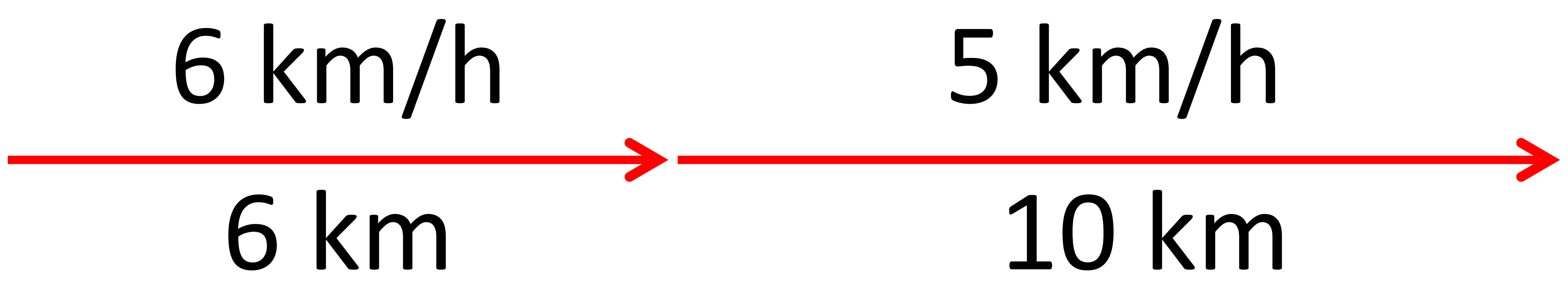
step 2.

$$t = \frac{s}{v} = \frac{1.44 \times 10^{11}\ m}{3 \times 10^8\ m/s} = 480\ s = 8\ min$$

Exercise

I went for a walk one day. I walked 6km at 6 km/h and then 10 km at 5 km/h in the same direction. Determine the average speed for the entire journey.

$$\xrightarrow[6\ \text{km}]{6\ \text{km/h}}\xrightarrow[10\ \text{km}]{5\ \text{km/h}}$$

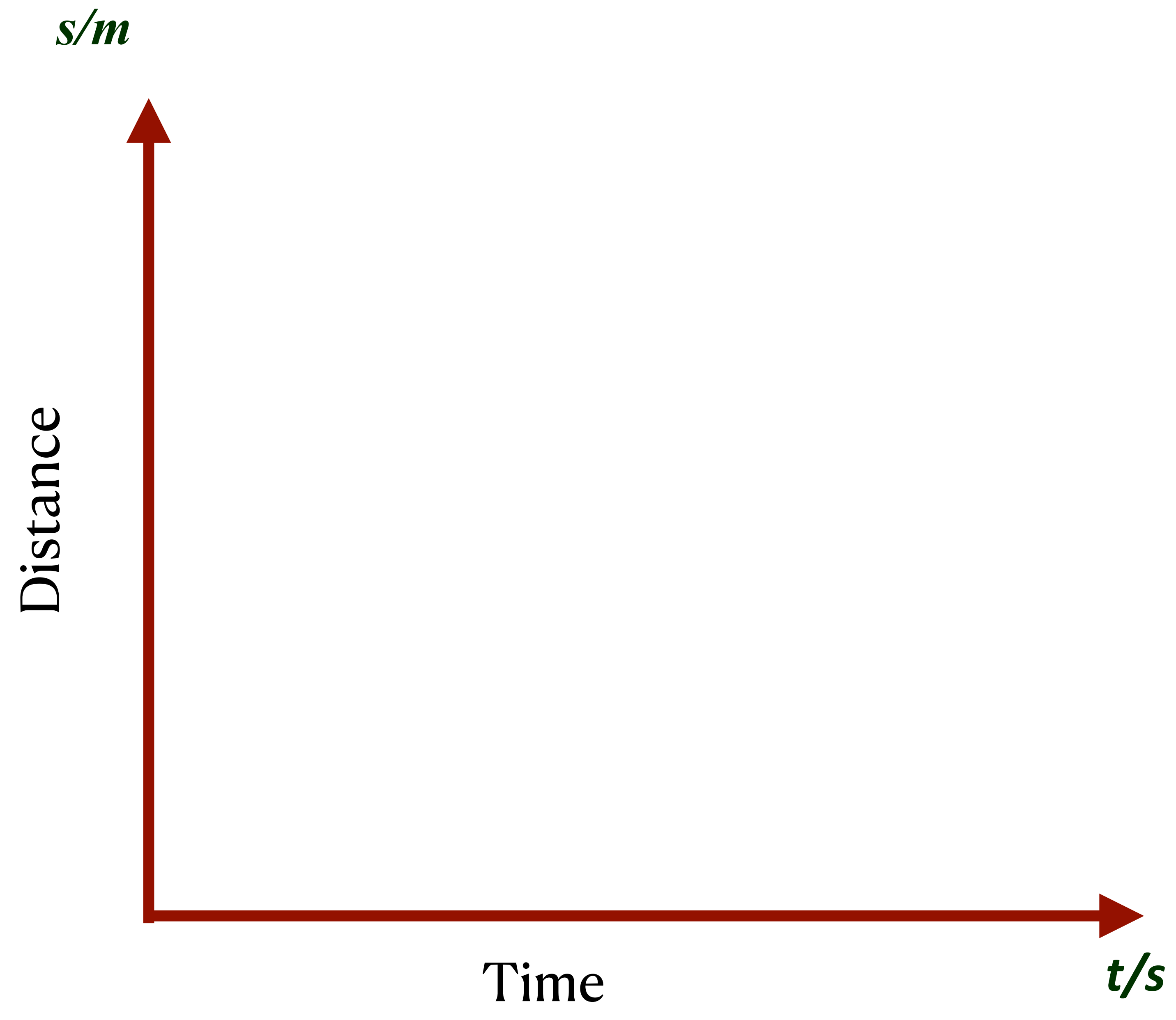


Total distance=Δs= 6 km+10 km=16 km

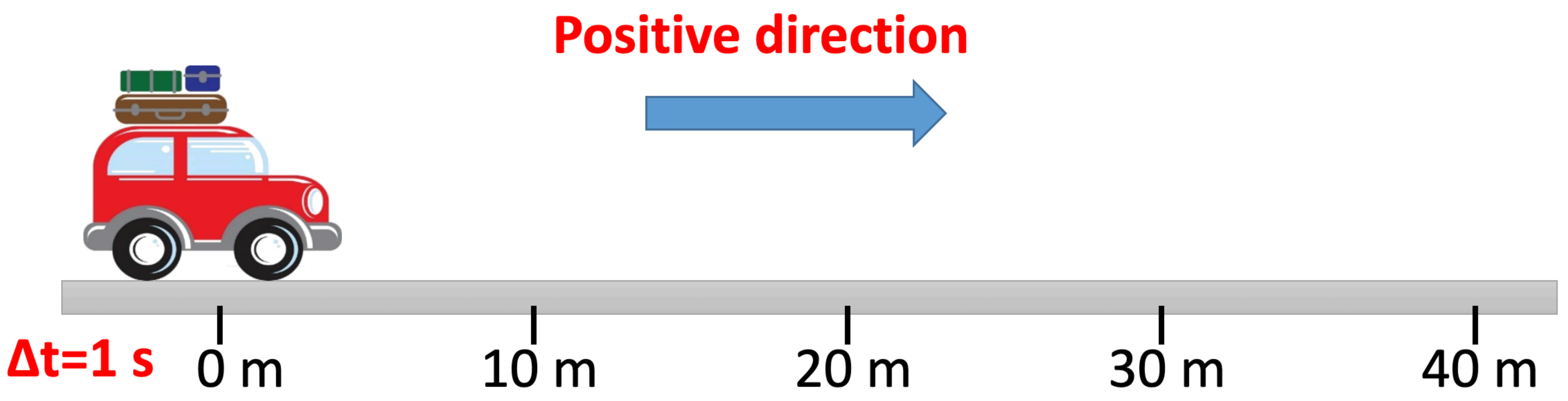
$$\left.\begin{aligned}\Delta t_1 &= \frac{\Delta s_1}{v_1} = \frac{6km}{6km/h} = 1h \\ \Delta t_2 &= \frac{\Delta s_2}{v_2} = \frac{10km}{5km/h} = 2h\end{aligned}\right\} \quad \Delta t = \Delta t_1 + \Delta t_2 = 1h + 2h = 3h$$

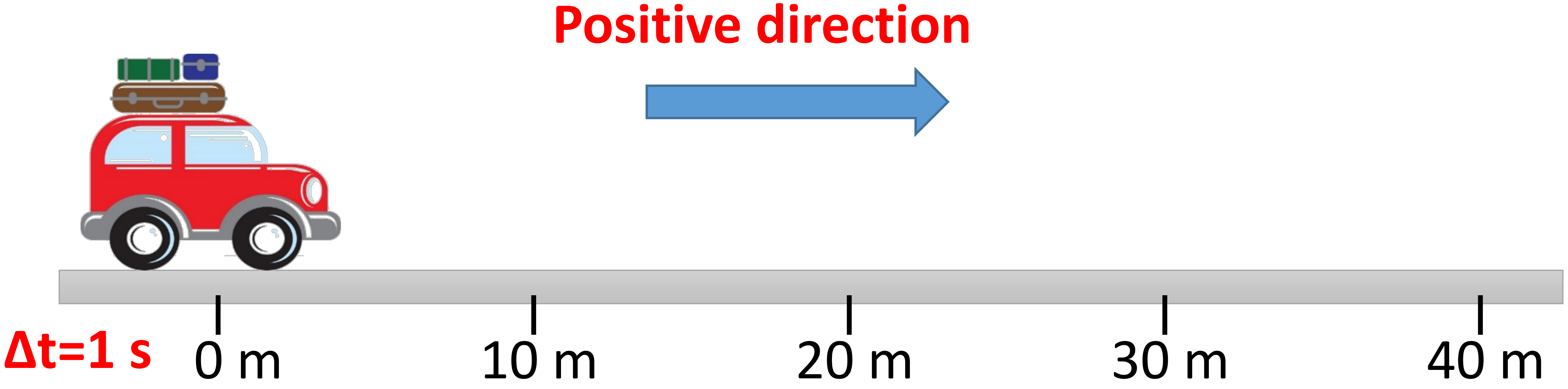
$$\boxed{< v >= \frac{\Delta s}{\Delta t} = \frac{16km}{3h} = 5.33km/h}$$

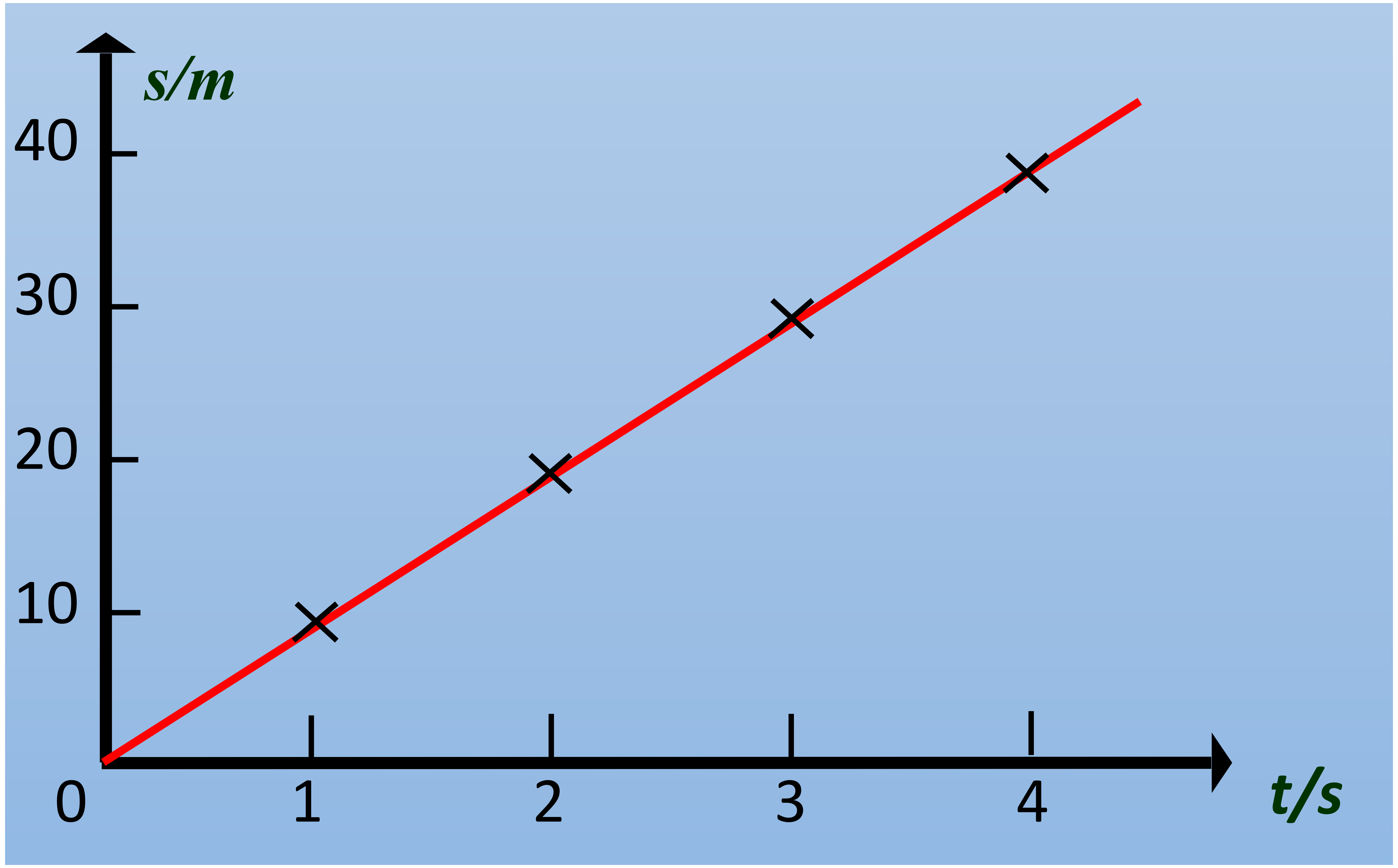
Distance-time graphs

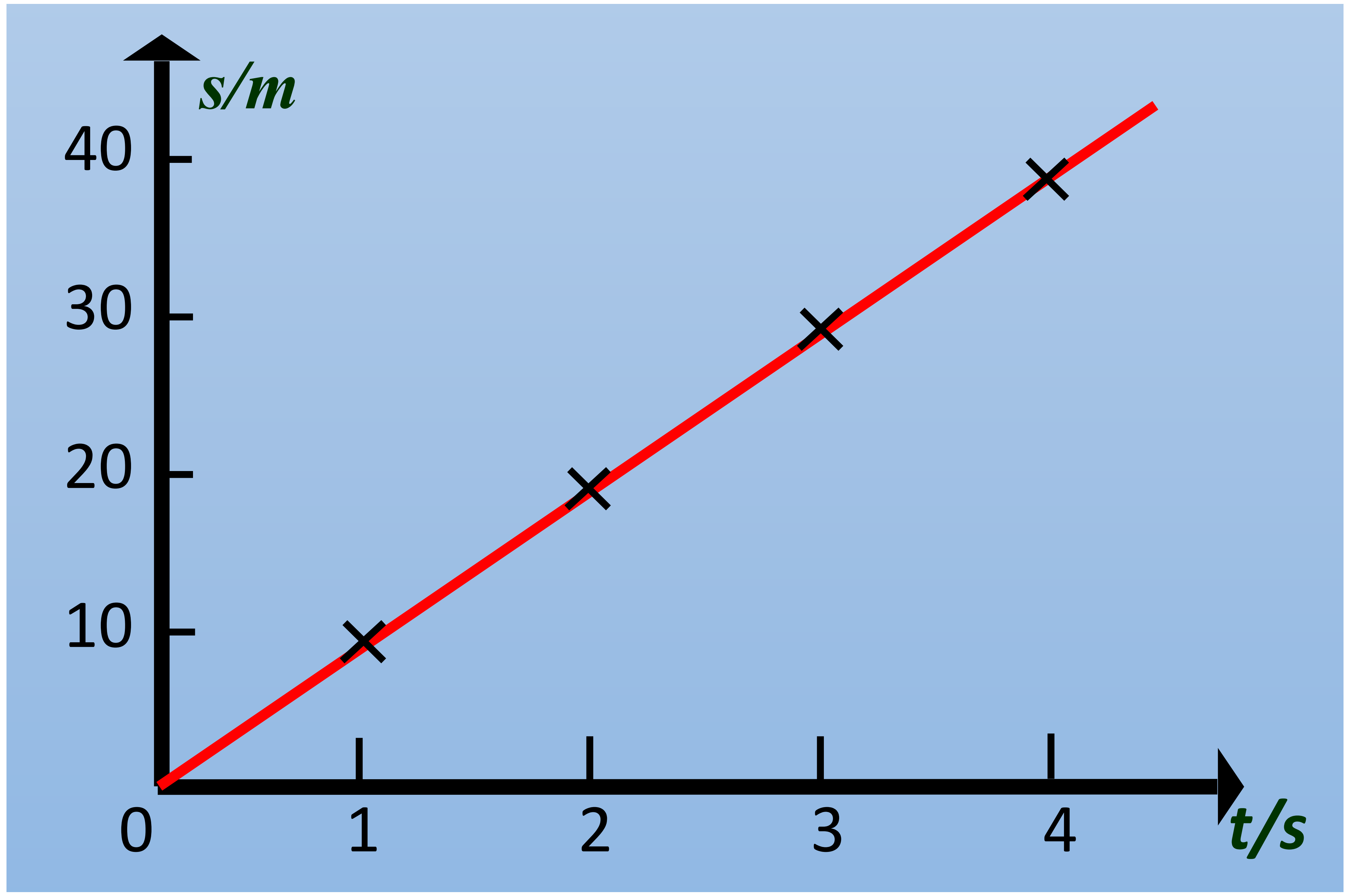


Can you draw a **distance-time graph** representing the motion of following car? What can you say about its motion? Relating the motion to the graph, what conclusions can you draw about distance-time graph?




Positive direction
Δt=1 s
0 m
10 m
20 m
30 m
40 m


s/m
40
30
20
10
0
1
2
3
4
t/s



equal distances in
equal intervals of time

Distance ***s*** is linear with time ***t***

uniform linear motion

$$\textit{speed} = \frac{\Delta s}{\Delta t}$$

= 40 m / 4 s

= 10 m/s

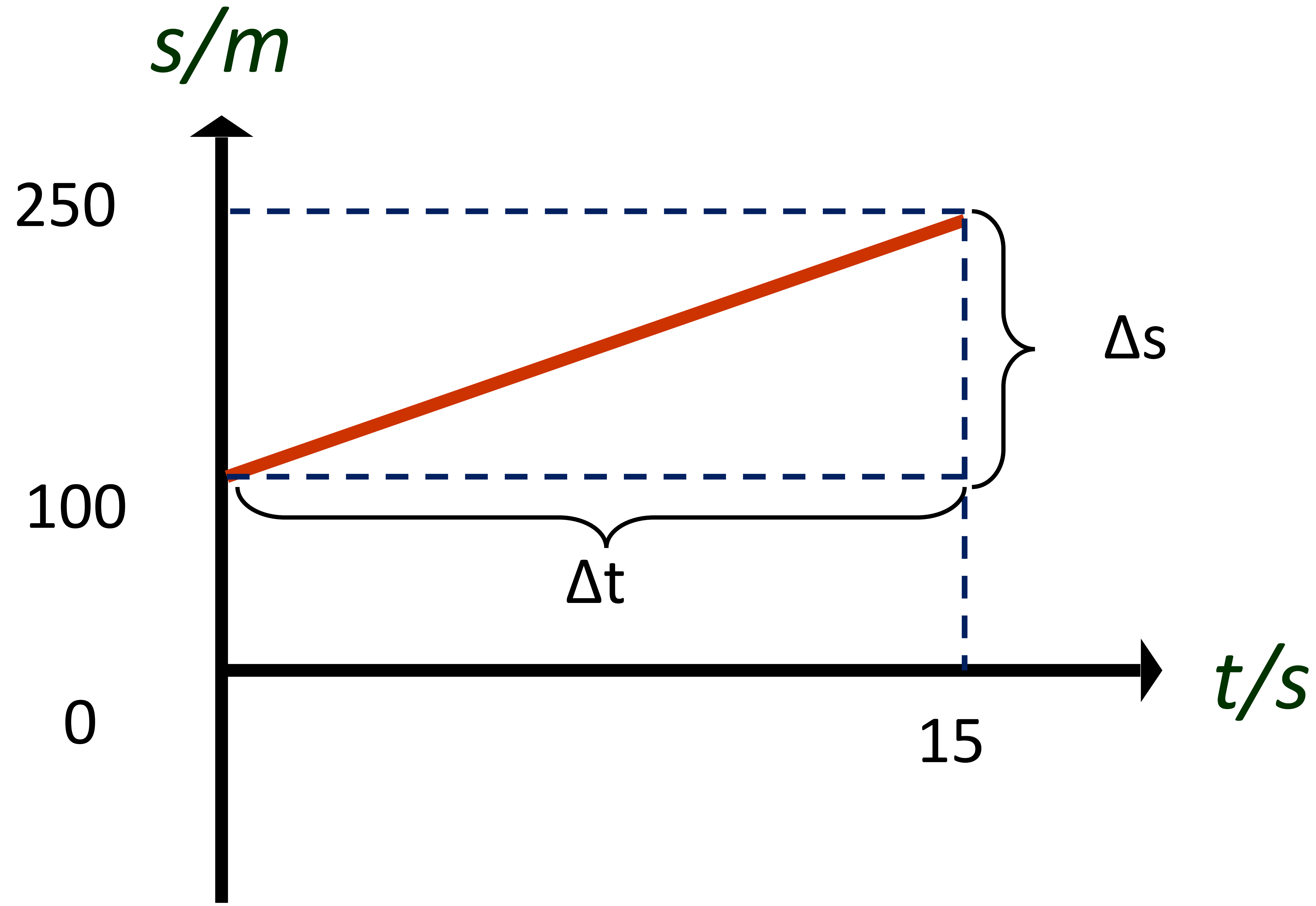
<u>**Same speed at any moment**</u>

Instantaneous speed

= average speed

= **gradient** of the line

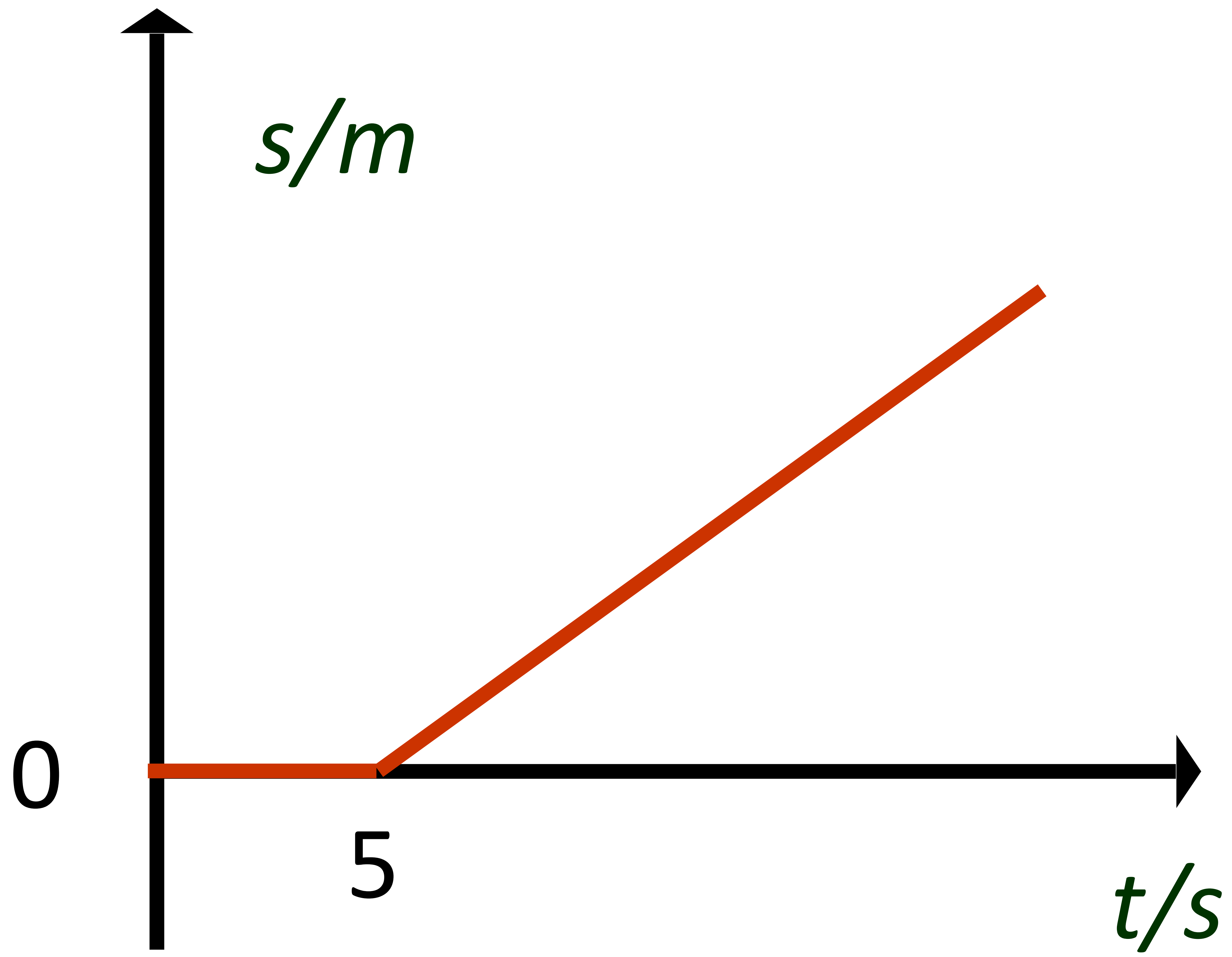
EXAMPLE



Start from 100 m

$v = \Delta s / \Delta t = (250\text{-}100)\ m / 15\ s = 10\ m/s$

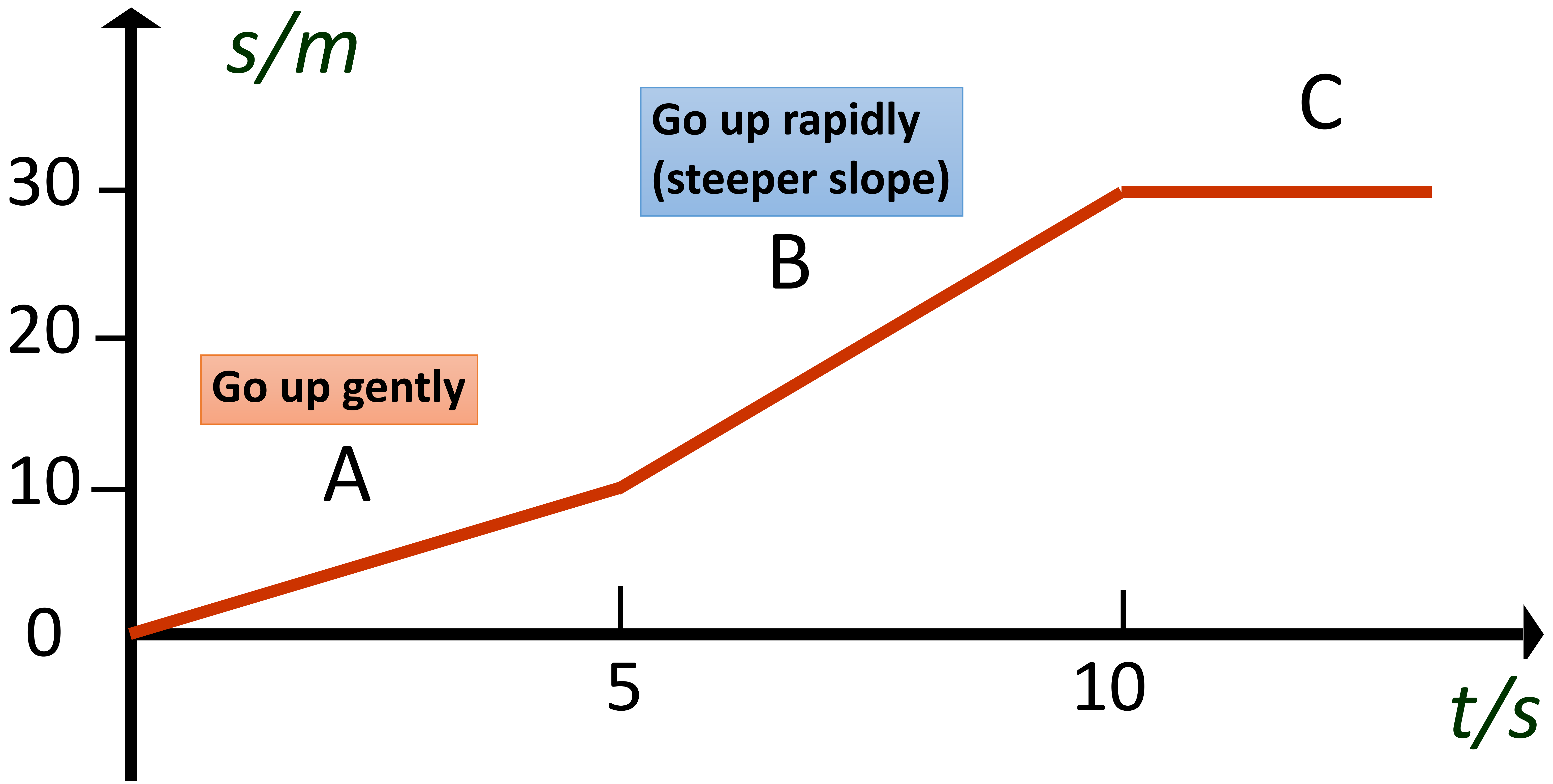
EXAMPLE



It stays still at the origin for the first 5 seconds

Then in uniform linear motion

EXAMPLE



A(0-5s): uniform linear motion at speed of 2 m/s

B(5-10s): uniform linear motion at speed of 4 m/s

C(after 10s): stay stationary

slower

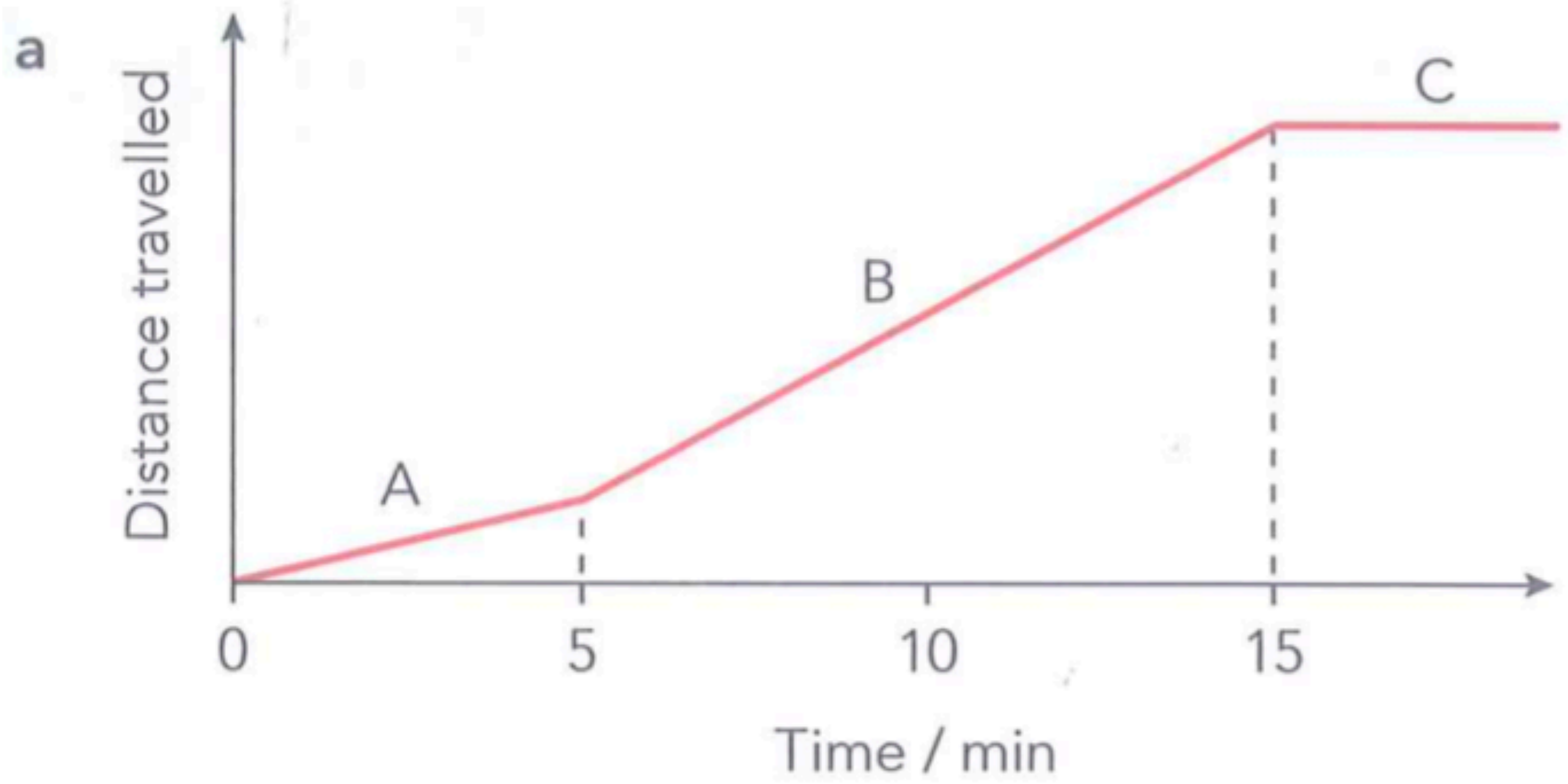
faster

Distance-time graphs

slope:

larger slope:

slope/gradient = 0:

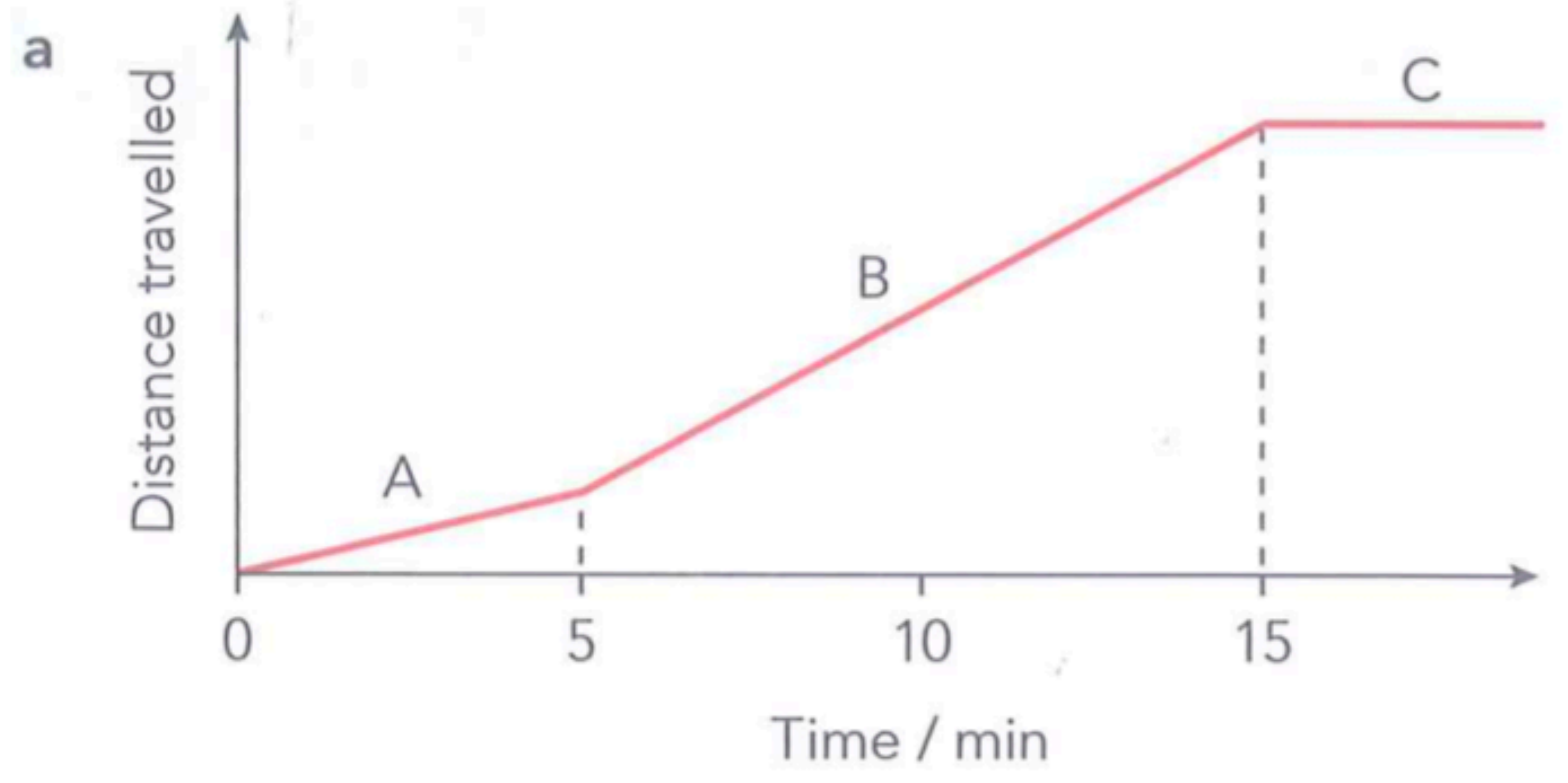


Distance-time graphs

slope: speed

larger Slope: larger speed/faster

slope = 0: not moving

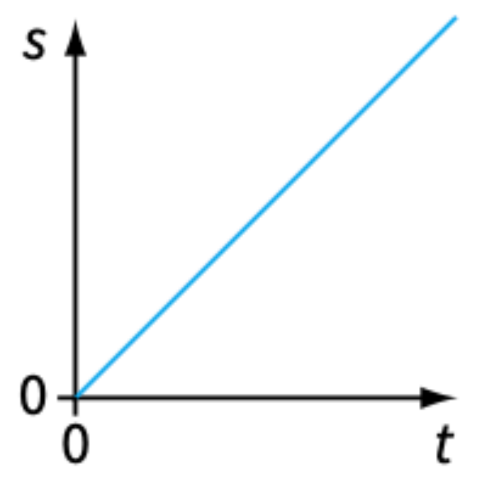


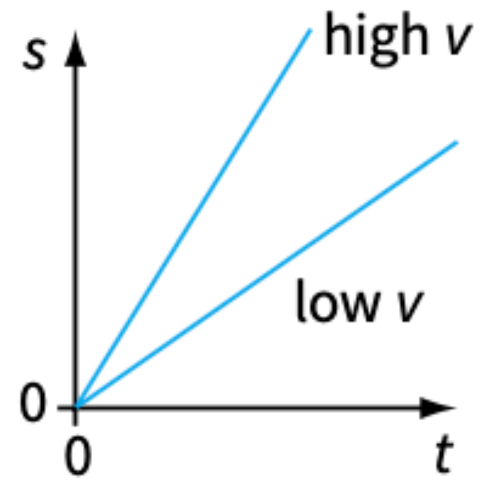
Distance-time graphs

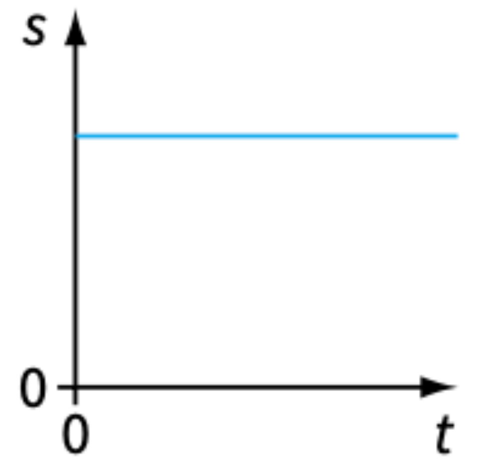
slope: speed

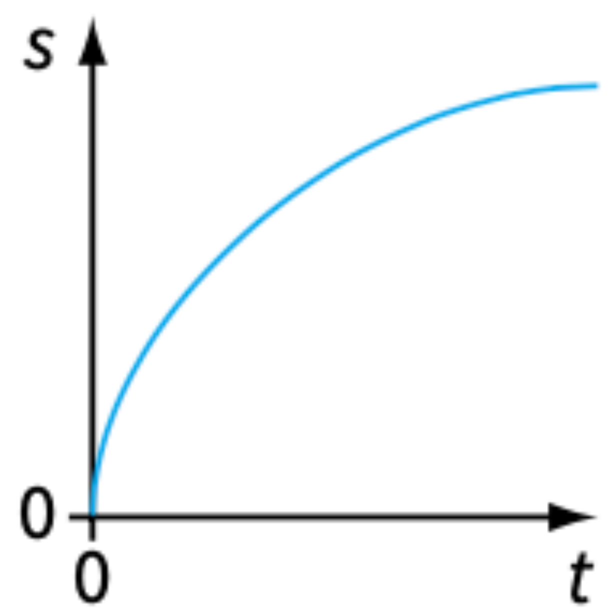
larger Slope: larger speed/faster

slope = 0: not moving









Exercise

Exercise 2.d

The following figure shows the distance-time graph for a woman running a mountain marathon.

A. How **far** did she travel?

B. What was her **average speed** in **km/h**?

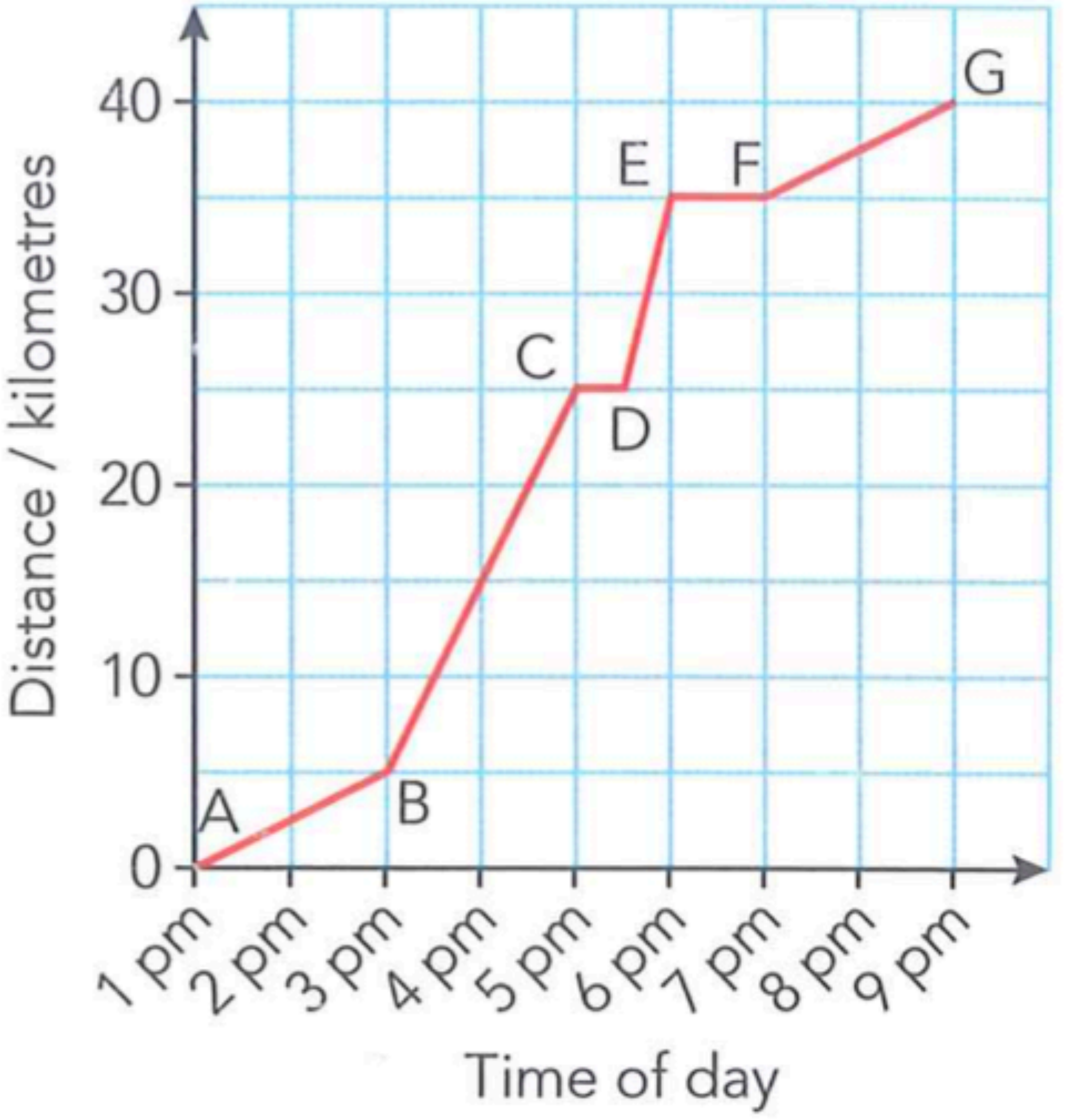
C. How many **stops** did she make?

D. The rules said she had to stop for half an hour for food. When did she take the break?

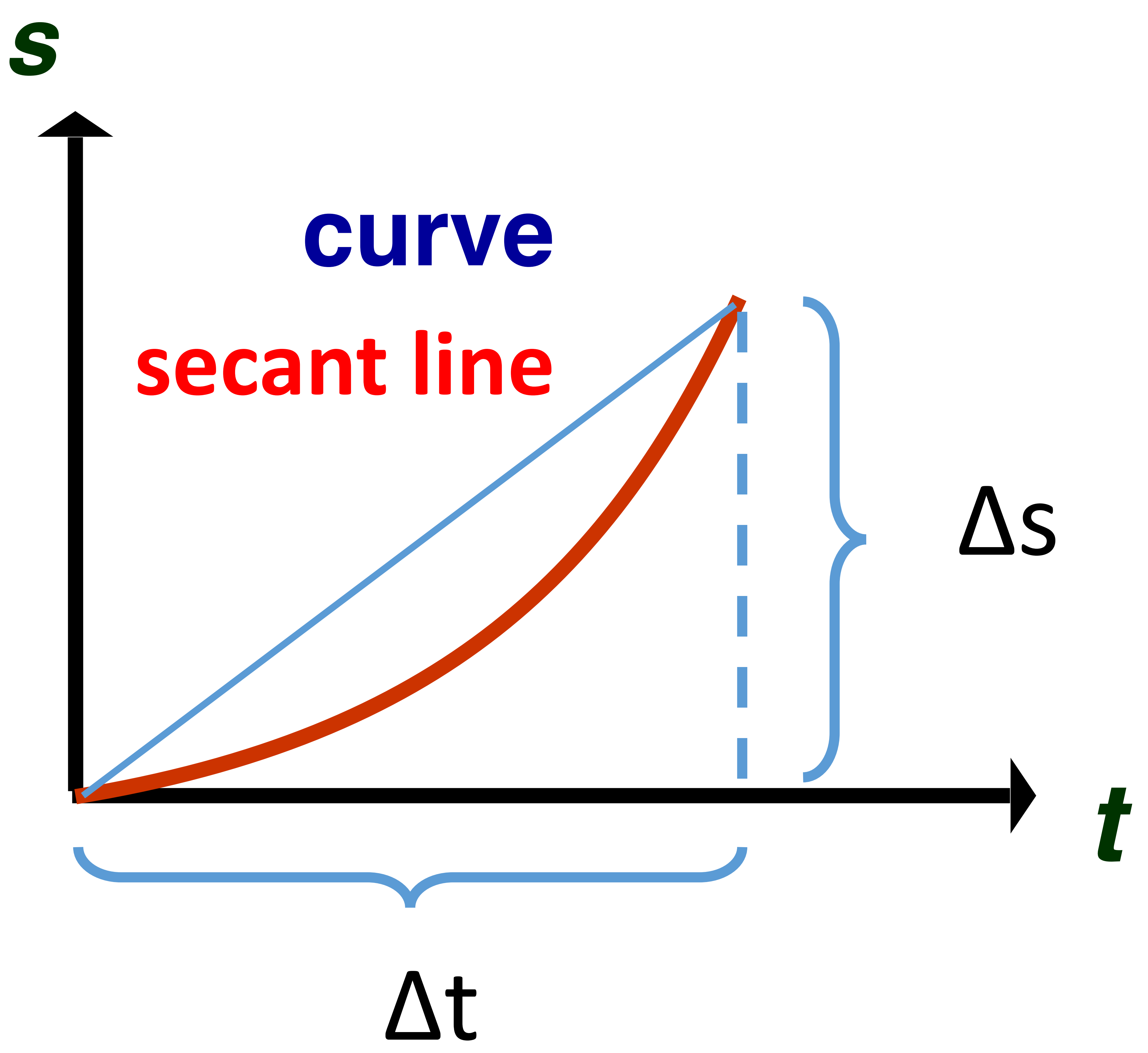
E. Later she stopped to help an injured runner. When did this happen?

F. What would her average speed have been if she had not stopped at all?

G. What was her **highest speed** and over what section did this happen?

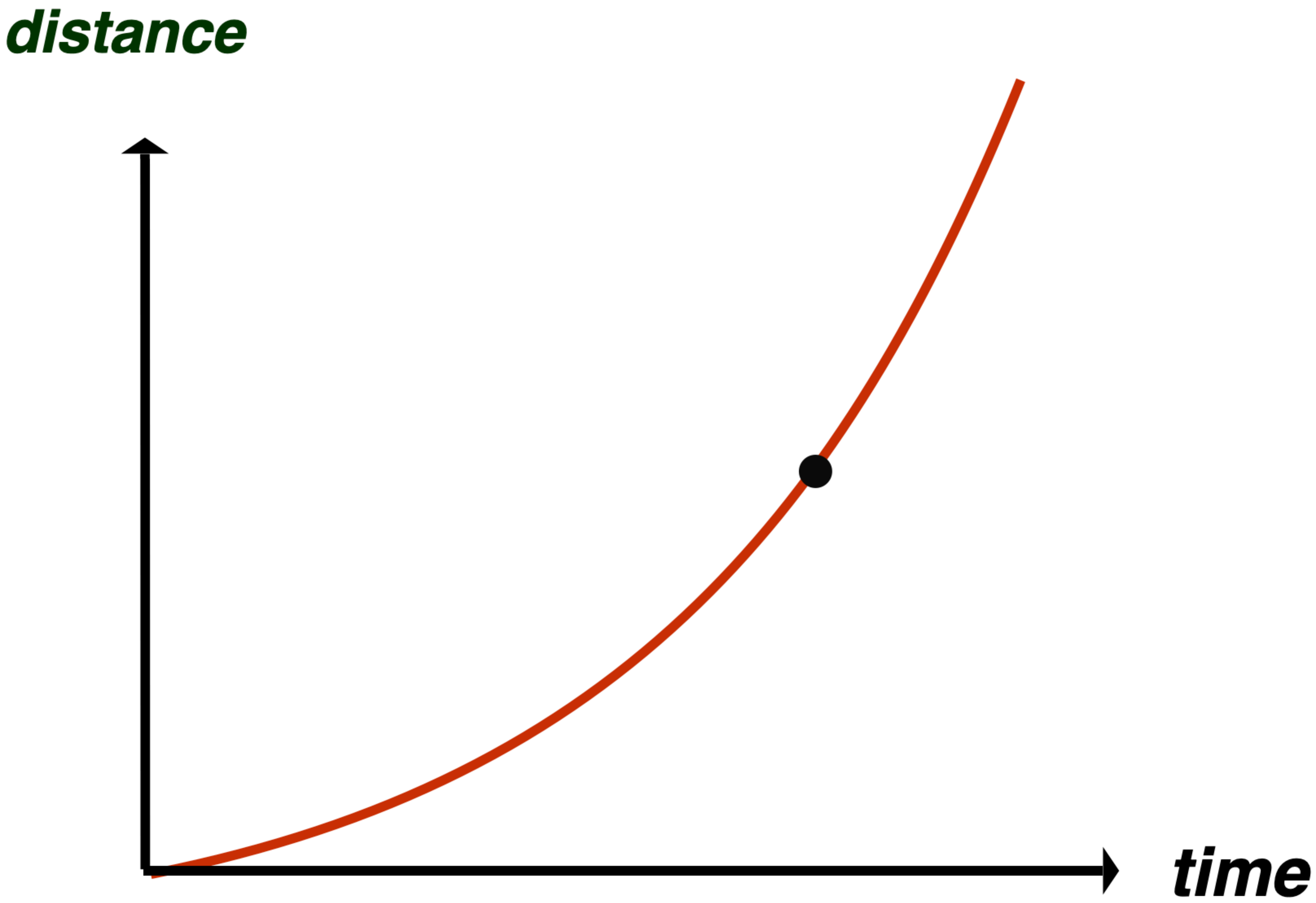


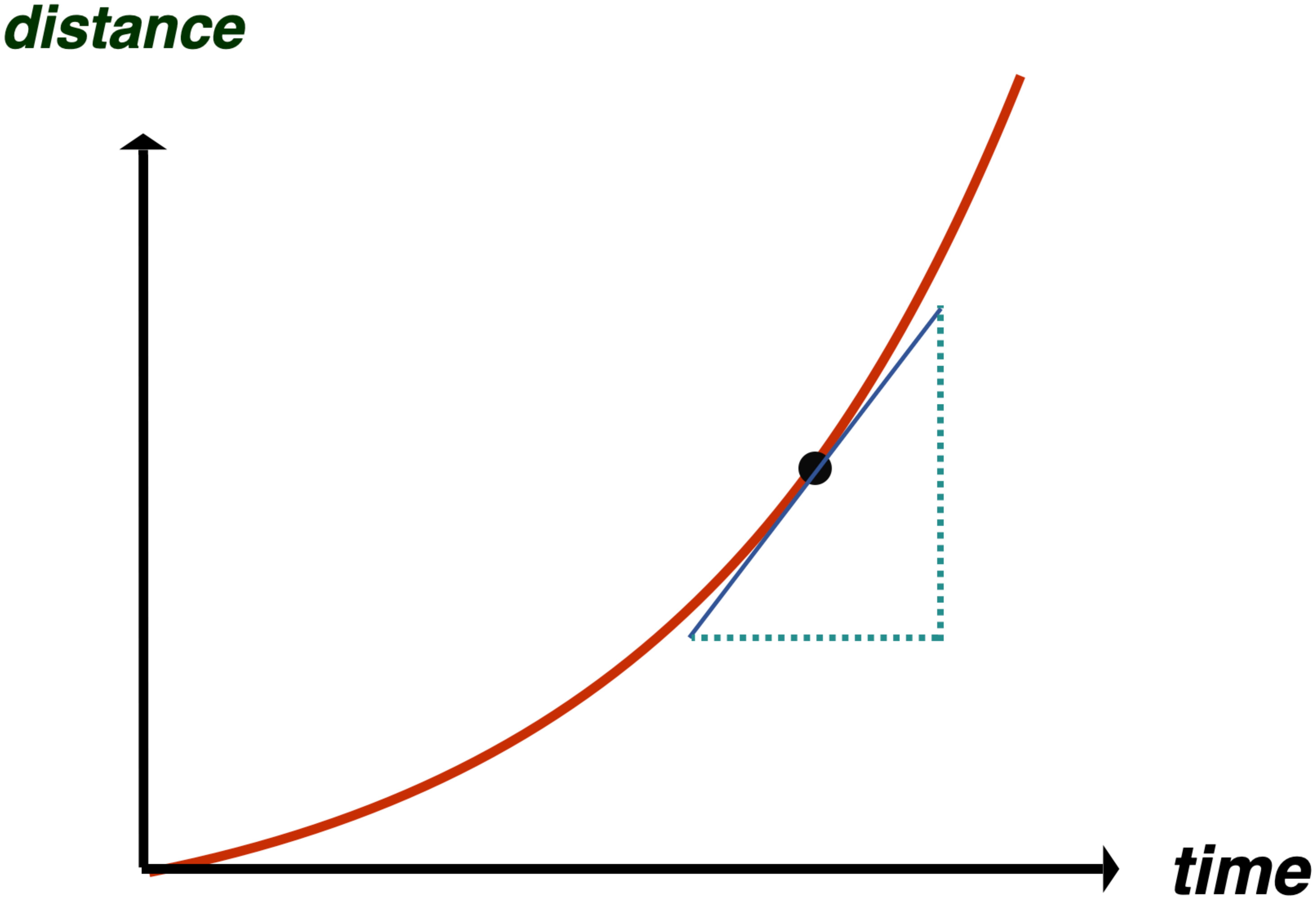
Average speed in distance – time graph



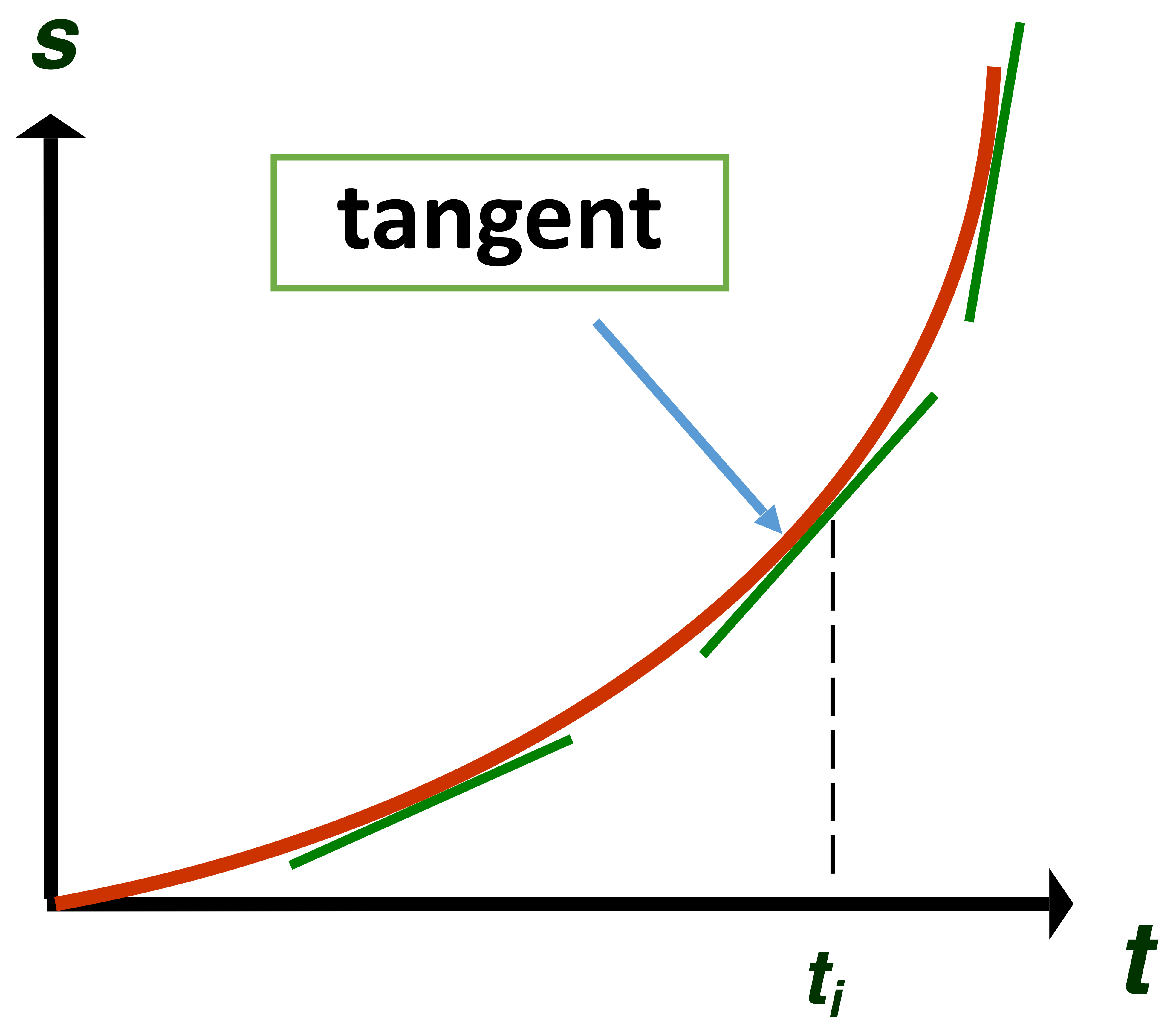
$$< v >= \frac{\Delta s}{\Delta t}$$

*****a secant is defined as line passing through two points of the curve.***


distance
time


distance
time

Instantaneous speed in distance – time graph



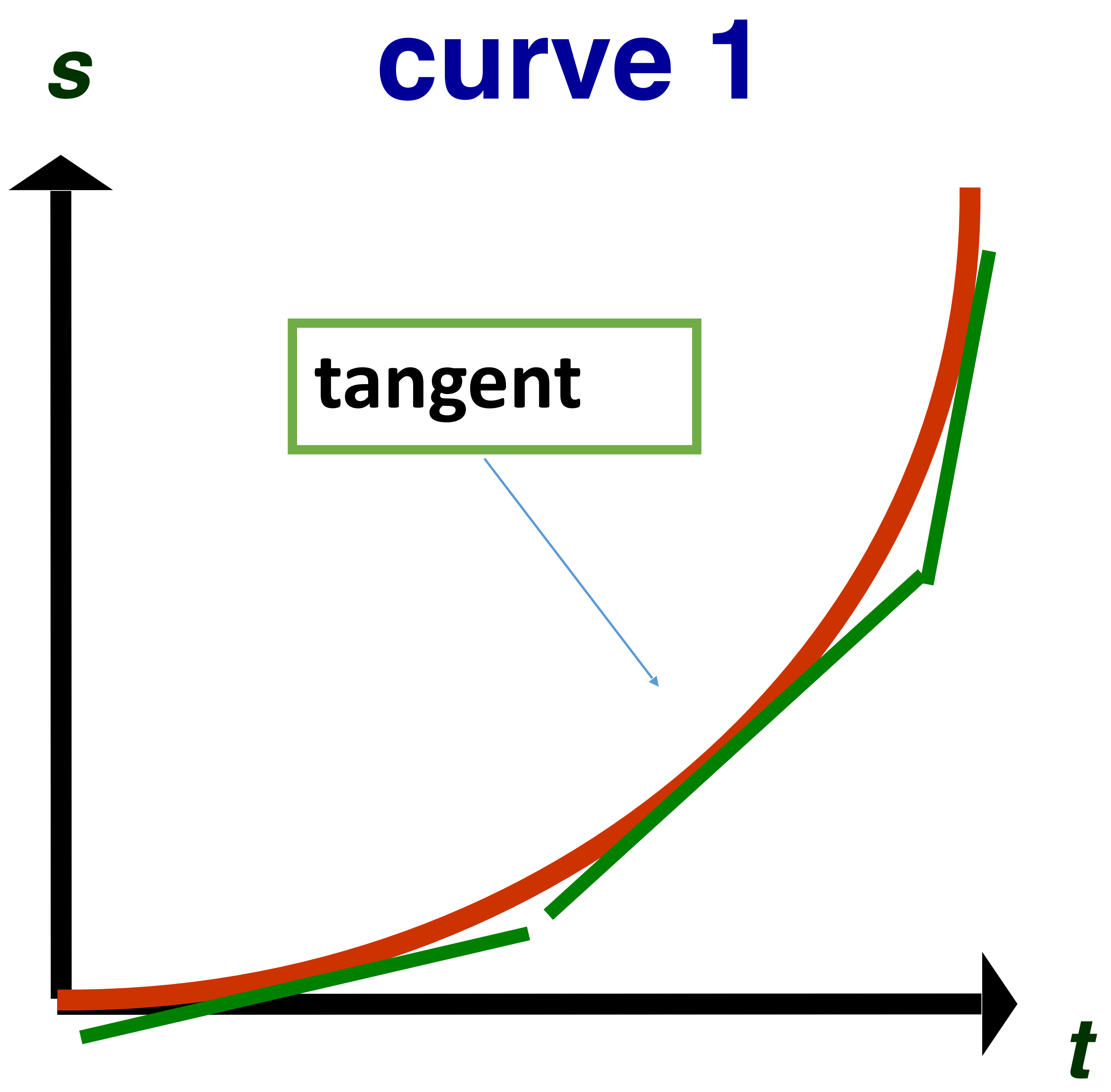
Instantaneous speed at t_x = slope of tangent at t_x

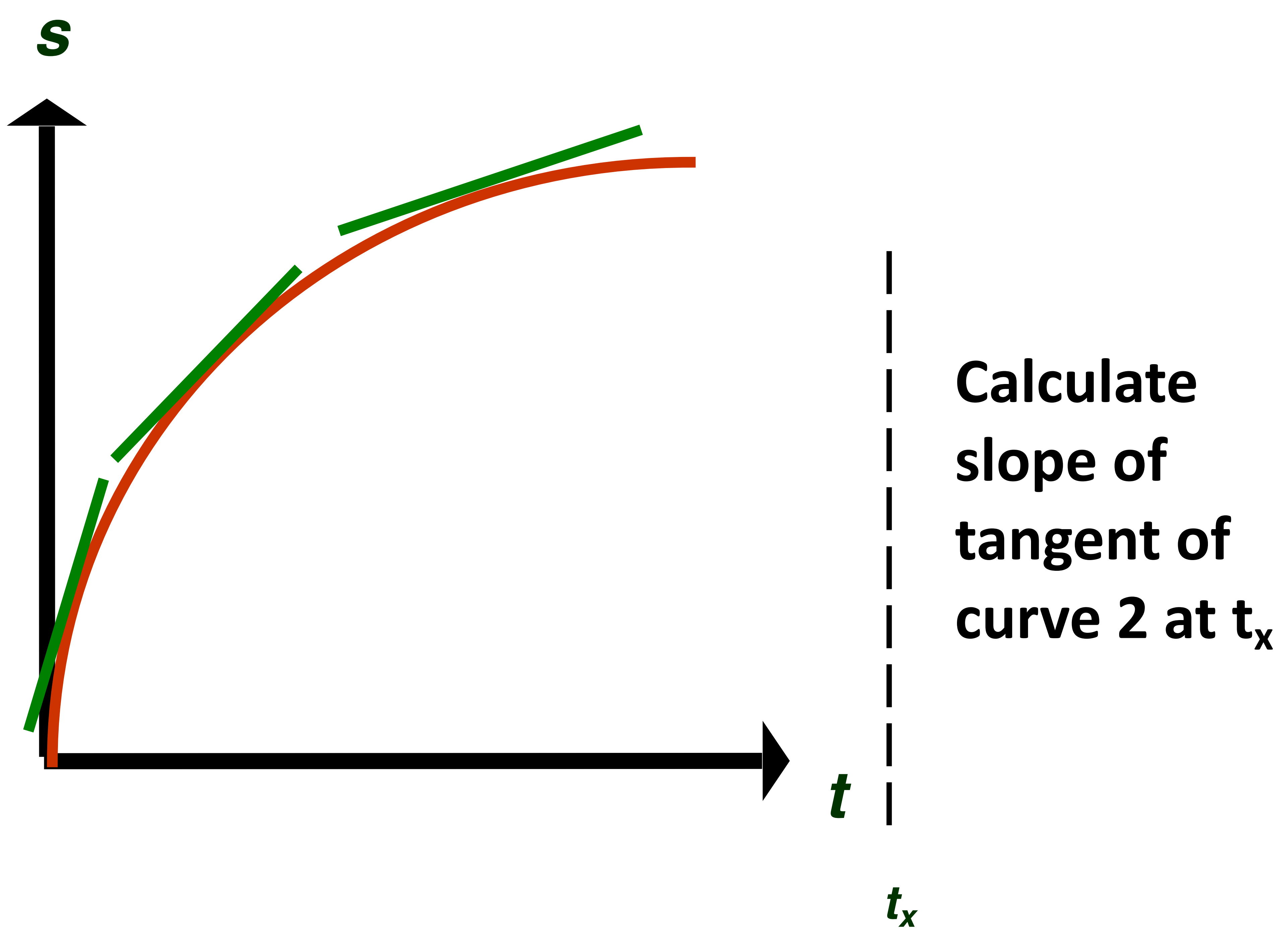
increasing velocity (increasing gradient)

Speed up

Find instantaneous velocity

curve 2

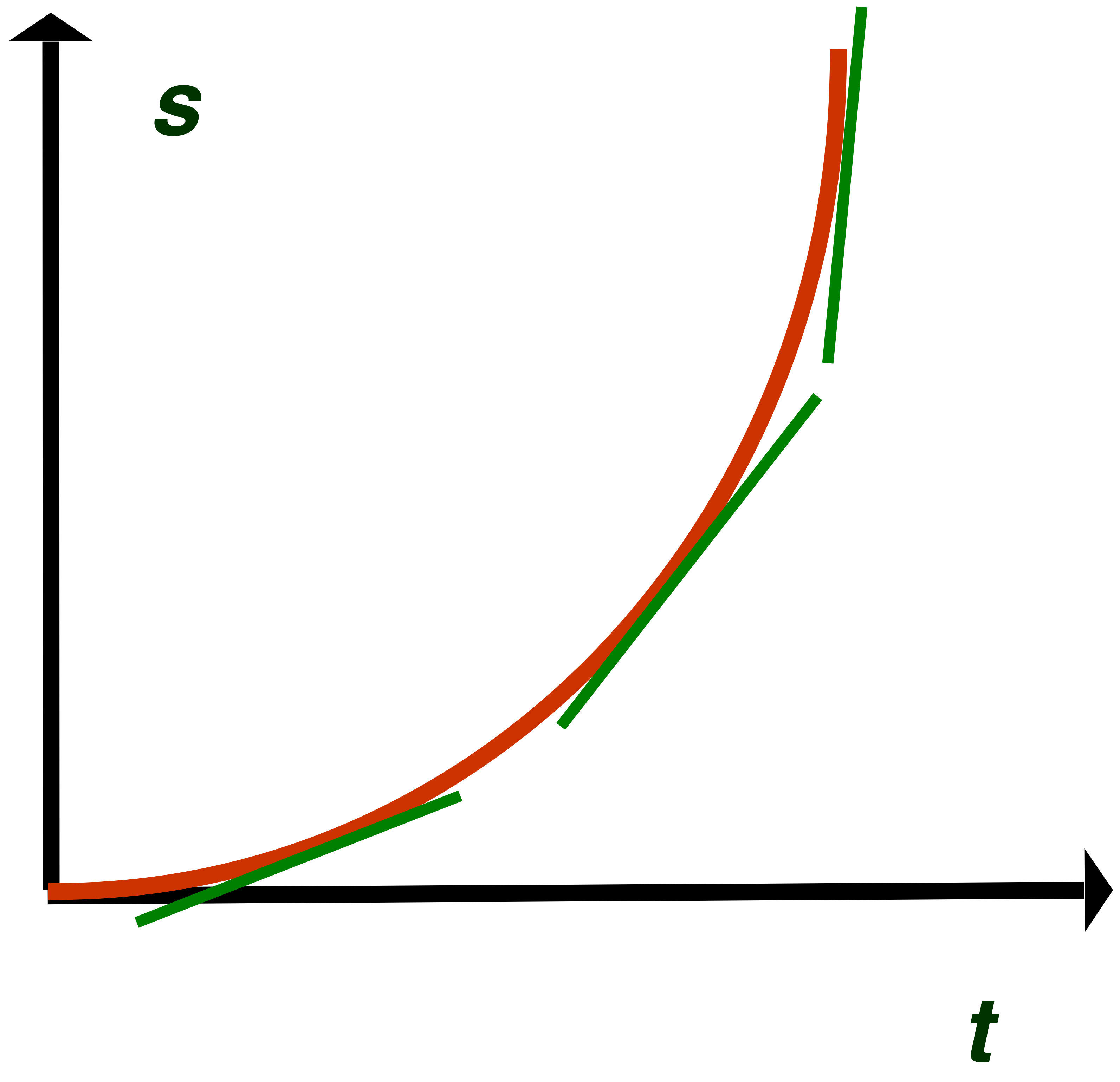




Curve 1: increasing speed (increasing gradient)
Speed up

Curve 2: decreasing velocity (decreasing gradient)
Slow down

Distance-time graph



Summary

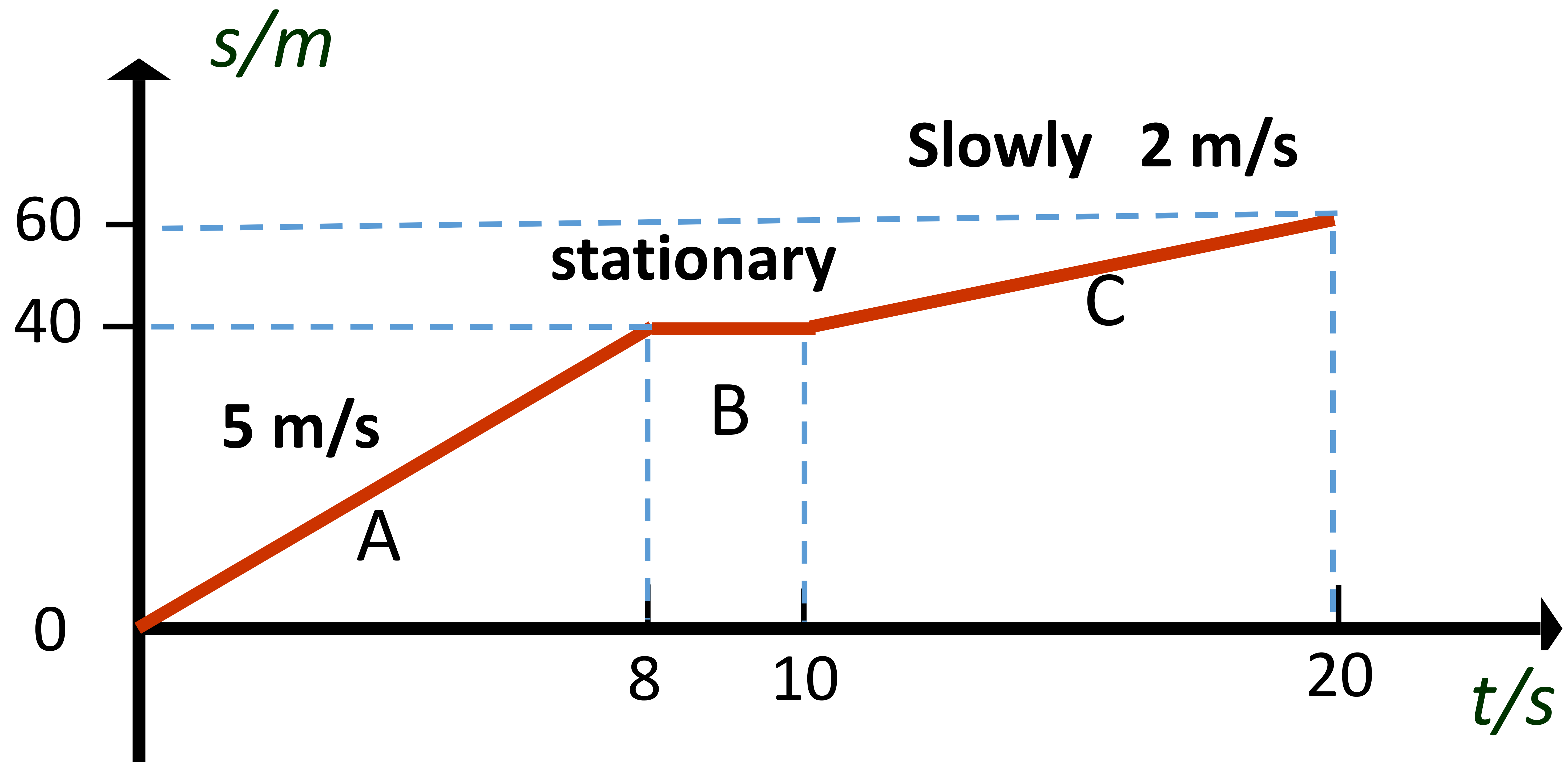
Every point on the graph shows the distance of a body at any instant of time.

the gradient of the graph is the instantaneous speed of the body.

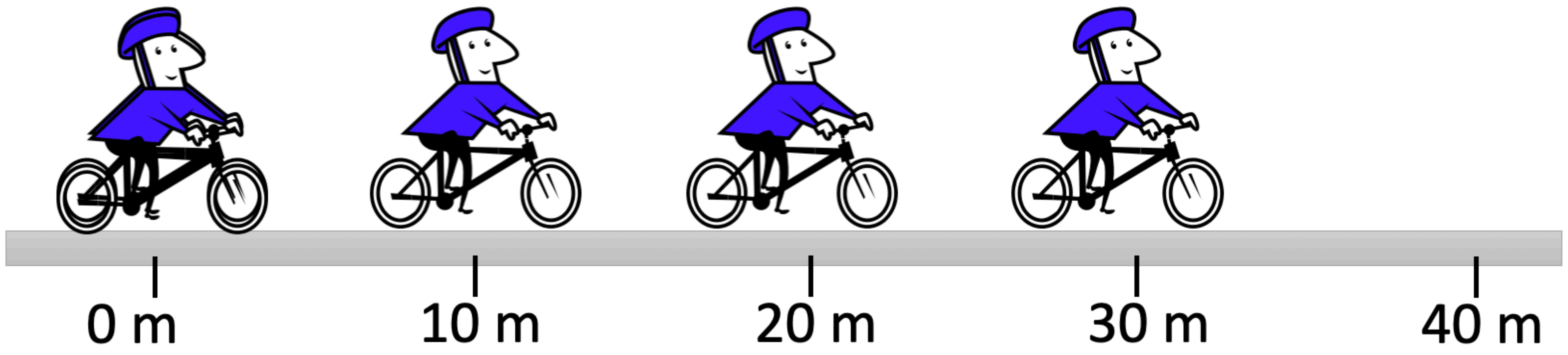
EXAMPLE

Plot a graph of the motion described as flows:

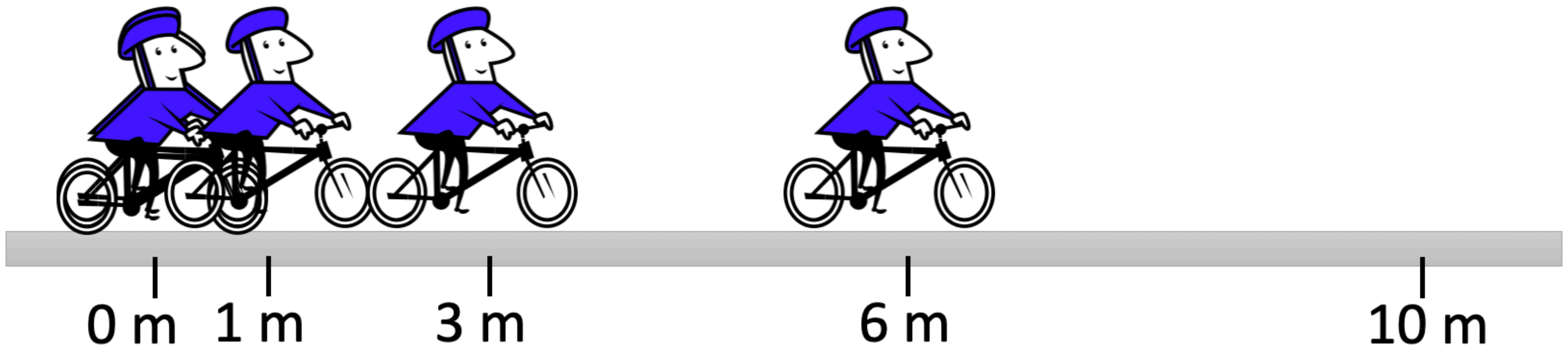
A car started from rest and travelled in the positive direction with a constant speed of 5 m/s for 8 s . And then rest for 2 s, it restarted at a slower speed of 2 m/s for the rest 20 m.



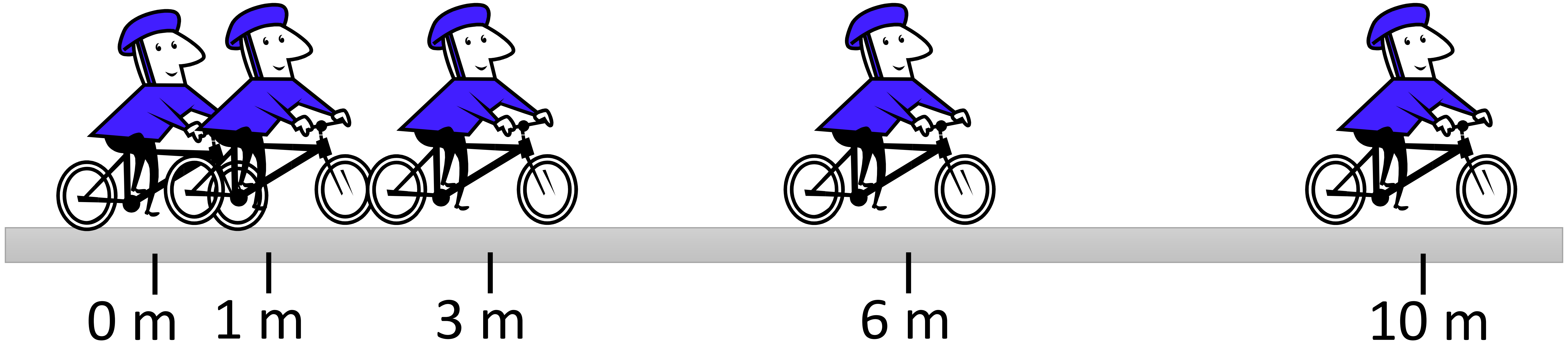
Understanding acceleration



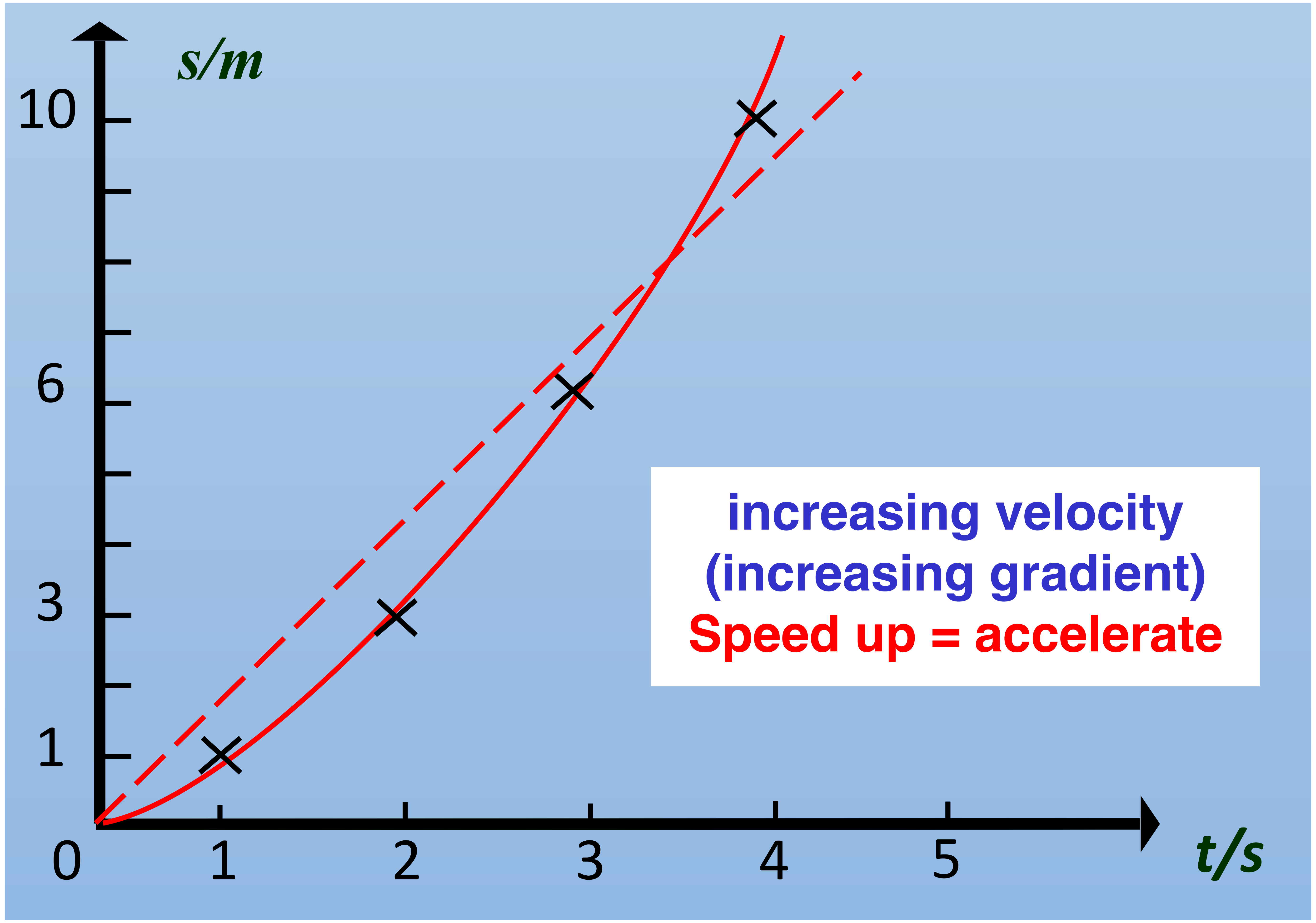
Uniform Linear Motion



Accelerated Motion



Accelerated Motion



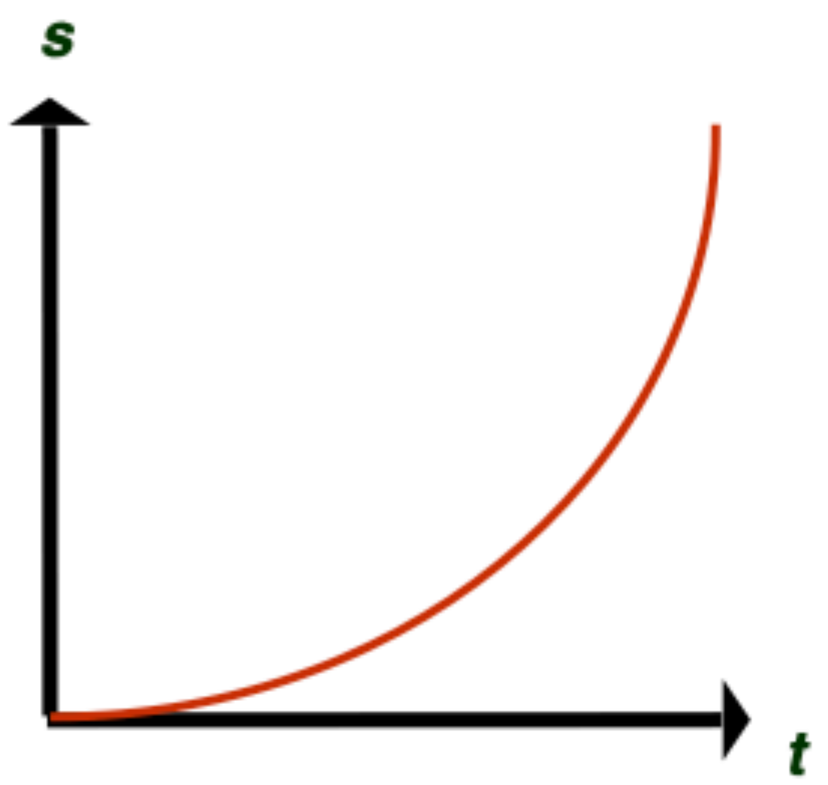
Understanding acceleration

In straight line movement :

<u>acceleration:</u> speed increases

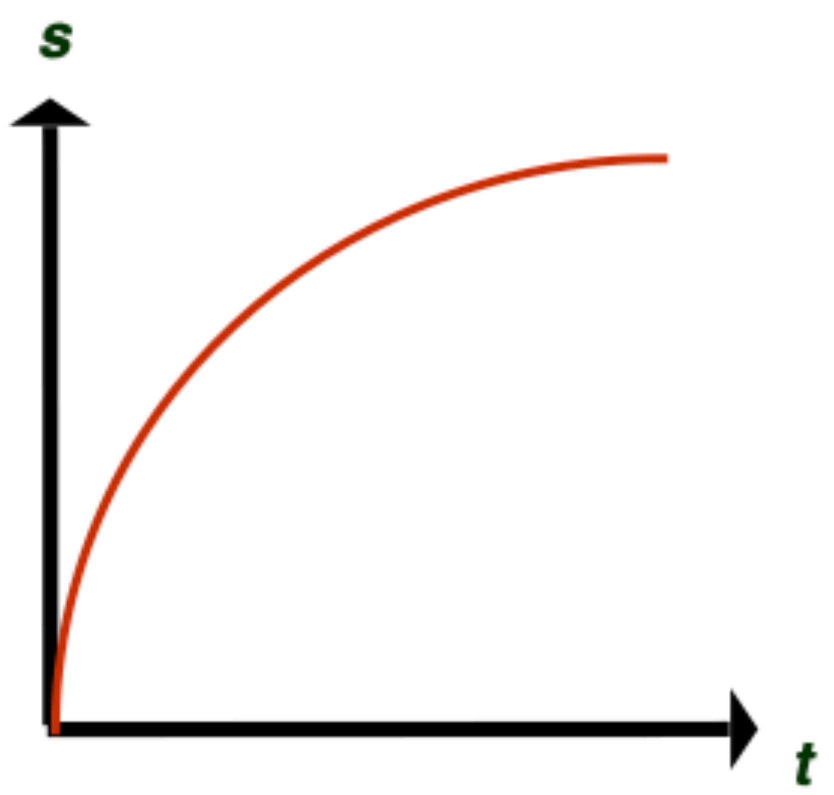
<u>deceleration:</u> speed decreases

curve 1



Speed Up
Accelerate

curve 2



decreasing velocity
(decreasing gradient)
Slow down

Decelerate

Calculating acceleration

Acceleration:

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

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

v: final velocity
u: initial velocity

Calculating acceleration

<u>Acceleration:</u>

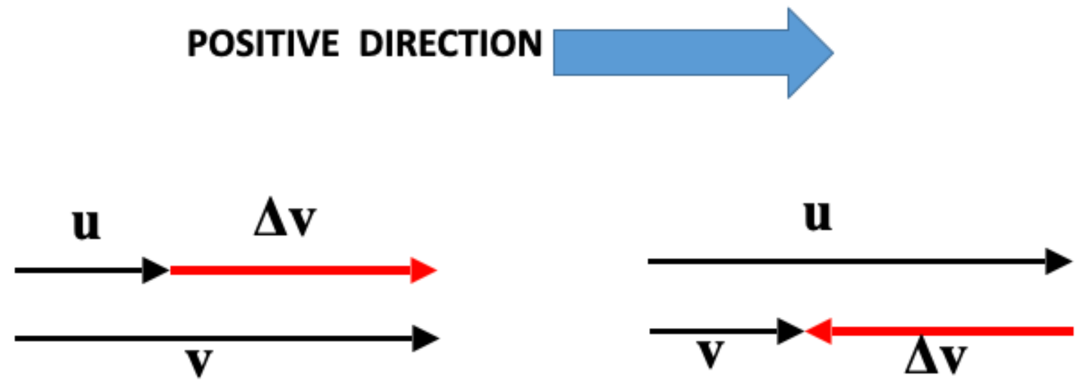
$$acceleration = \frac{change\ in\ velocity}{time\ taken}$$

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

v: final velocity
u: initial velocity

Unit: m/s^2

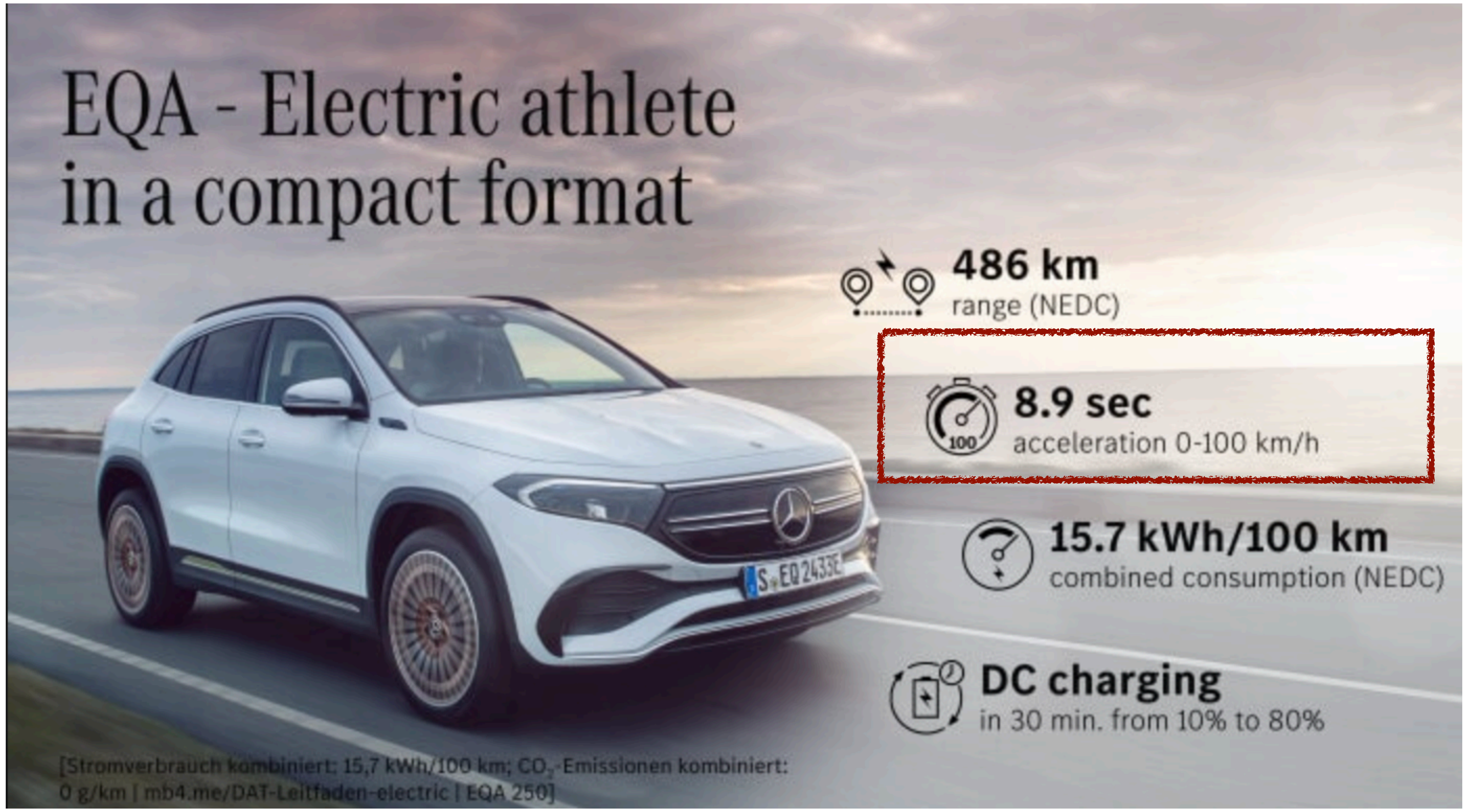
Is acceleration a scalar or a vector?



$a > 0 => acceleration$

$a < 0 => deceleration$

Understanding acceleration



What information do you get from this car advert?

Uniform accelerated linear motion

Linear motion with constant acceleration

Initial velocity u **Final velocity v**

$u=0\ m/s \qquad v=5\ m/s \qquad \Delta v = v-u = 5m/s$

$$a = \frac{\Delta v}{\Delta t} = \frac{5m/s}{2s} = 2.5m/s^2$$

Acceleration

Exercise

During an aircraft's landing, its speed changes from 300m/s to 50m/s uniformly in 80s. What is its **acceleration**?

Acceleration

Exercise 2.i

During an aircraft's landing, its speed changes from 300m/s to 50m/s in 80s. What is its **acceleration**?

step 1.

final speed $v = 50\ m/s$, initial speed $u = 300\ m/s$

Acceleration $a = \ ?$

Negative acceleration means deceleration!!

step 2.

$$a = \frac{v - u}{\Delta t} = \frac{50\ m/s - 300\ m/s}{80\ s} \approx -3.13\ m/s$$

Acceleration

Exercise

A car accelerates from rest with an acceleration 0f 2m/s, what is its speed at 5s?

$\Delta t=1$ s 0m/s → 2 m/s → 4 m/s → 6 m/s → 8 m/s ...

Acceleration

Exercise

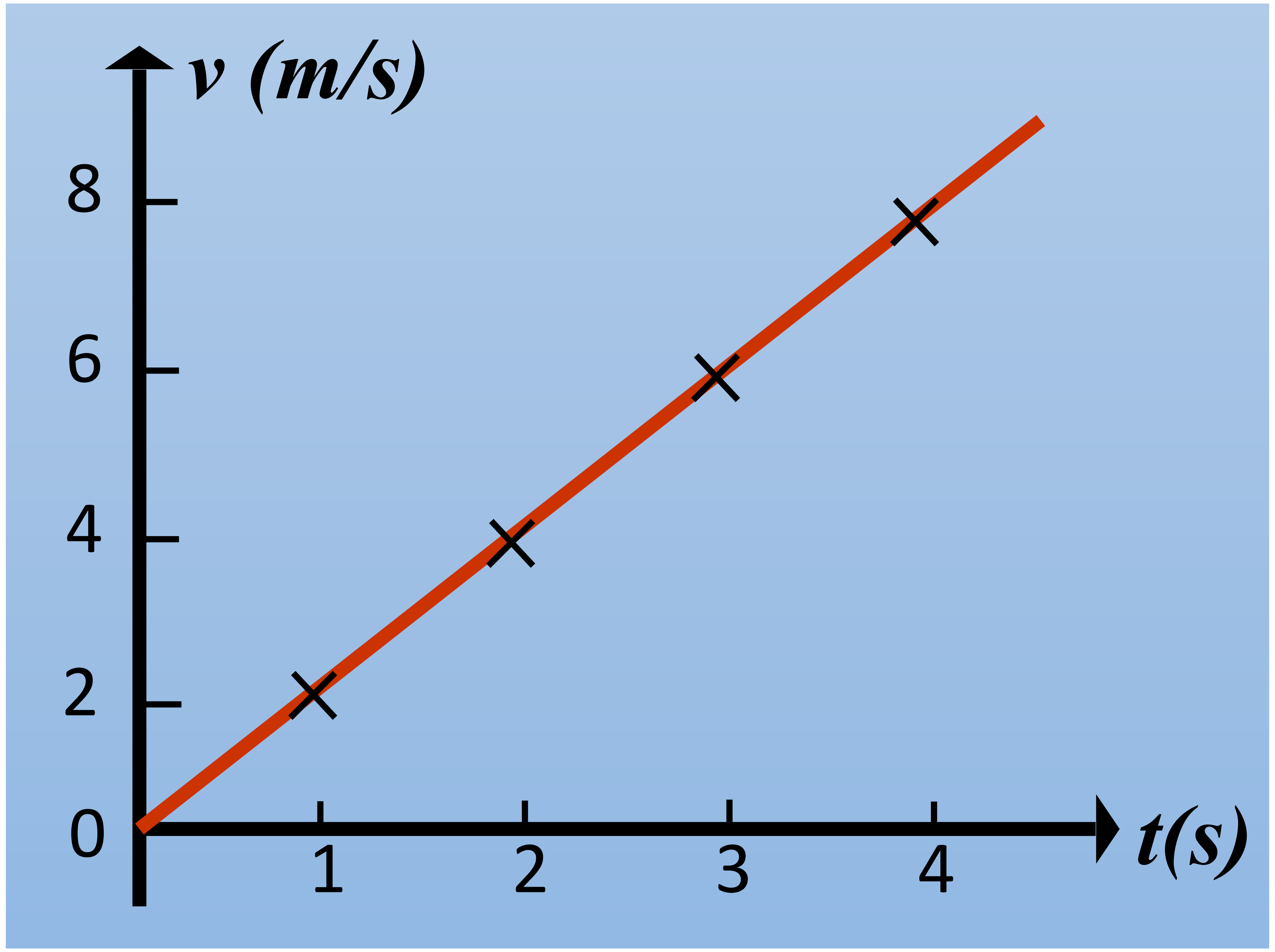
A car accelerates from rest with an acceleration 0f 2m/s, what is its speed at 5s?

Speed against time graph (v-t graph)

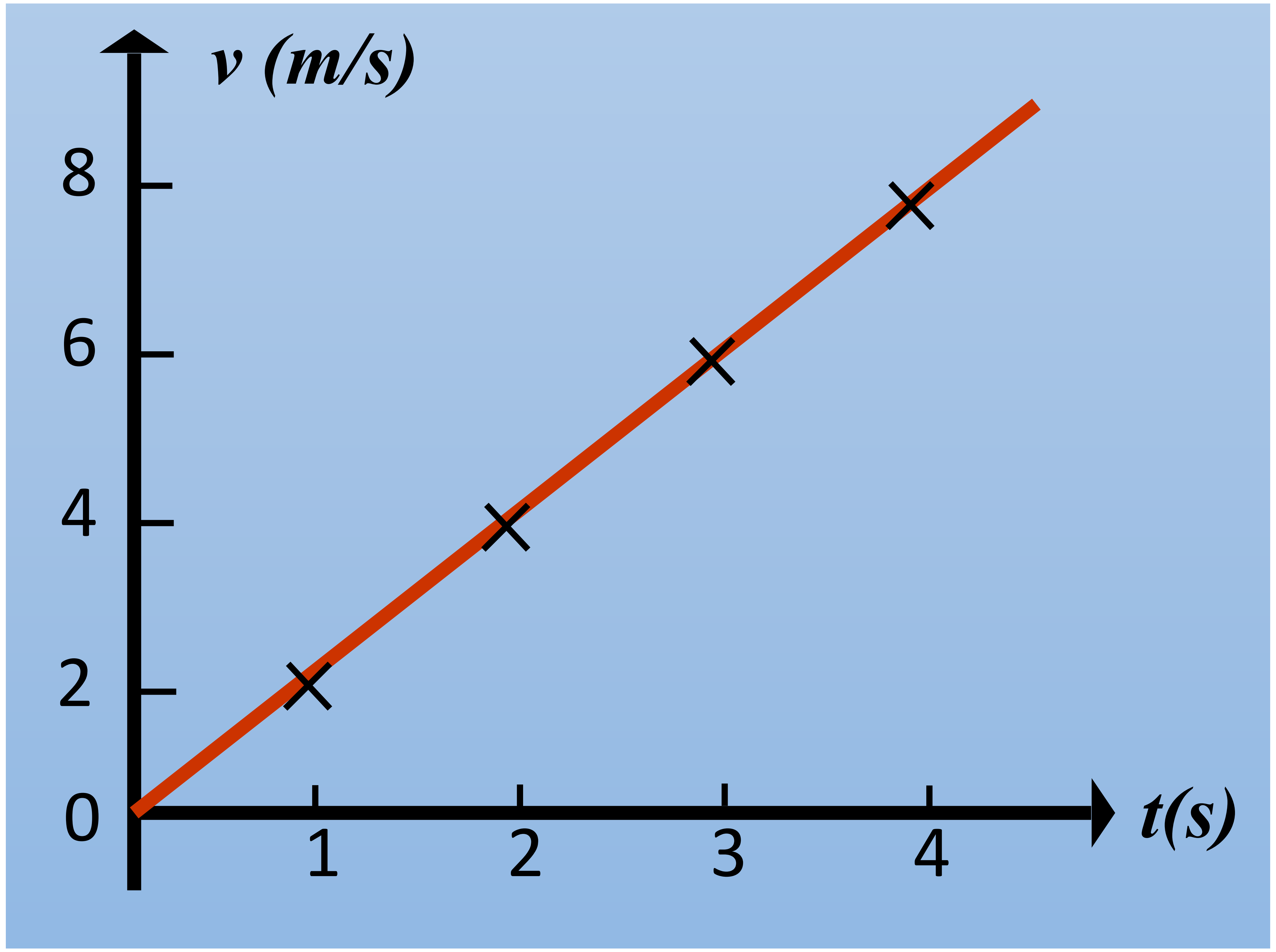
e.g. Uniformly accelerated motion

$\Delta t = 1$ s 0 m/s → 2 m/s → 4 m/s → 6 m/s → 8 m/s ...

speed-axis



time-axis



speed-time graph

Velocity ***v*** is linear with time ***t***

gradient or slope of the line

$$\alpha = \frac{\Delta v}{\Delta t} = 2m/s^2$$

Uniformly accelerated linear motion

Speed-time graphs summary

Slope:

Larger slope:

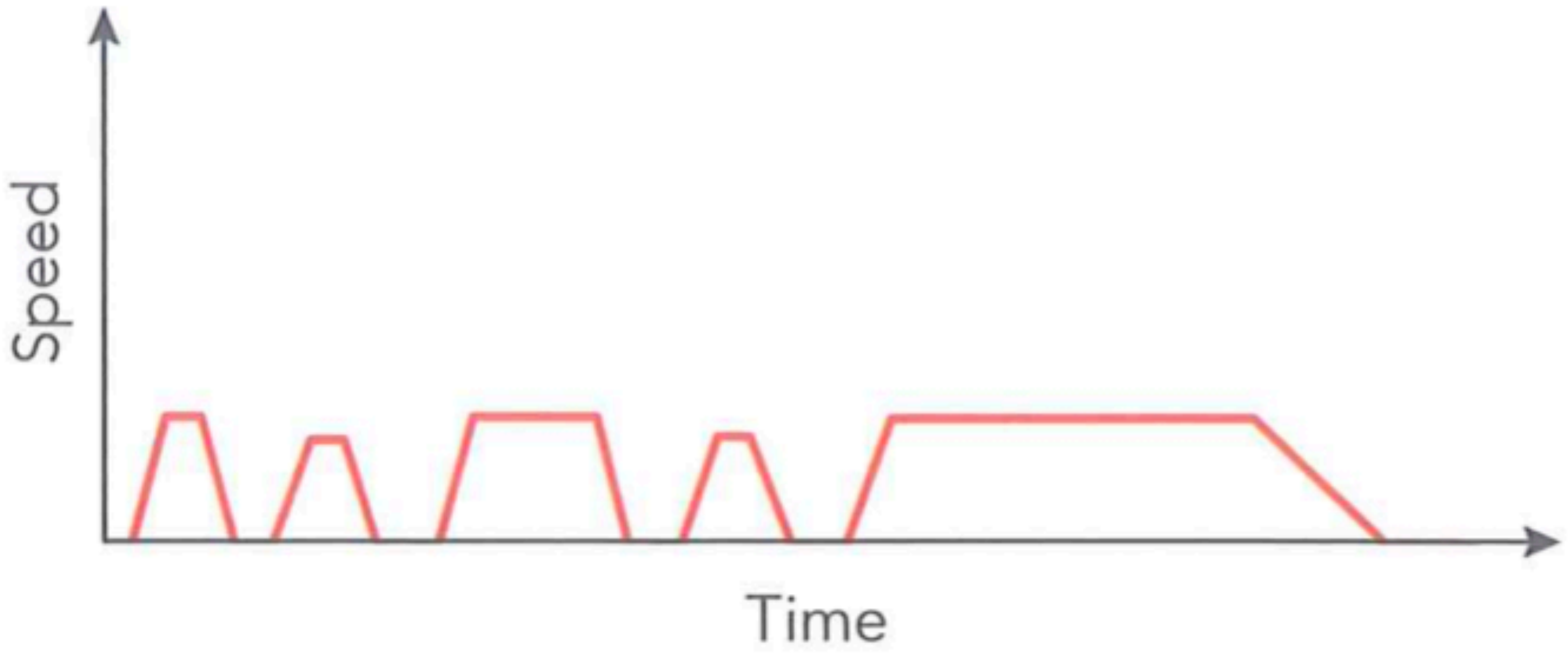
Positive slope:

Negative slope:

Slope =0 (a horizontal graph):

Straight line:

Curved line:



Speed-time graphs summary

Slope: magnitude of acceleration

Larger slope: larger acceleration

Positive slope: accelerating

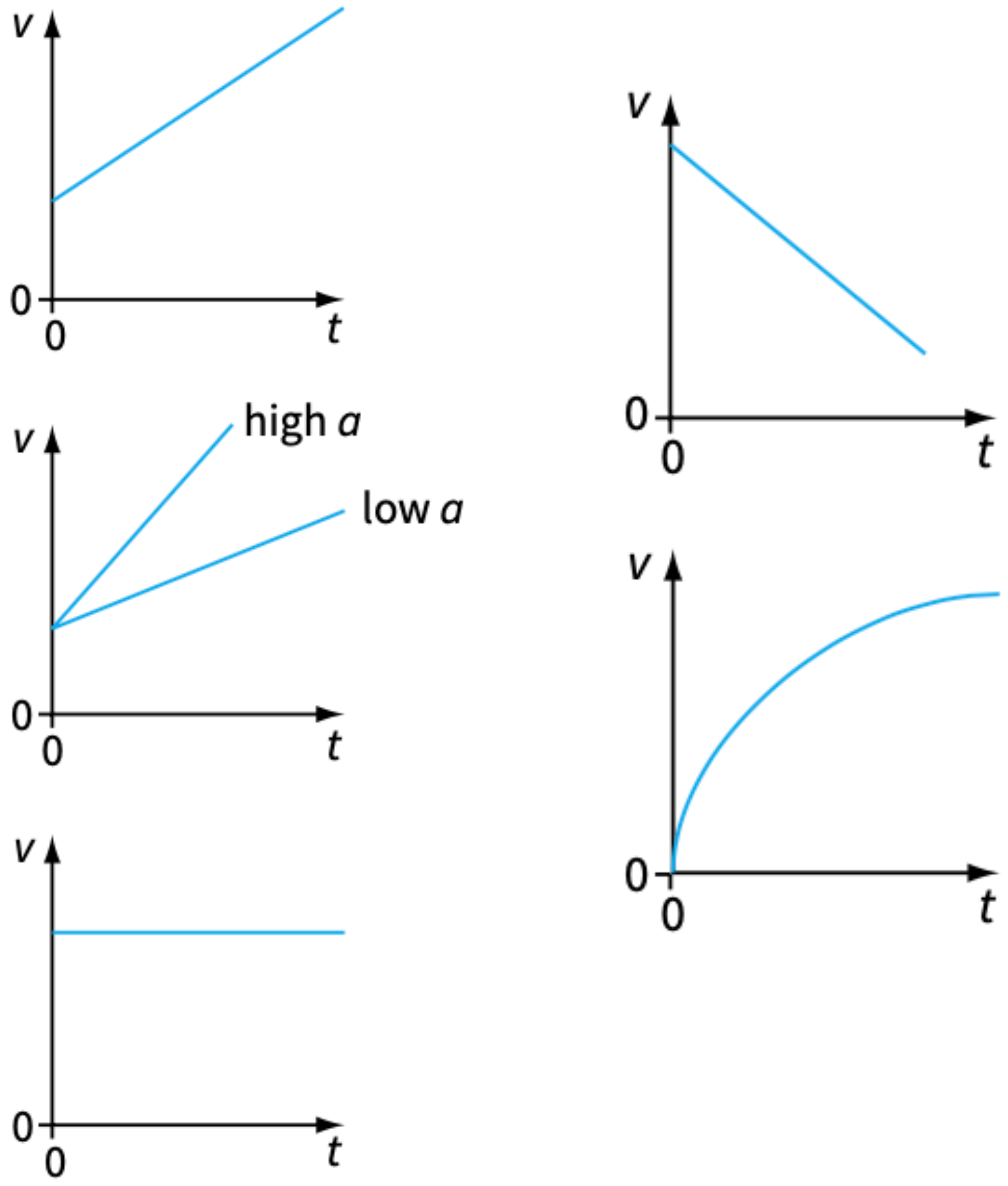
Negative slope: decelerating

Slope =0 (a horizontal graph): a = 0,

constant speed(including stationary)

Straight line: constant acceleration

Curved line: changing acceleration



Speed-time graphs summary

Slope: magnitude of acceleration

Larger slope: larger acceleration

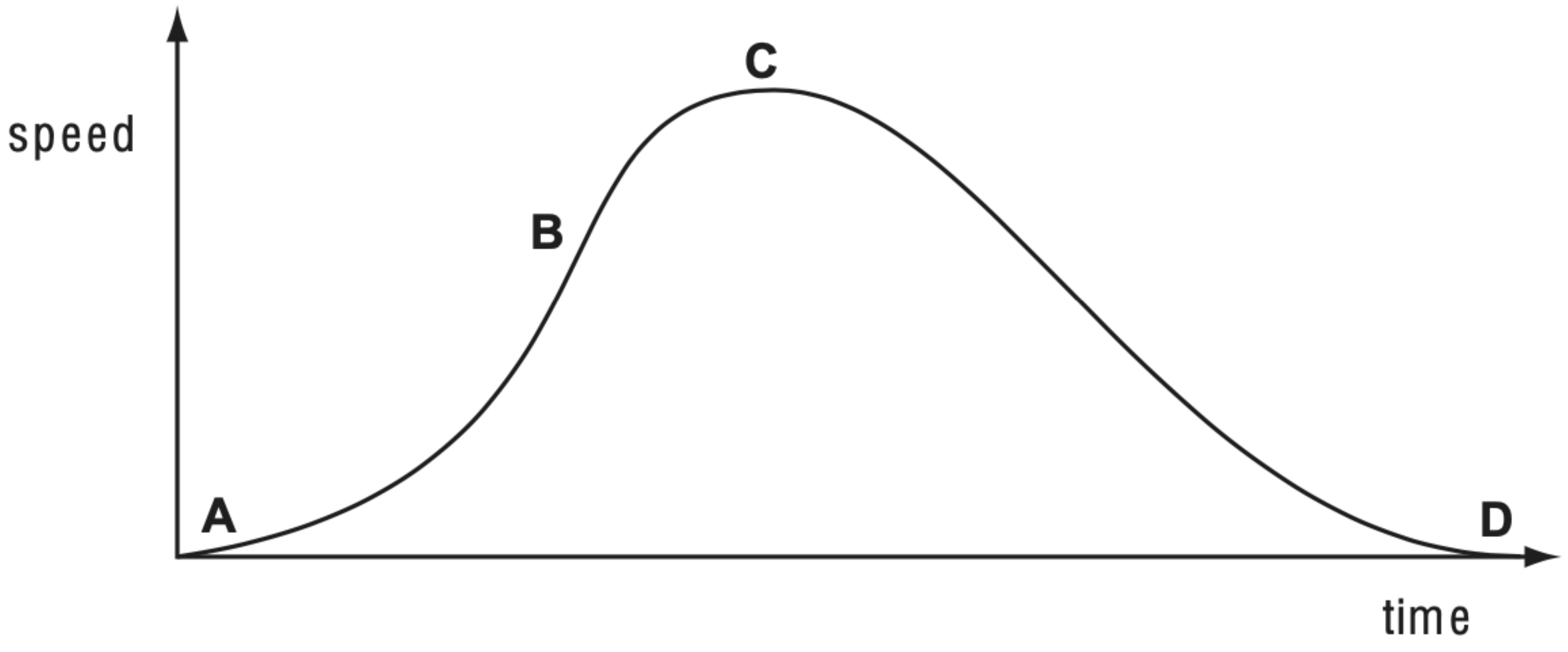
Positive slope: accelerating

Negative slope: decelerating

Slope =0 (a horizontal graph): a = 0, constant speed

Straight line: constant acceleration

Curved line: changing acceleration



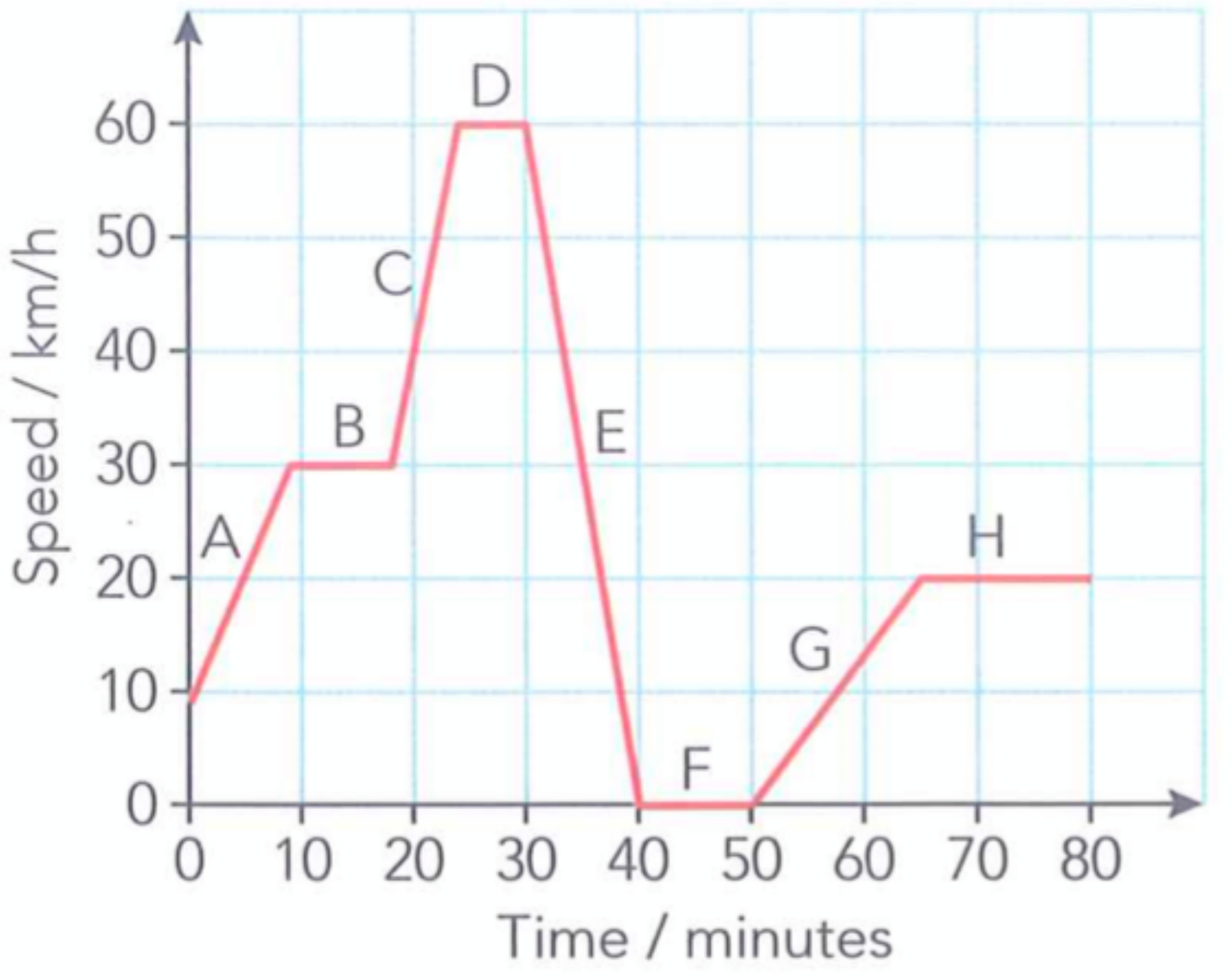
largest speed?

Acceleration

Exercise 2.h

Look at the speed-time graph on the right. Name the sections that represent:

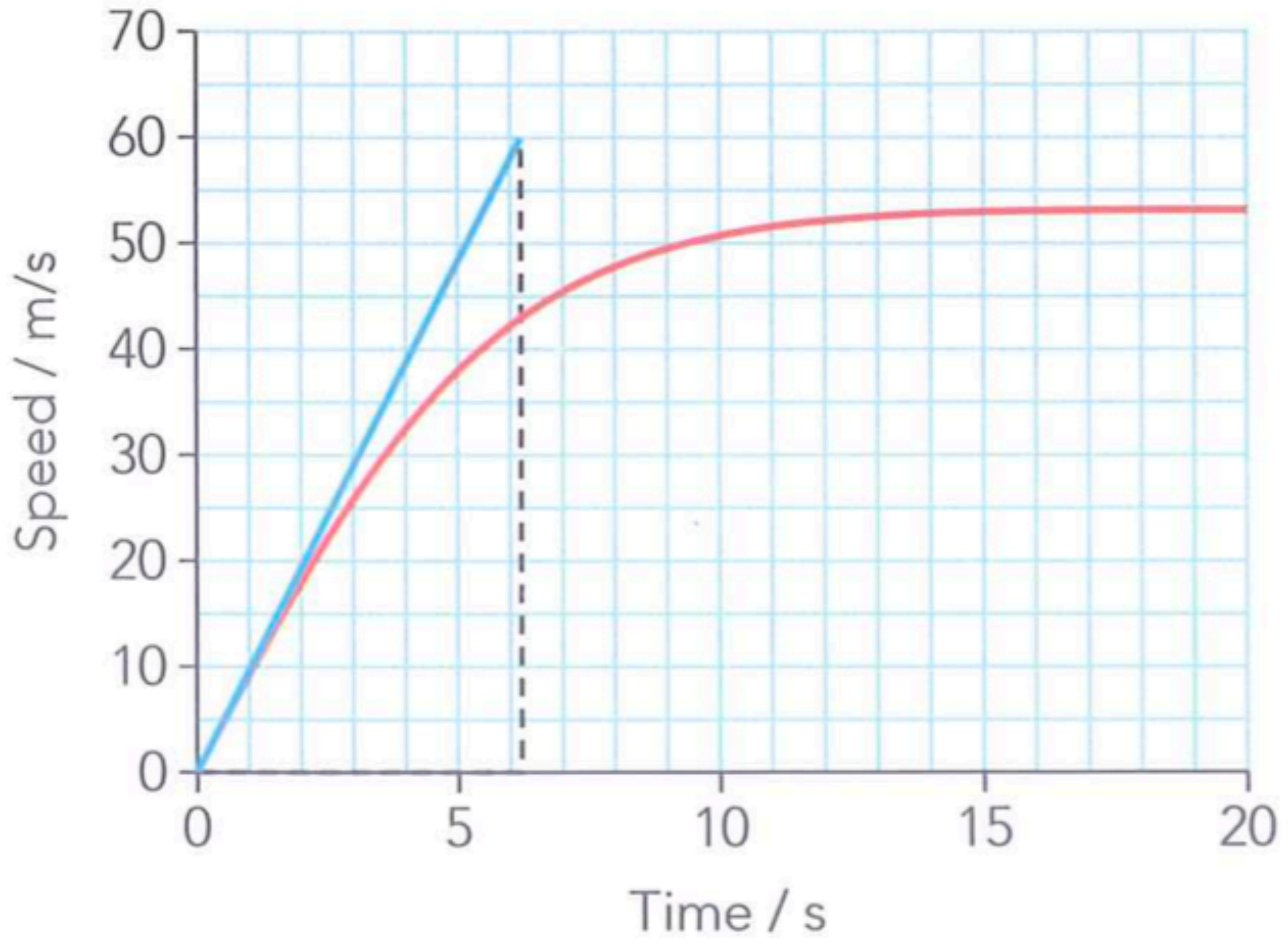
- steady speed
- speeding up (accelerating)
- being stationary
- slowing down (decelerating)



Acceleration

Exercise 2.j

What is the skydiver's acceleration at a. 0s, b 5.5s

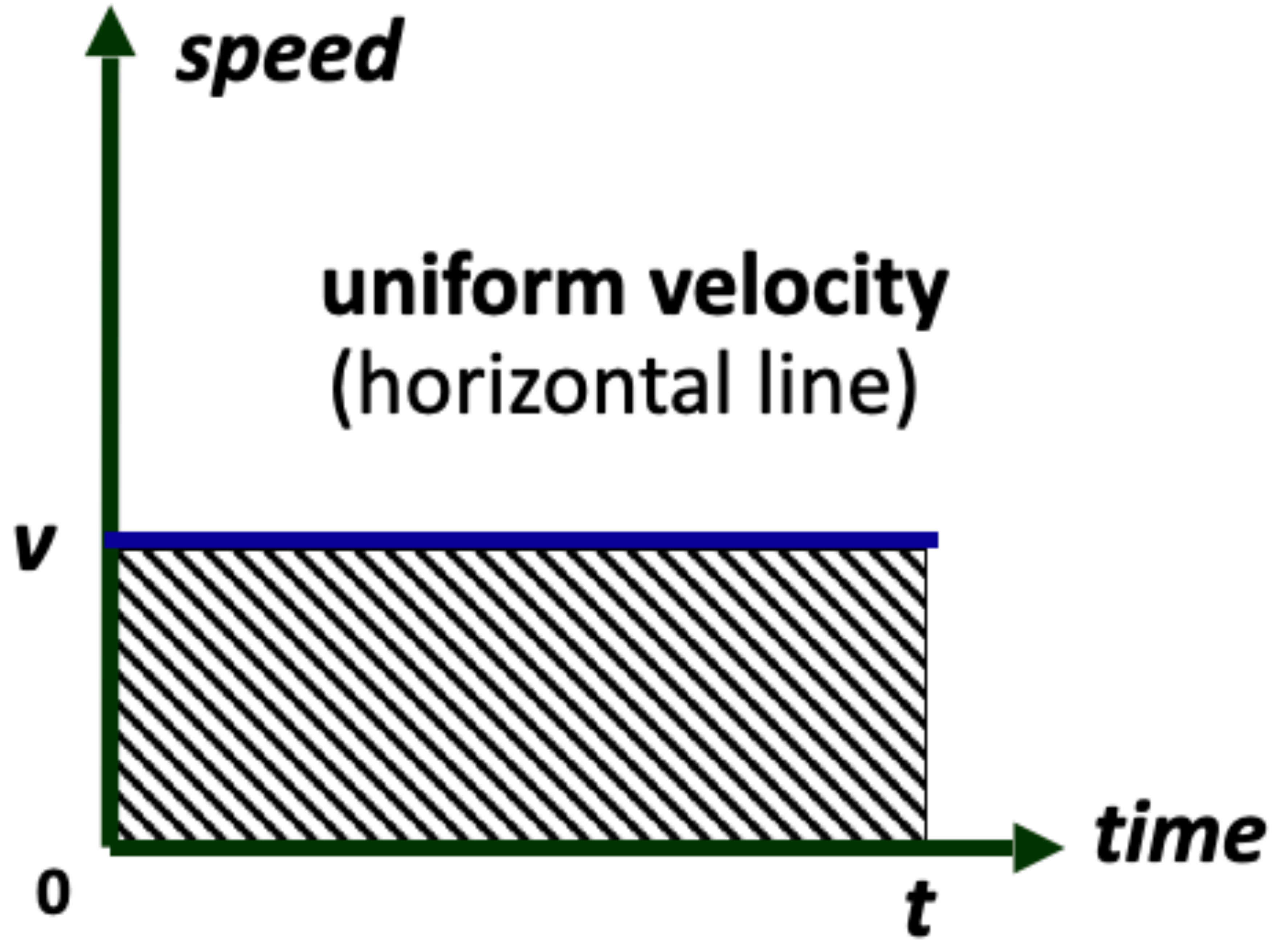


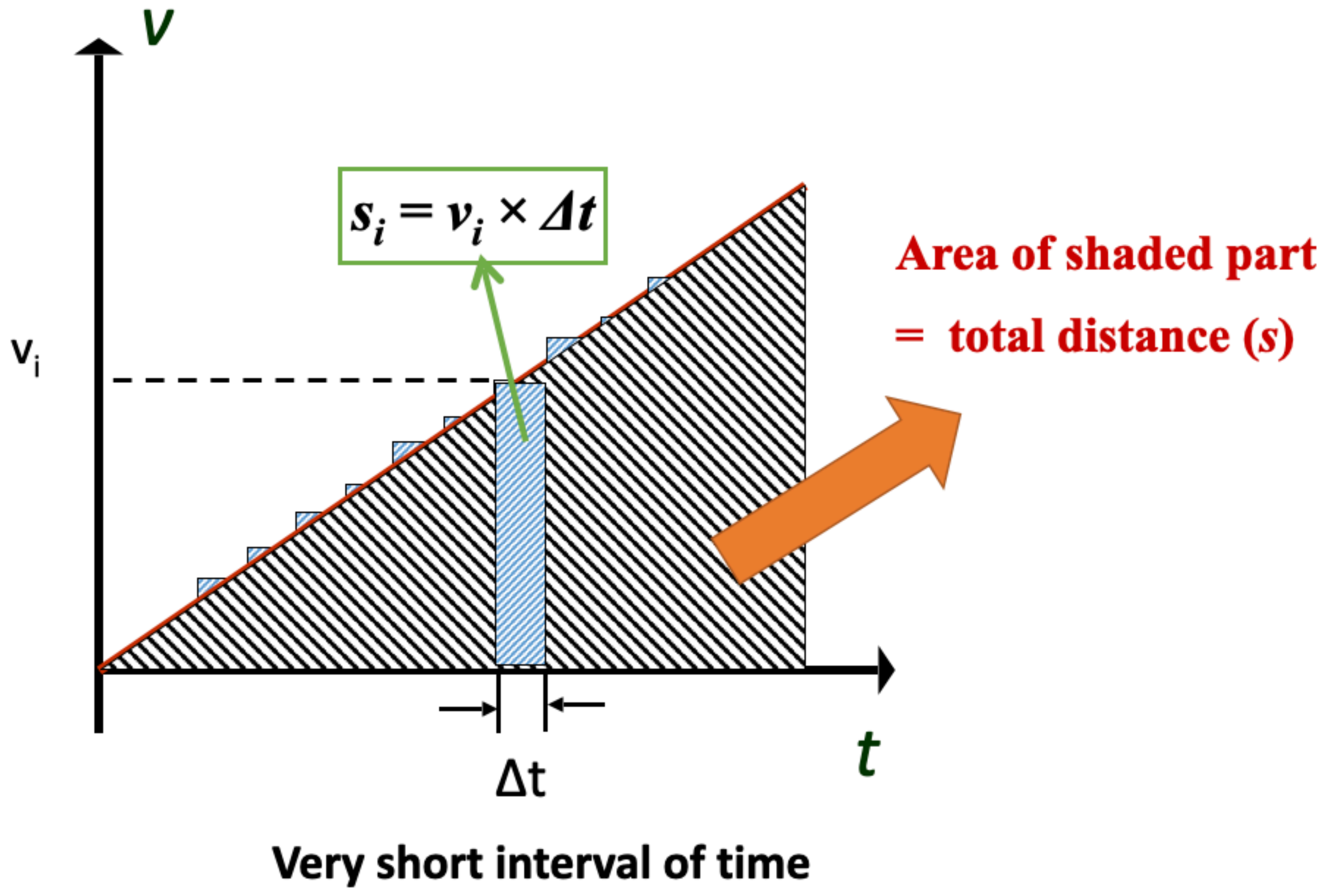
Finding distance travelled

Speed-time graph tells us how **speed** changes. Can we know distance from it?

Finding distance travelled

Speed-time graph tells us how **speed** changes. Can we know distance from it?





Finding distance travelled

Speed-time graph tells us how speed changes. Can we know distance from it?

distance = area under speed-time graph

Calculating distance from speed-time graph: Straight-line graph => rectangles and triangles

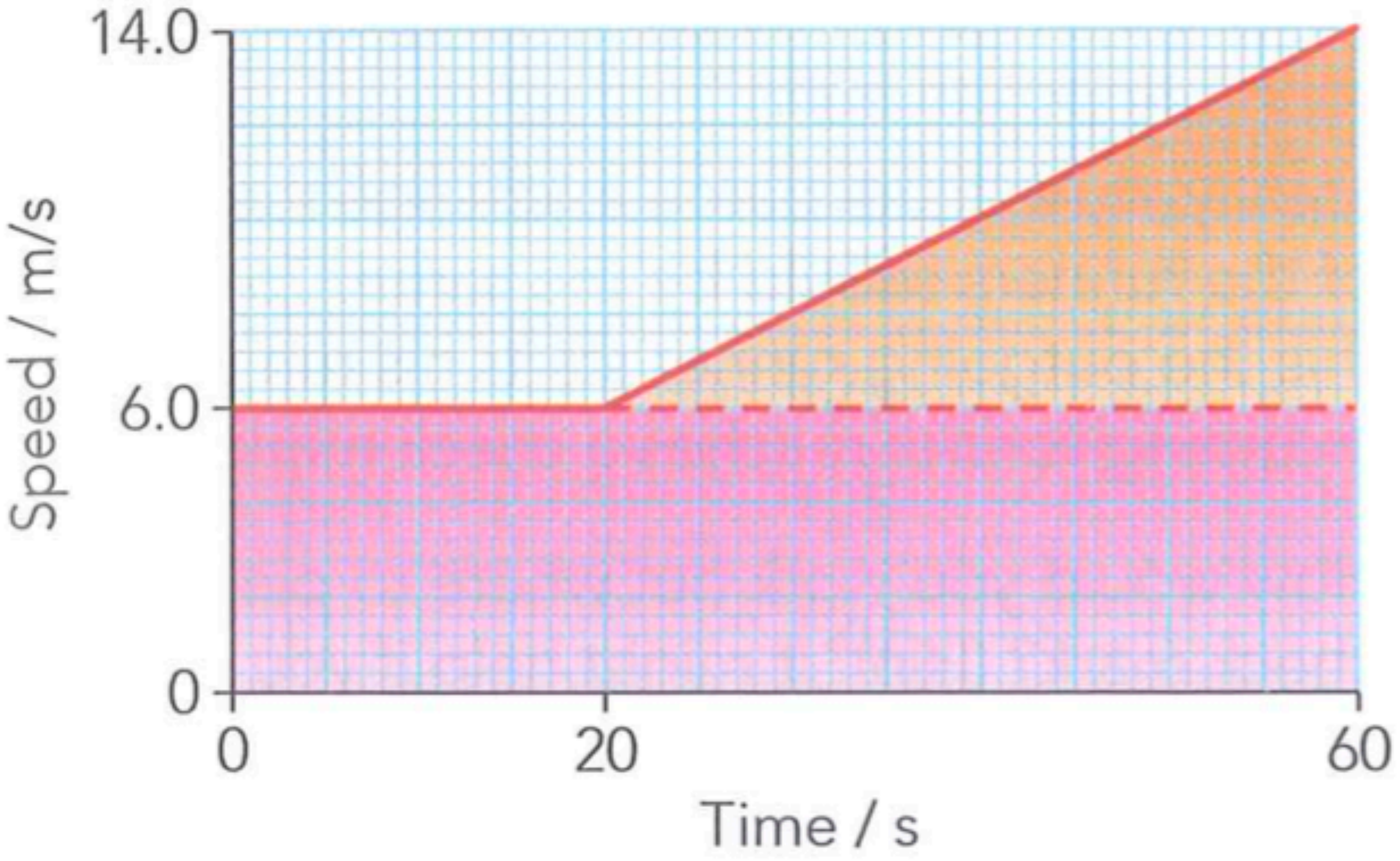
Area of rectangle = width $\times$ height

Area of triangle = $\frac{1}{2} \times base \times height$

Finding distance travelled

Exercise 2.k

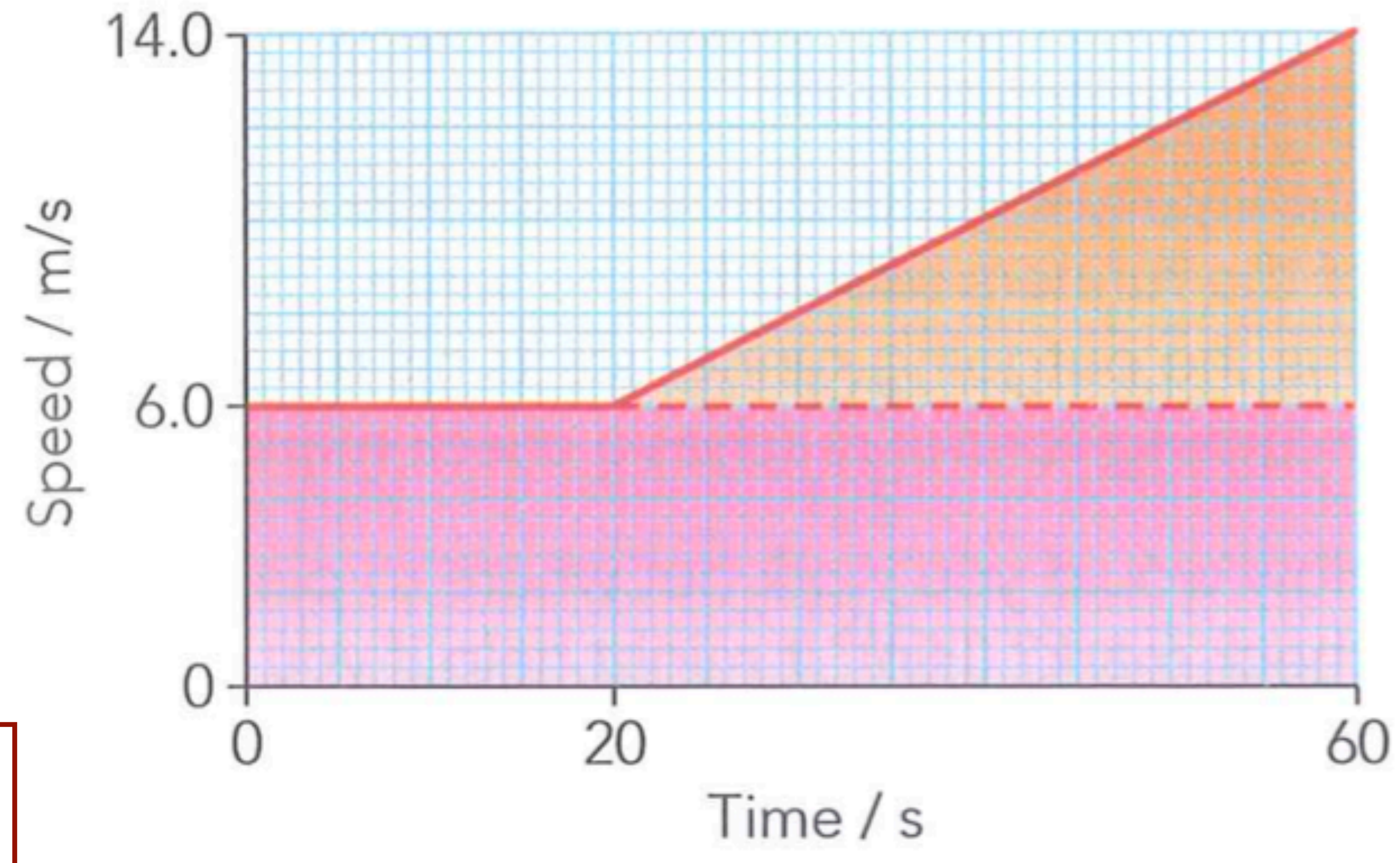
A train's motion can be represented by the graph below. Calculate the distance the train travels in a. 15s, b 60s.



Finding distance travelled

Exercise 2.k

A train's motion can be represented by the graph below. Calculate the distance the train travels in a. 15s, b 60s.



step 1.

The area can be divided into a rectangle and a triangle

step 2.

Area of a triangle = $\frac{1}{2} \times base \times height = \frac{1}{2} \times 40s \times 8.0\ m/s = 160\ m$

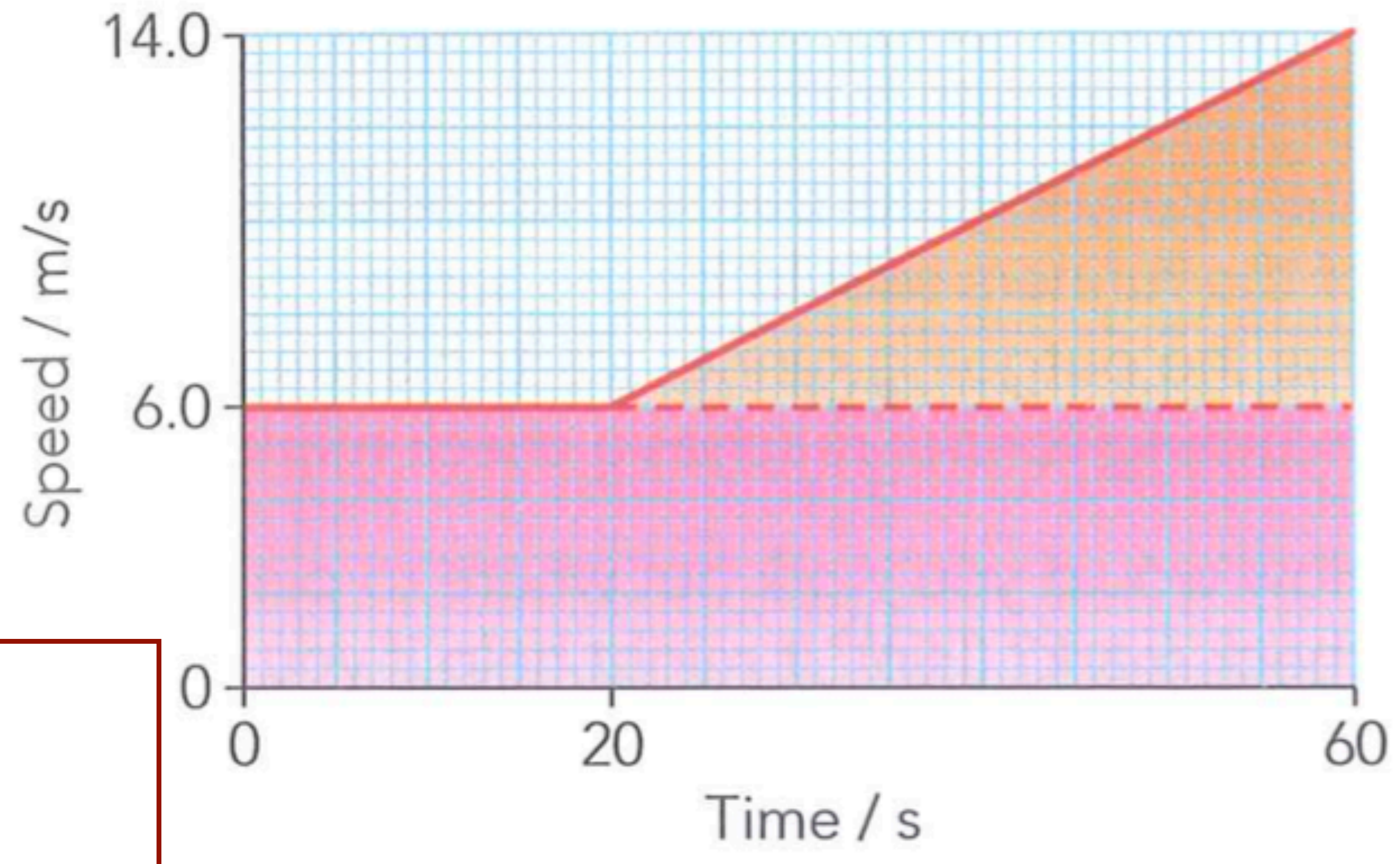
Area of a rectangle = $width \times height = 60s \times 6.0\ m/s = 360\ m$

Total distance travelled $= 360\ m + 160\ m = 520\ m$

Finding distance travelled

Exercise 2.k

A train's motion can be represented by the graph below. Calculate the distance the train travels in a. 15s, b 60s.



step 1.

Distance = area under speed-time graph

step 2.

Area of a rectangle = $width \times height = 20s \times 6.0\ m/s = 120\ m$

Area of a trapezoid =

$$\frac{1}{2} \times (short\ base + long\ base) \times height = \frac{1}{2} \times (6.0 + 14.0) m/s \times 40s = 400\ m$$

Total distance travelled $= 120\ m + 400\ m = 520\ m$

Finding distance travelled

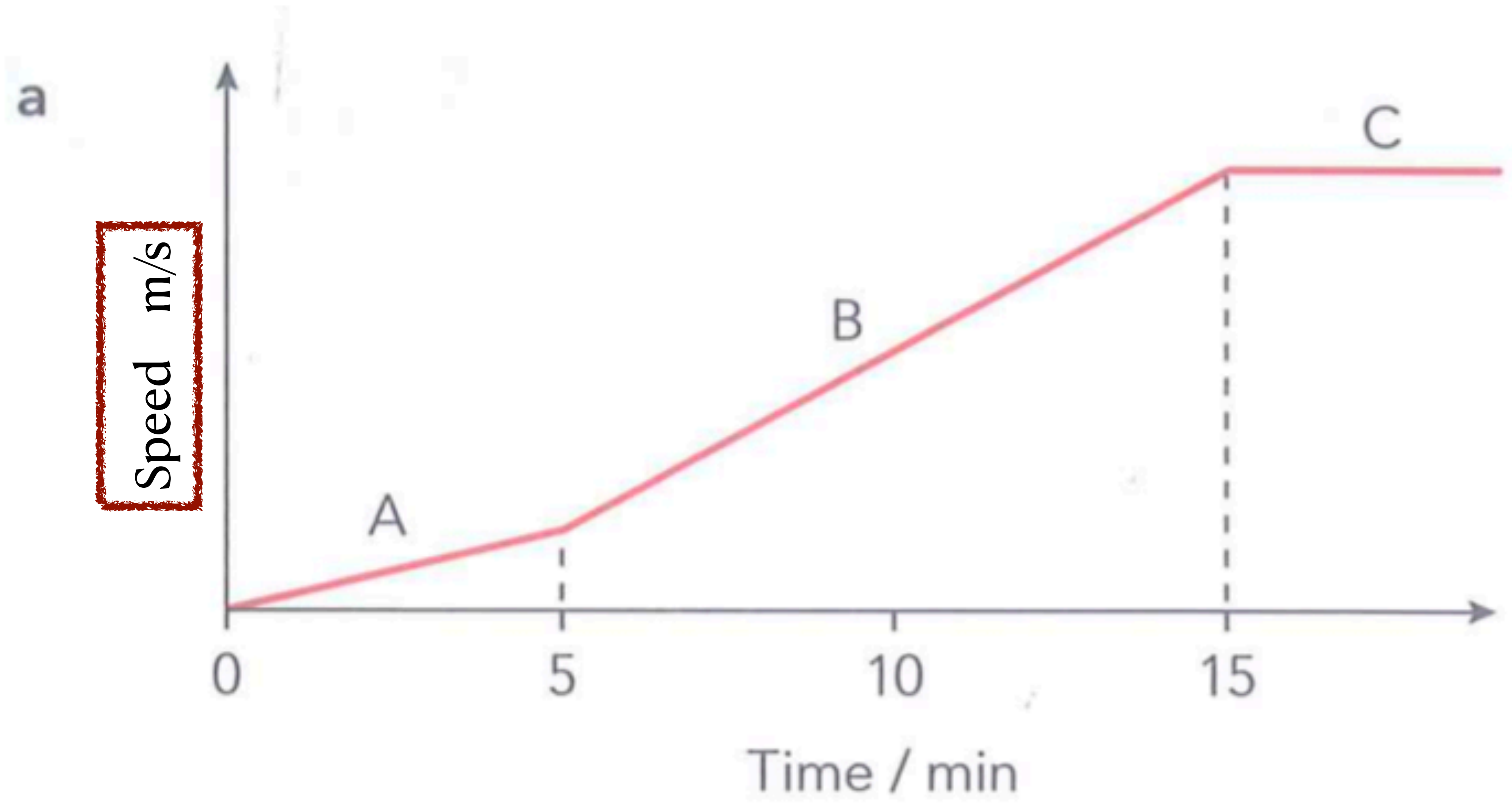
Exercise 2.l

Draw a speed-time graph to show a car that accelerates uniformly from 6m/s for 5s then travels at a steady speed go 12m/s for 5s.

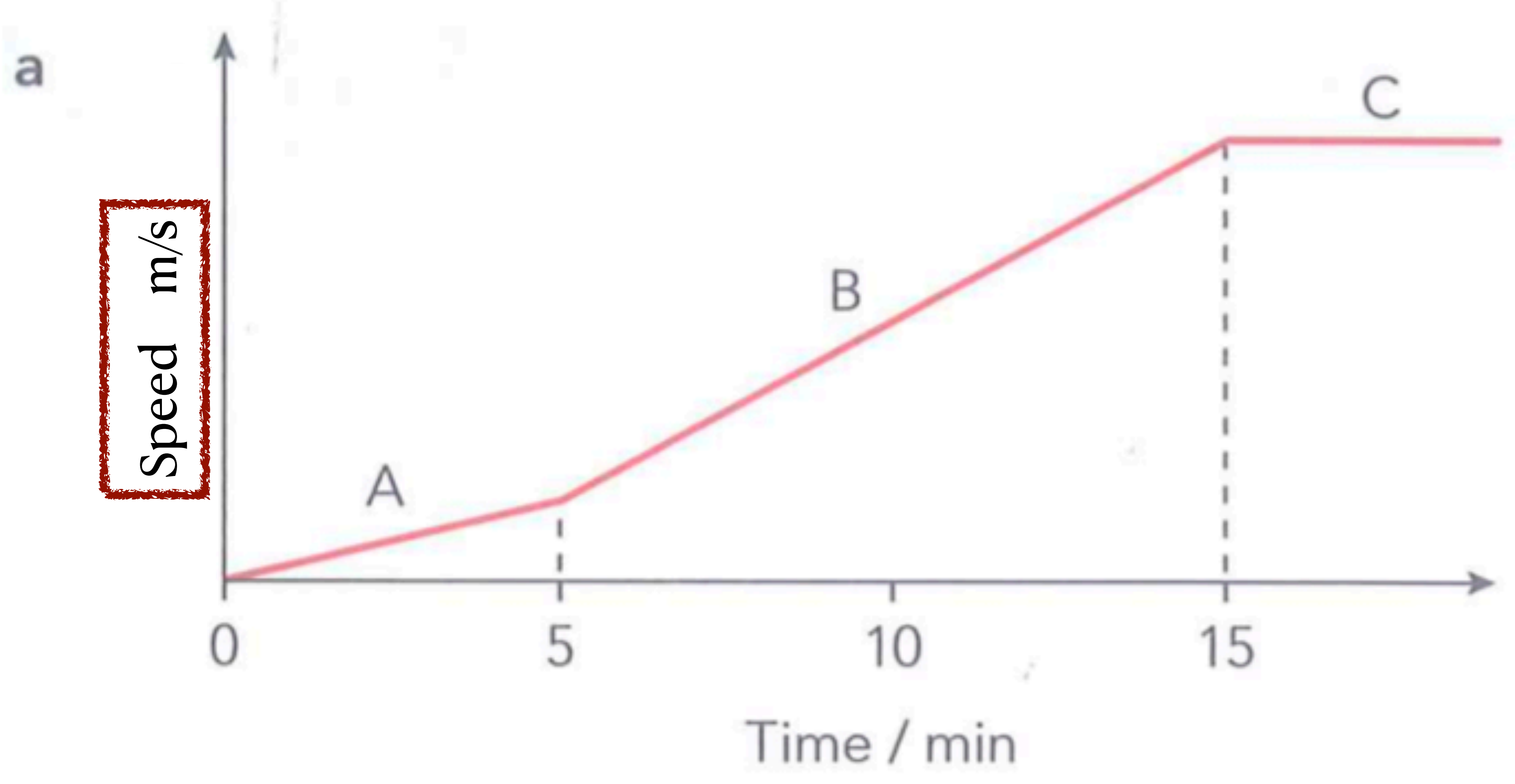
On your graph, shade the area that shows the distance travelled by the car in 10s.

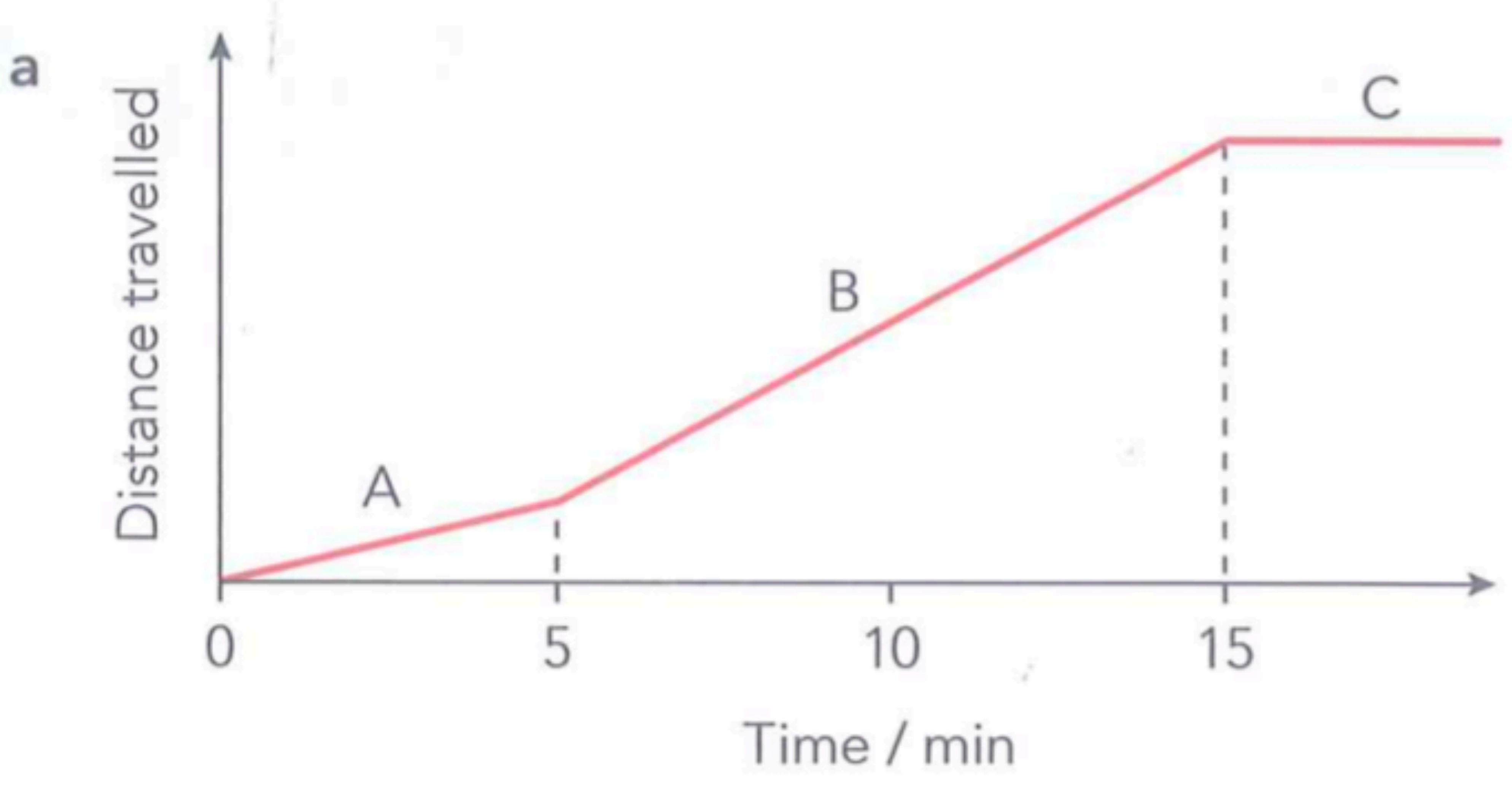
Calculate the distance travelled in this time.

Finding distance travelled



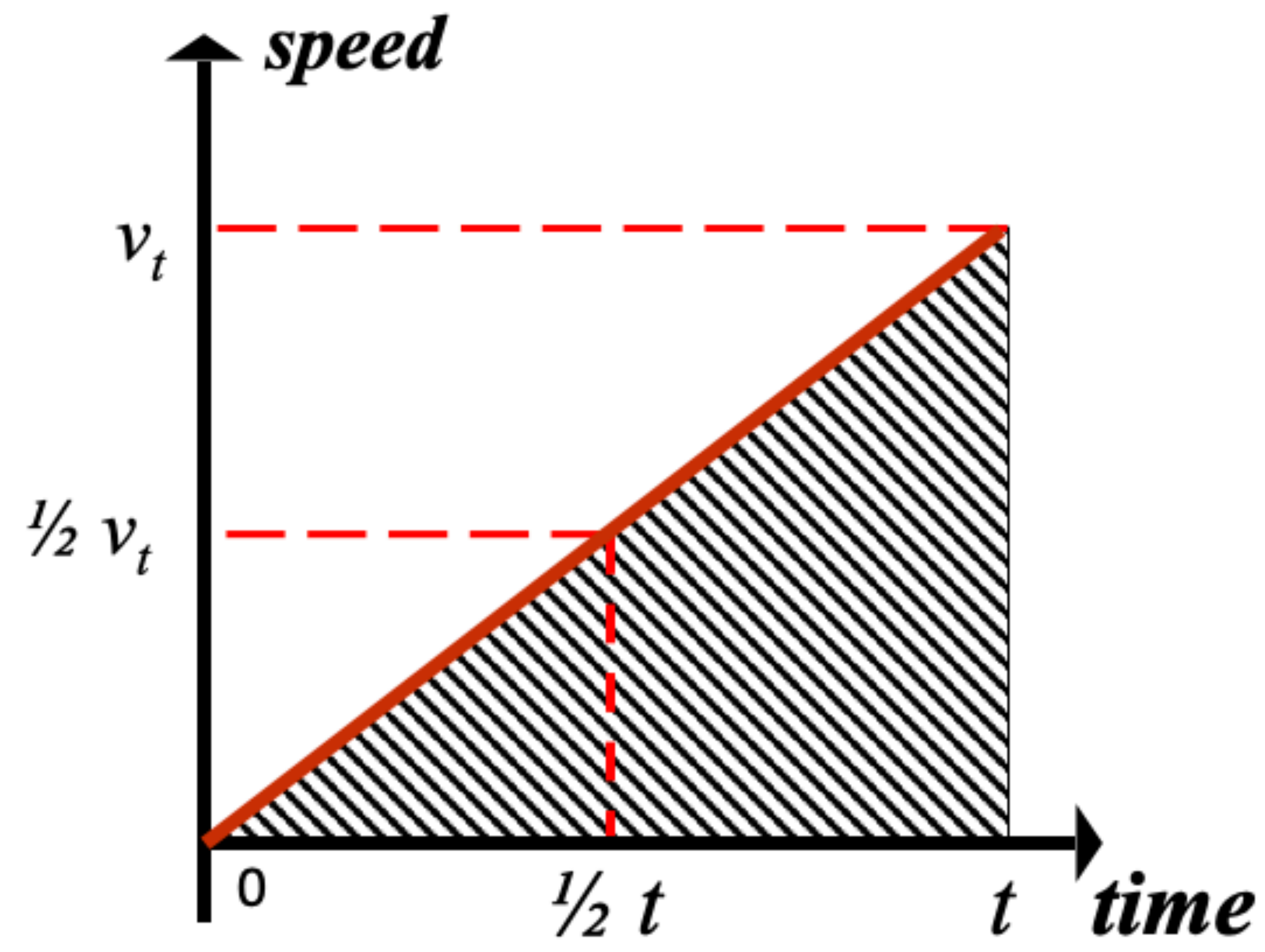
Finding distance travelled

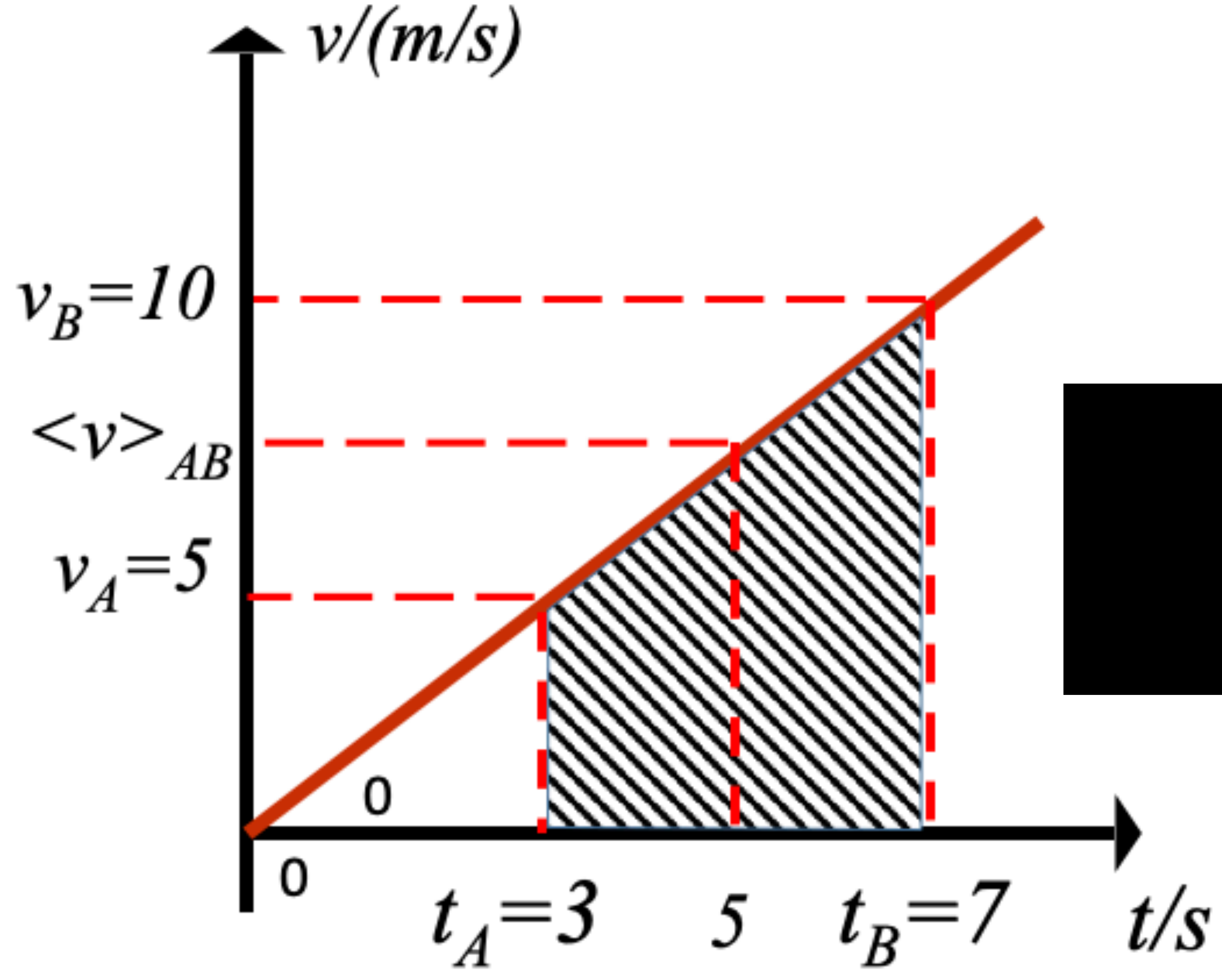




More about Uniformly accelerated motion

$a = constant$





Average speed = (u+v)/2

Distance

= Area of shadowed part

$=1/2 \times v_t \times t$

= *Area of shadowed trapezoid*

$$= \frac{1}{2} \times (v_A + v_B) \times (t_B - t_A)$$

Uniformly accelerated motion

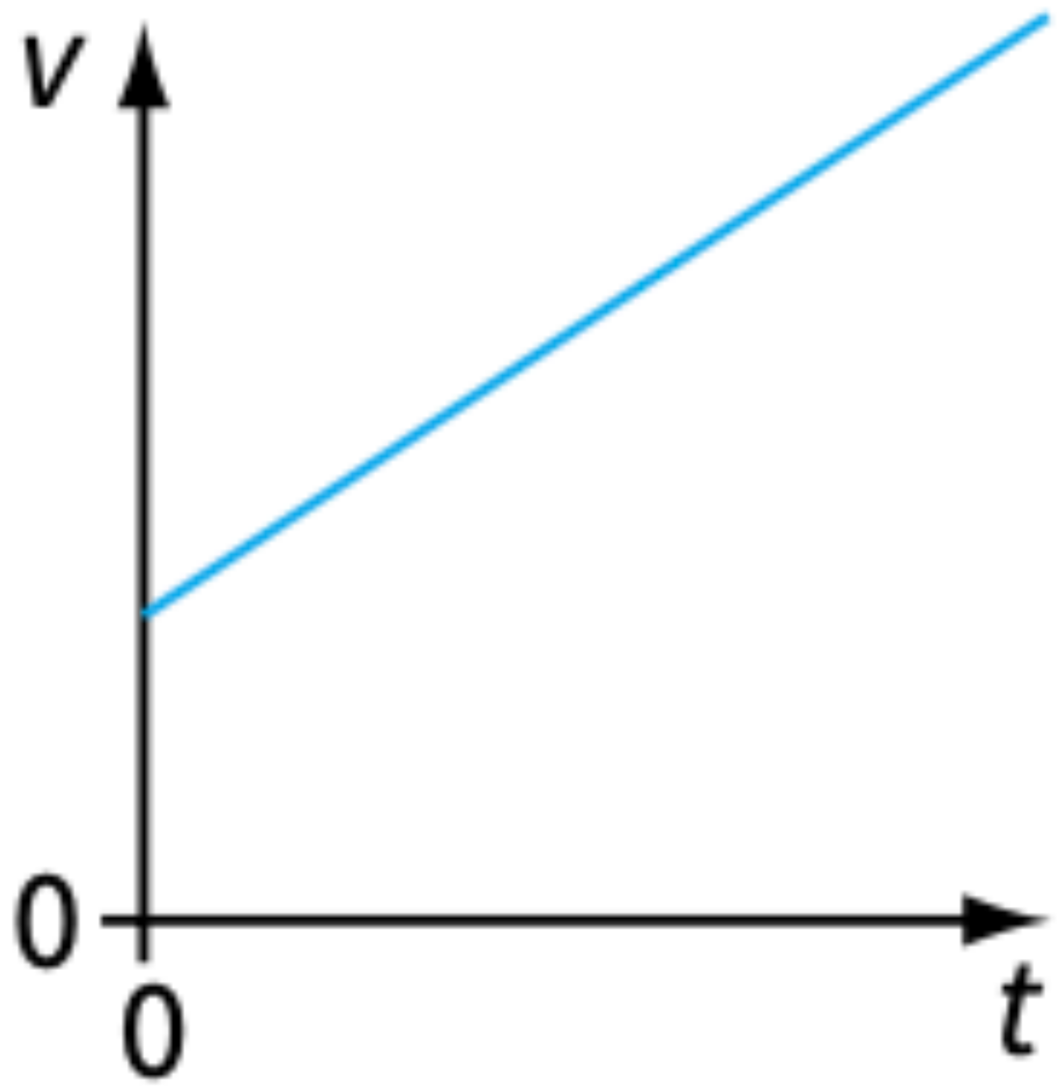
$a = constant$

$$v = u + at$$

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

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

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



Falling

Free fall: any motion of a body where gravity is the only force acting upon it.

$$a = g = 9.8 m/s^2$$ (near surface)

- distance-time graph?
- speed-time graph?
- acceleration-time graph?

Falling

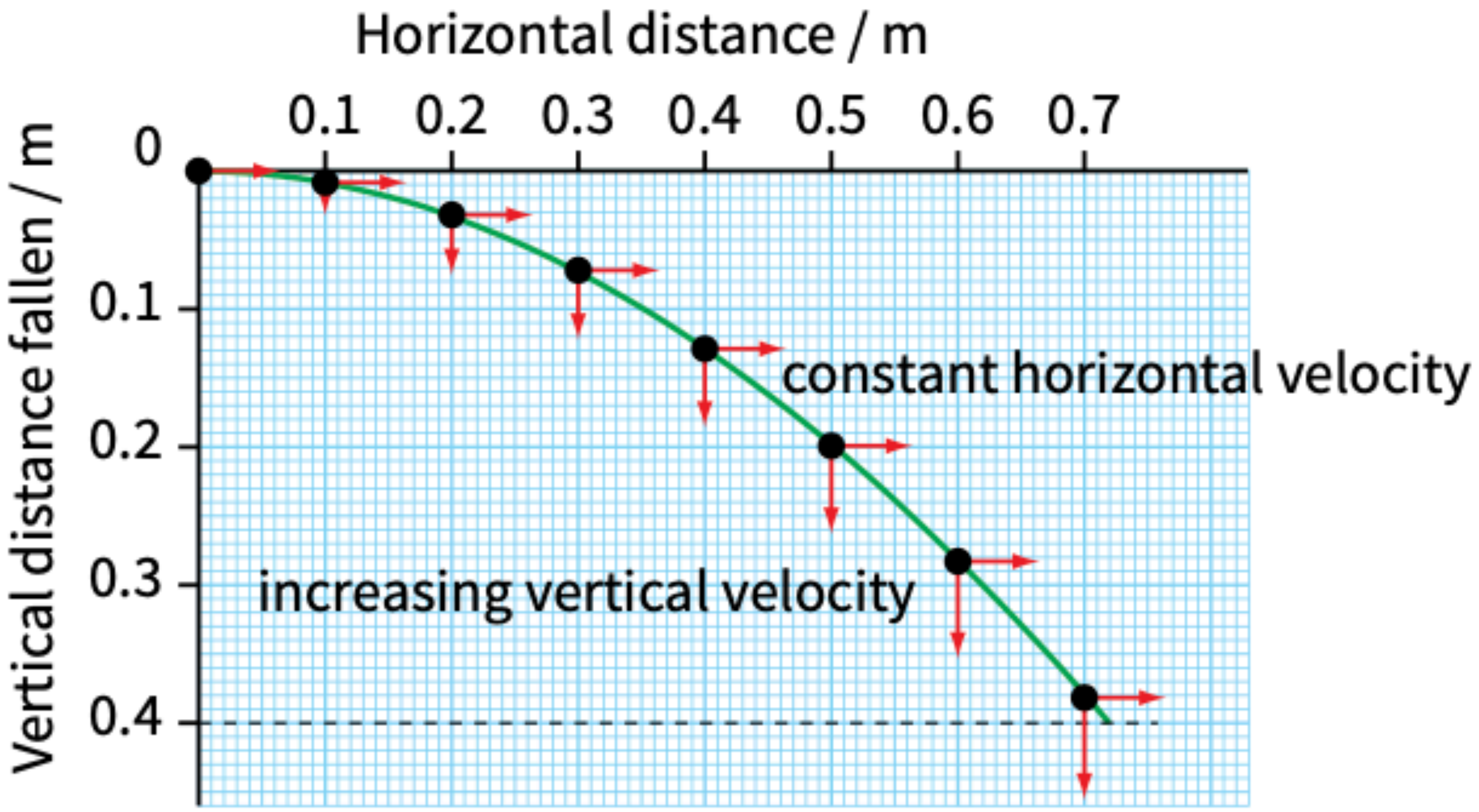
Falling with resistance:

Resistance change —> acceleration change

Projectile

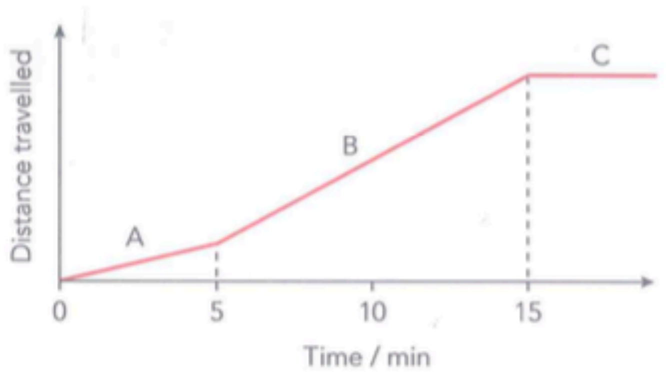
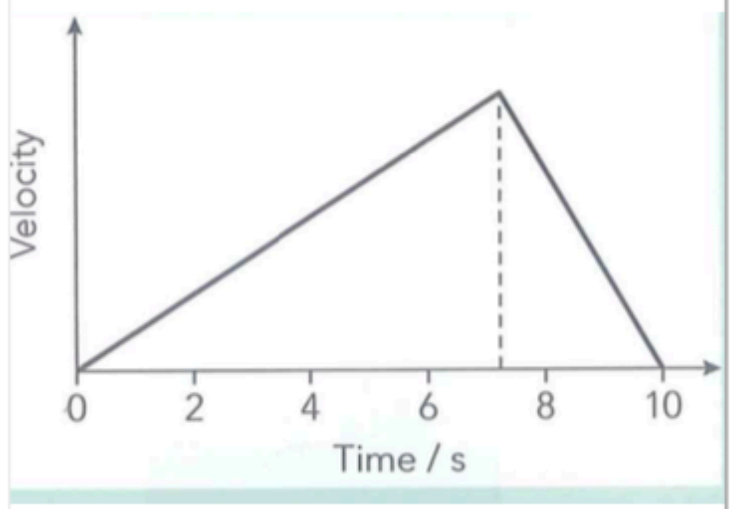
Horizontally/X direction: uniform speed

Vertically/Y direction: free fall



Summary

1. Speed vs velocity & acceleration
2. Distance/speed-time graphs
3. Uniformly accelerated motion

	distance-time graph	speed-time graph
example		
distance		
speed		
acceletation		