MOTION

IB PHYSICS | UNIT 2 | MOTION

2.1

Velocity

IB PHYSICS | UNIT 2 | MOTION

What is Motion?

An object's change in __position__________
relative to a reference point.

Relative to the earth:
Moving 17,500 mph

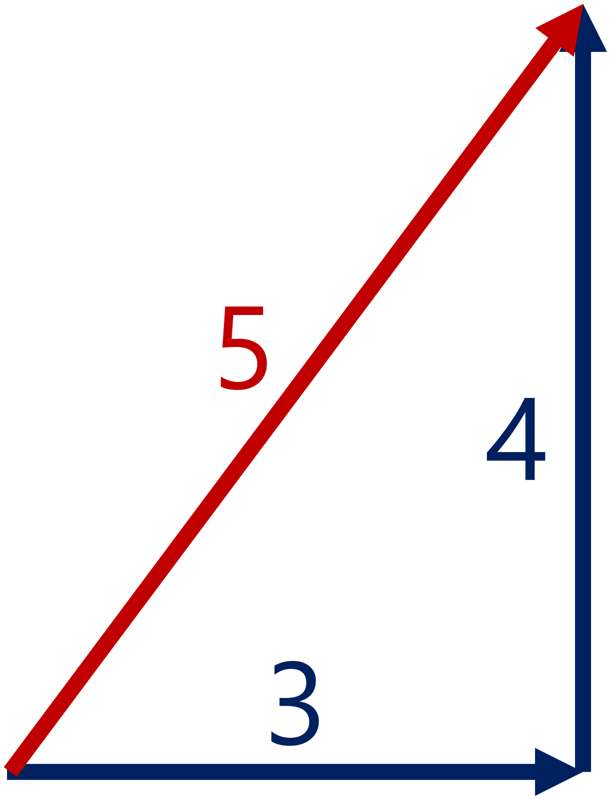
Relative to the shuttle:
Not moving

Distance vs. Displacement

Distance How far travelled
Displacement How far from origin

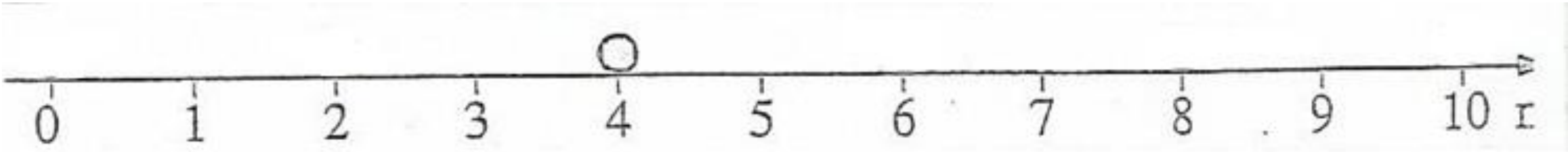
Try this | Distance and Displacement

You walked 3 miles East, turned left, then walked 4 miles North. What is your distance? displacement?

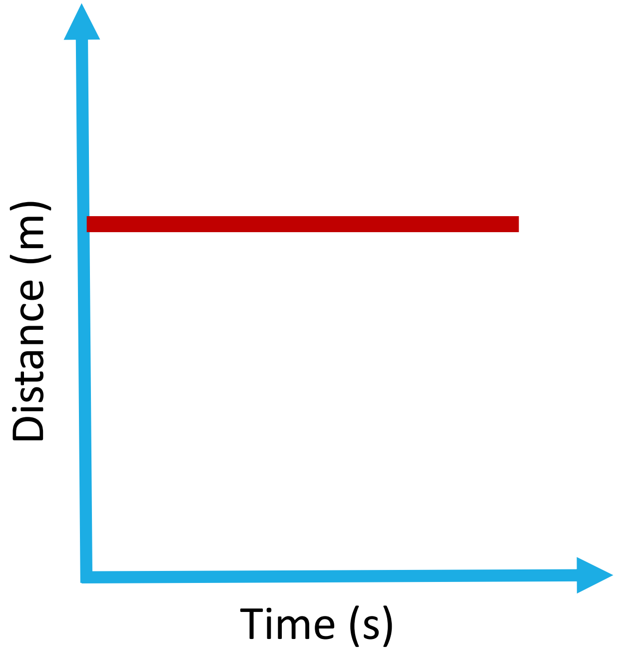


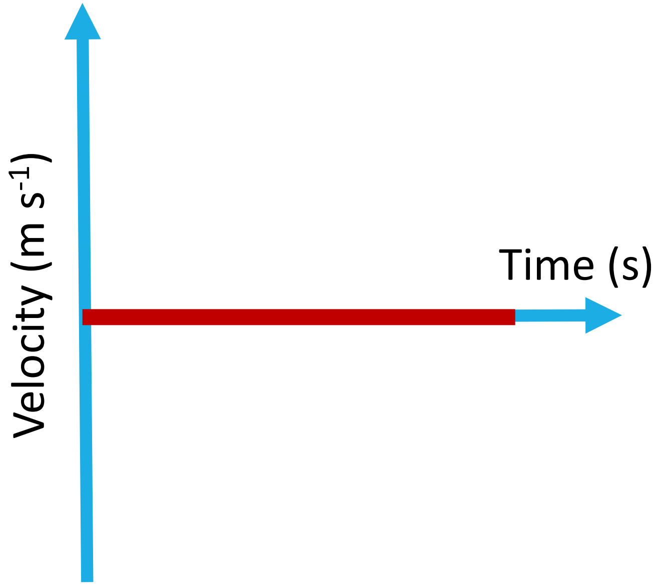
Distance	7 miles
Displacement	5 miles

Constant Displacement



Not moving





Average Speed and Velocity

$$\text{Average Speed} = \frac{Total\ Distance}{Total\ Time}$$

* Always Positive

$$\text{Average Velocity} = \frac{Total\ Displacement}{Total\ Time}$$

* Includes Direction

Calculating Average Speed

New world record for a marathon (26.2 miles) was set several years ago. David Kimetto finished in 2.04 hours. What was his average speed?

$$v = \frac{d}{t} = \frac{26.2}{2.04} = 12.8\ \mathrm{mi\ hr^{-1}}$$

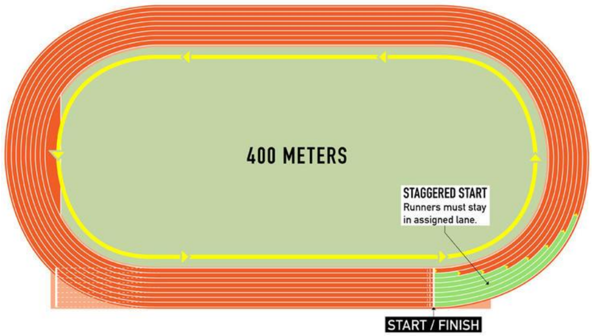
Marathon Runners are FAST

Run With Ryan

Best Of the ASICS Treadmill Challenge

Consider this...

The gold medalist for the men's 400 m (one complete lap of the track) in Rio was Wayde van Niekerk with a WR time of 43.03 s. What was his average speed? Average velocity?

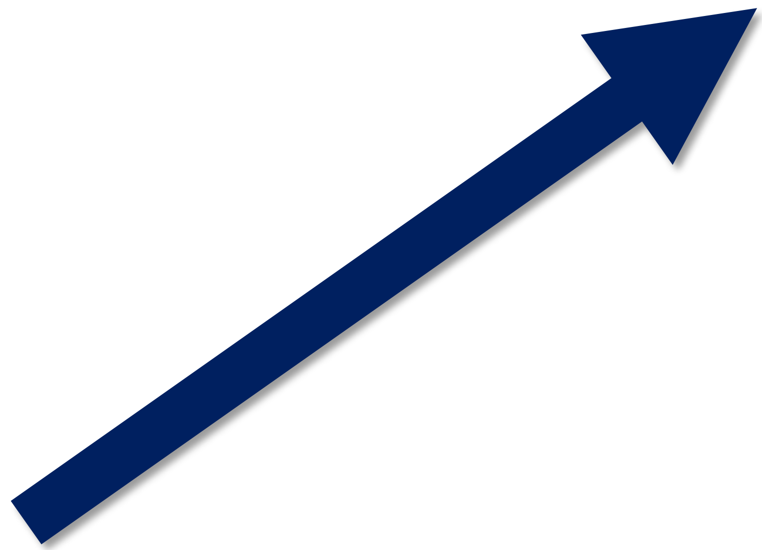


$$Avg\ Sped = \frac{400\ m}{43.03\ s} = 9.3\ m\ s^{-1s}$$

$$Avg\ velocity = \frac{400\ m}{0\ s} = \mathbf{0\ m\ s^{-1}}$$

What is a Vector?

A Vector is a quantity that includes both **direction** and **magnitude**



Vector vs Scalar

Vector Quantities	Scalar Quantities
Displacement	Distance
Velocity	Speed
Force	Energy

Racing against Usain...

In 2012, Usain Bolt's Gold Medal 100 meter dash took just 9.63 seconds.

In 1896, the gold medalist finished in 12.00 seconds.

Making the assumption that they are traveling at a constant velocity (they aren't really), how far behind Usain would the 1896 medalist be?

Method 1:

$$100 - \left(\frac{9.63}{12}\right)100 = \mathbf{19.75\ m}$$

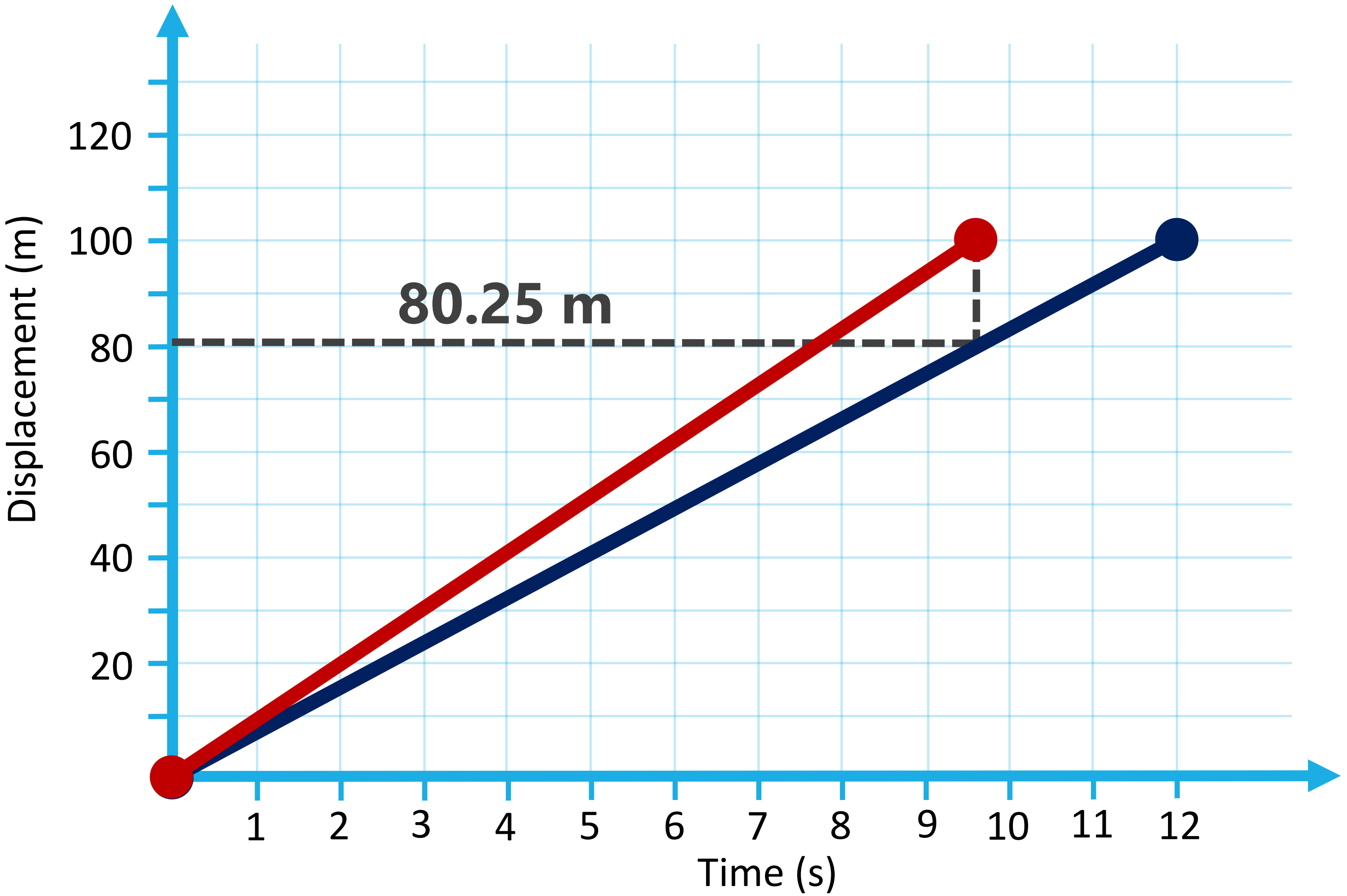
Method 2:

$$\frac{100}{12} = 8.3\ \mathrm{m\ s^{-1}}$$

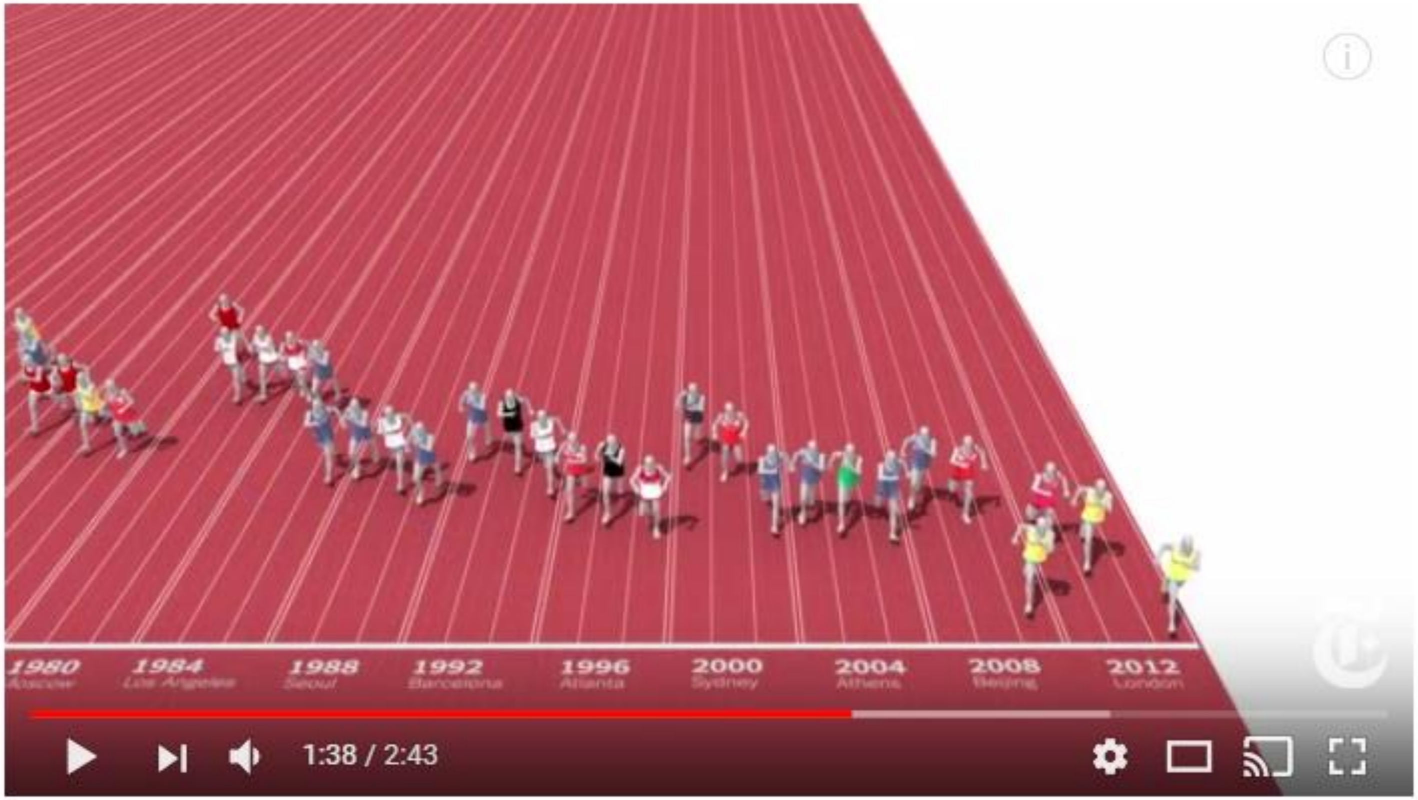
$$(8.3\ \mathrm{m\ s^{-1}})(9.63\ \mathrm{s}) = 80.25\ \mathrm{m}$$

$$100 - 80.25 = \mathbf{19.75\ m}$$

Plot this problem on a D vs T graph

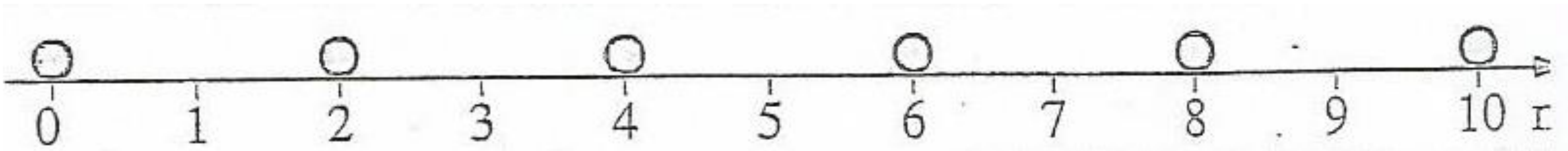


Racing against Usain…

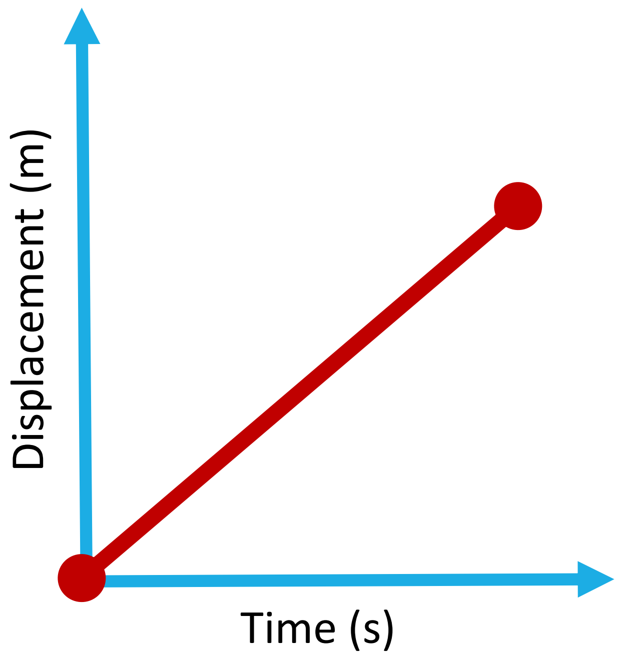


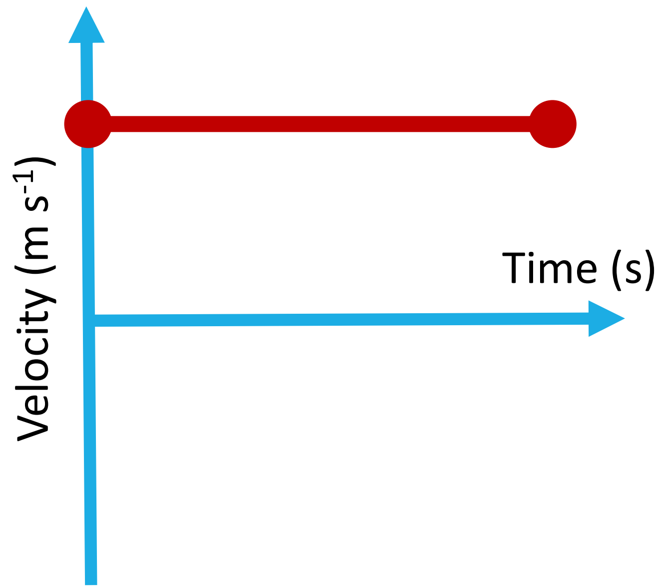
London Olympics 2012 | Usain Bolt's Gold in the 100 Meter Sprint | The New York Times

Constant Positive Velocity

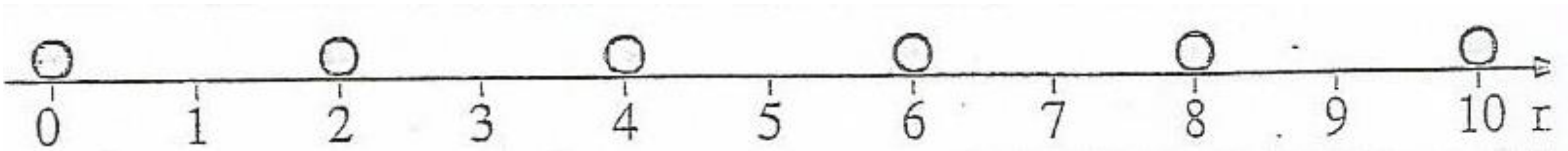


Changing position at a constant rate **forward**

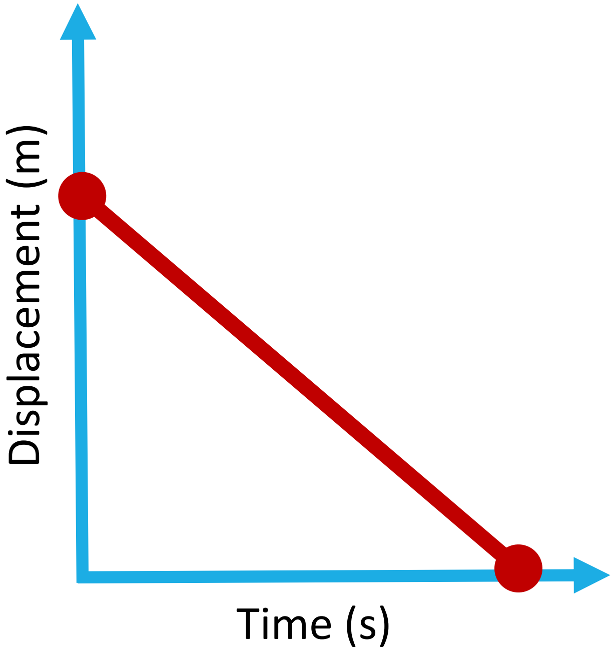


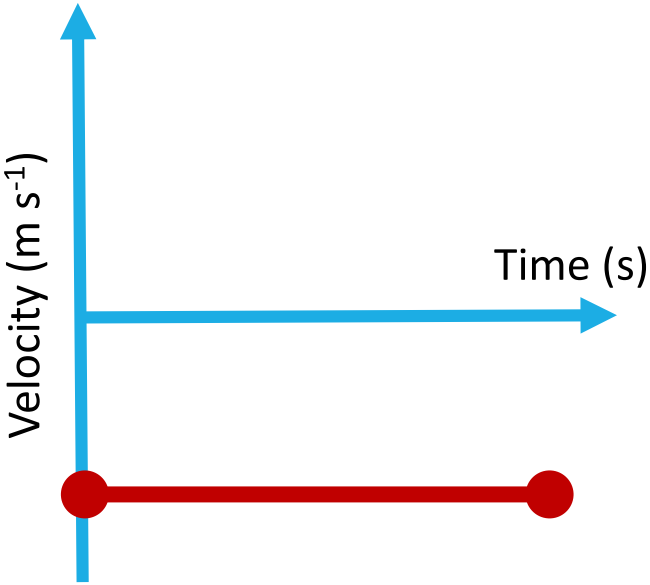


Constant Negative Velocity

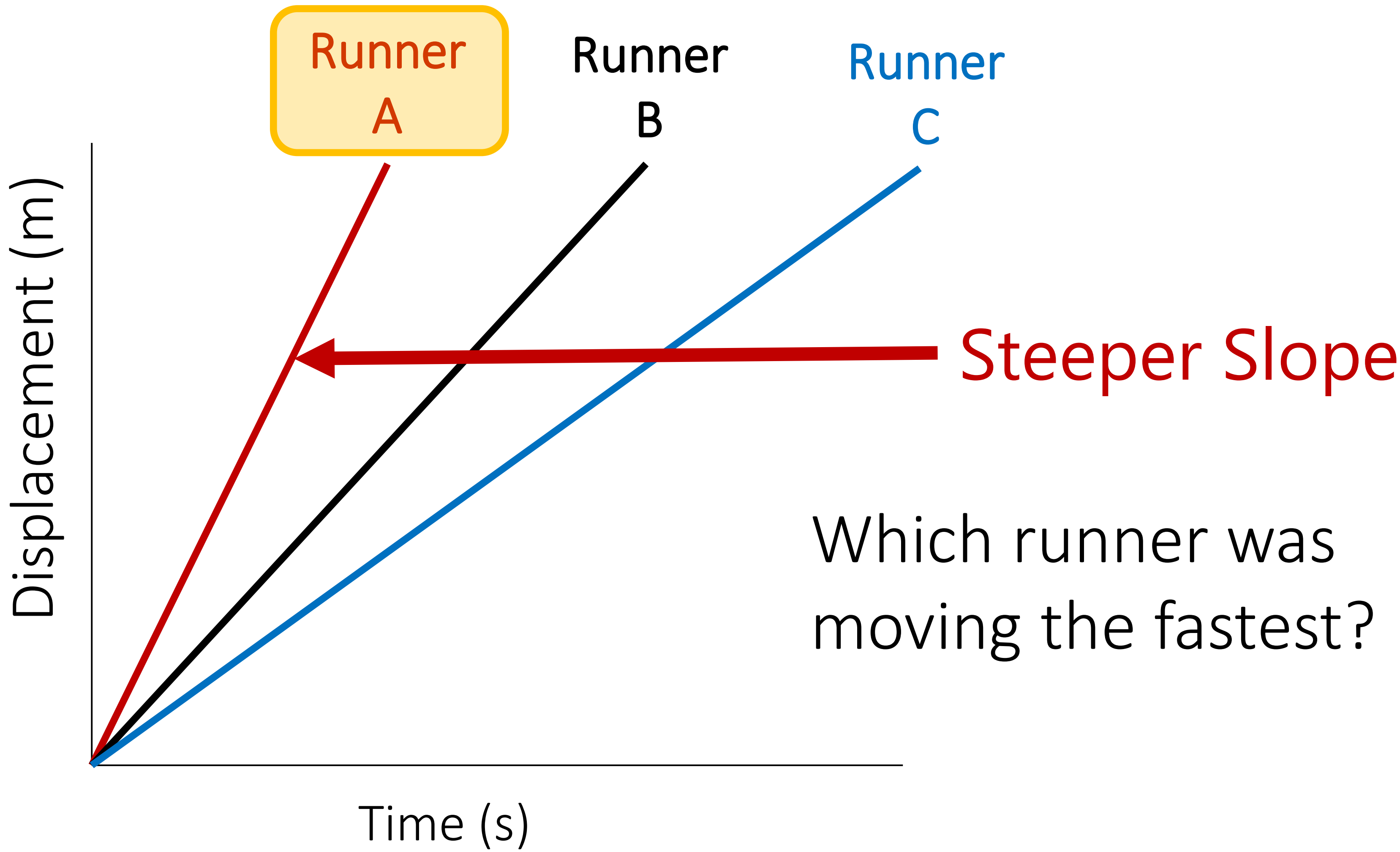


Changing position at a constant rate **backward**



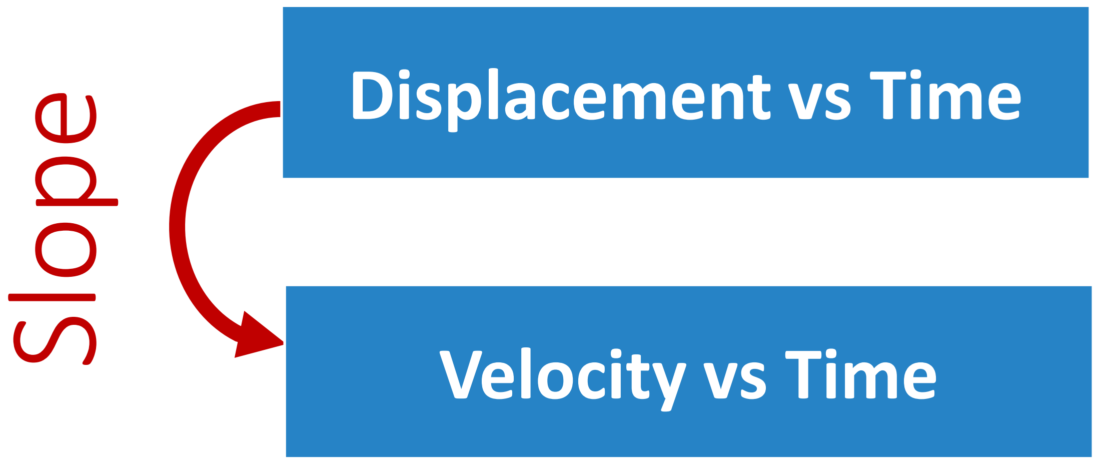


Plotting Displacement vs Time

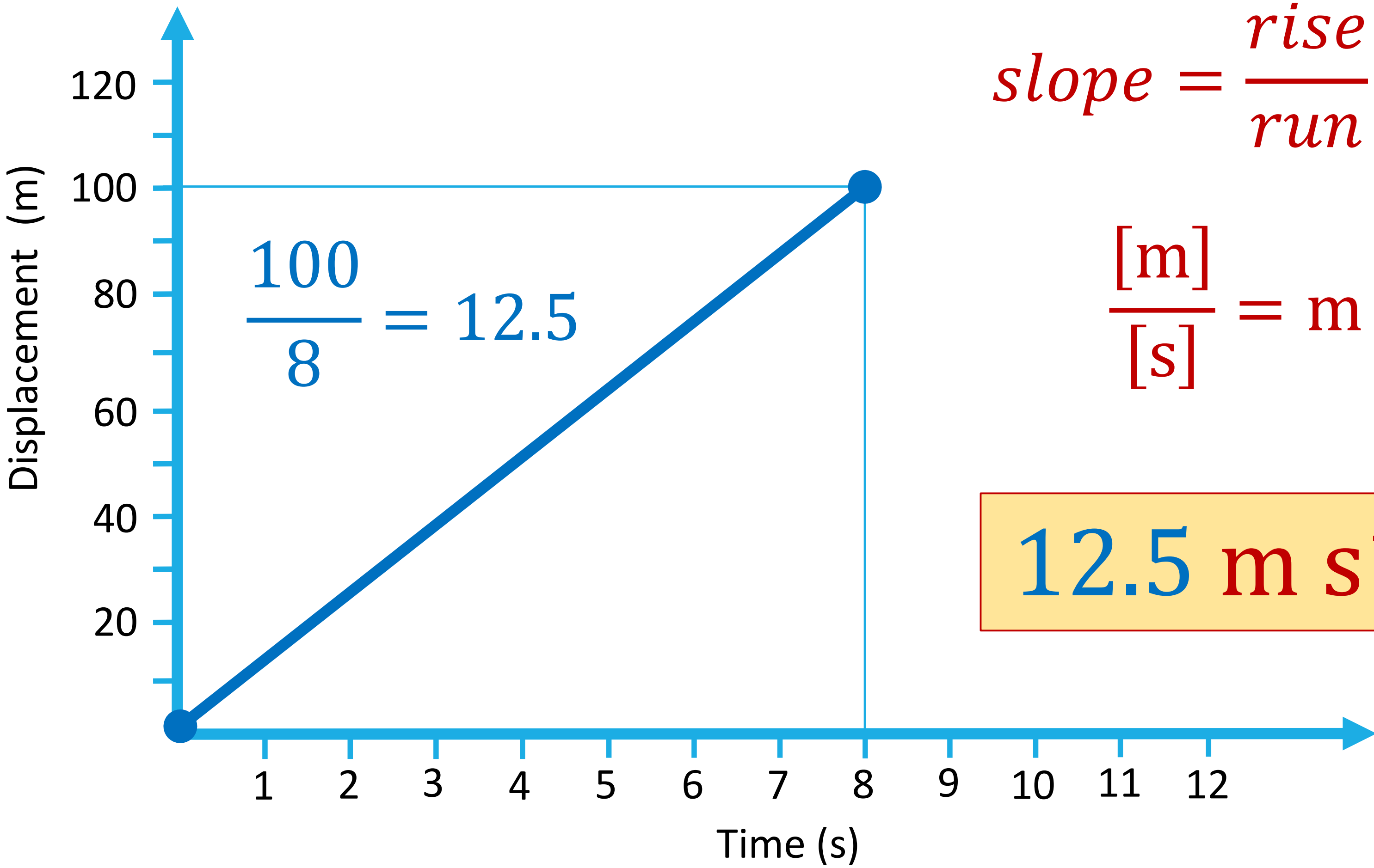


Which runner was moving the fastest?

The power of the slope!



What is the Average Velocity?



$$slope = \frac{rise}{run} = \frac{\Delta x}{\Delta y}$$

$$\frac{[\mathrm{m}]}{[\mathrm{s}]} = \mathrm{m\ s^{-1}}$$

$$12.5\ \mathrm{m\ s^{-1}}$$

2.2

Acceleration

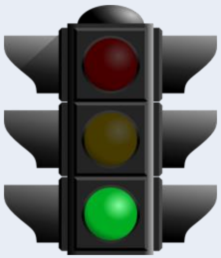
IB PHYSICS | UNIT 2 | MOTION

What is…

Velocity
change in **position** over time "speed *with direction*"
Acceleration
change in **velocity** over time

Types of Acceleration

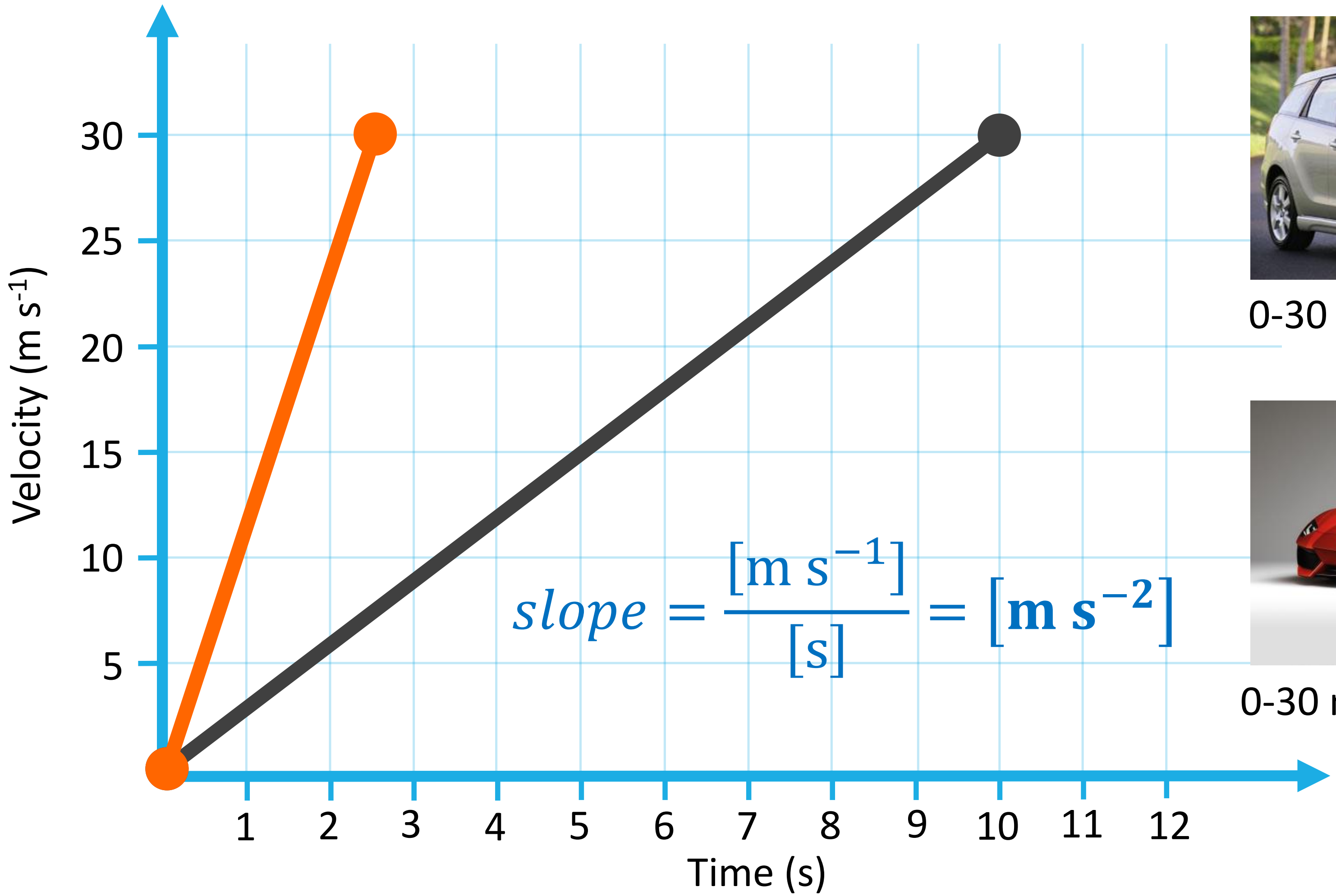
Speeding Up



Slowing Down

Changing Direction

Acceleration

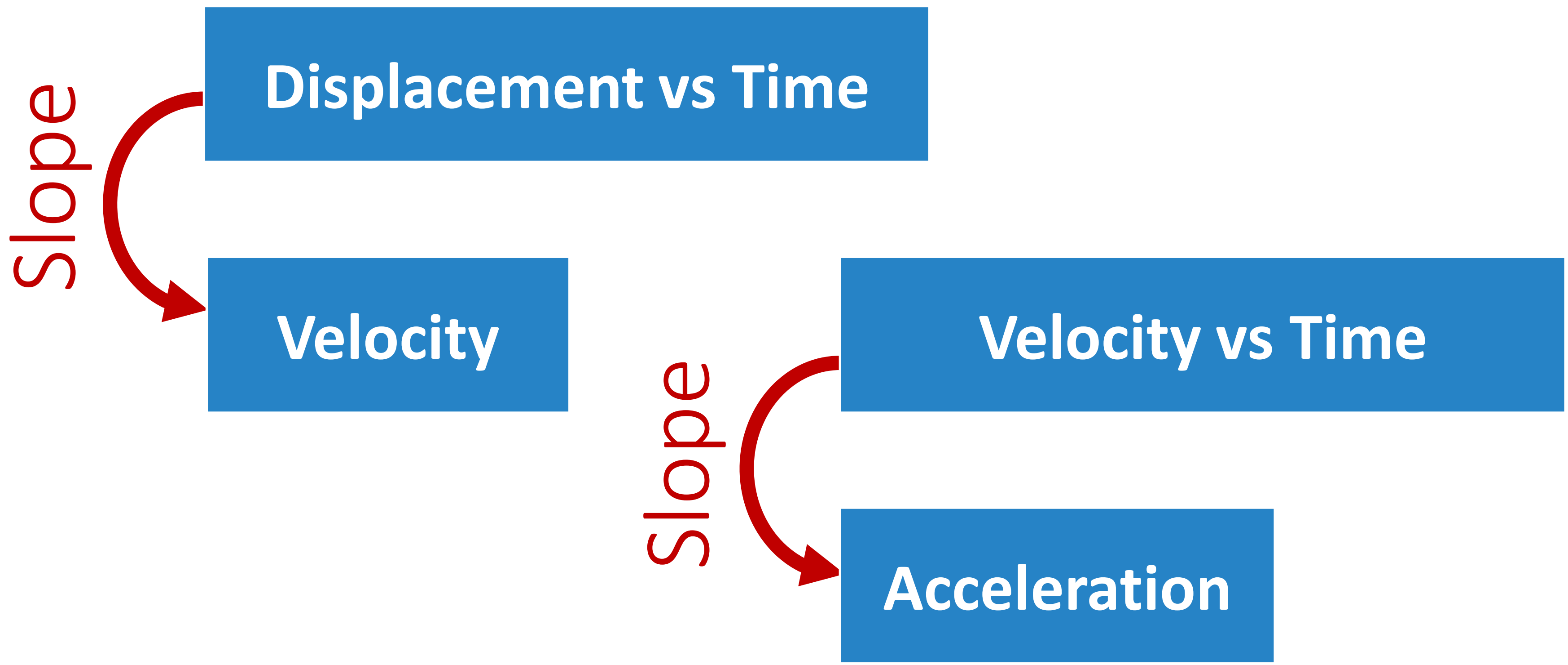


$$slope = \frac{[\mathrm{m\ s^{-1}}]}{[\mathrm{s}]} = [\mathbf{m\ s^{-2}}]$$

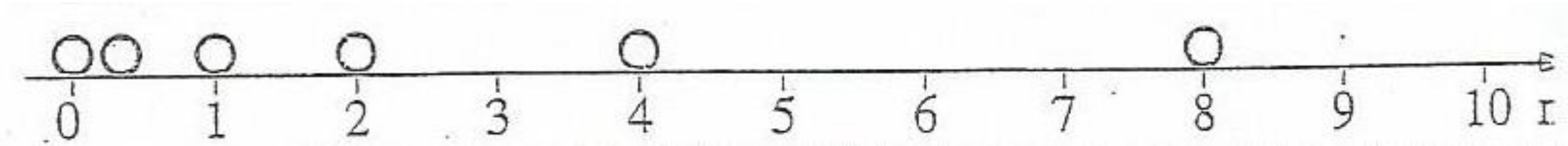
0-30 m s^{-1} in 10 seconds

0-30 m s^{-1} in 2.5 seconds

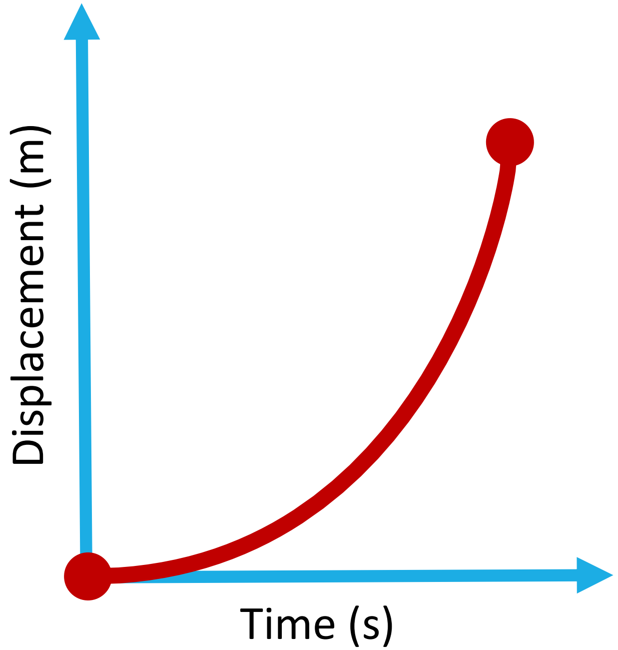
The power of the slope!

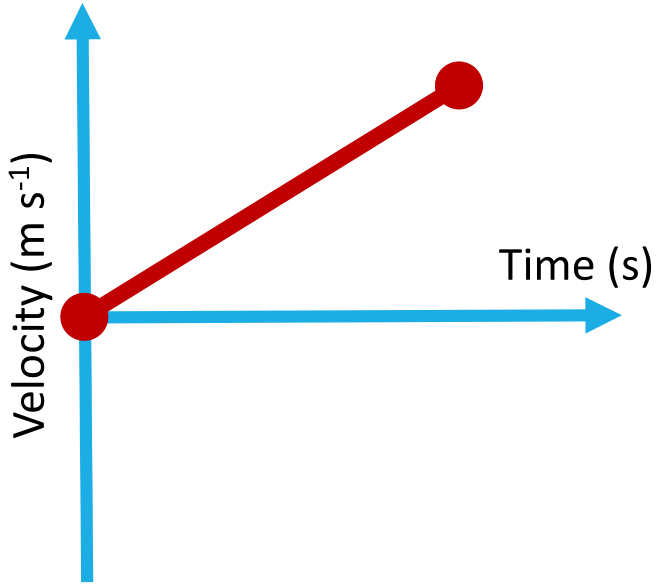


Constant Positive Acceleration

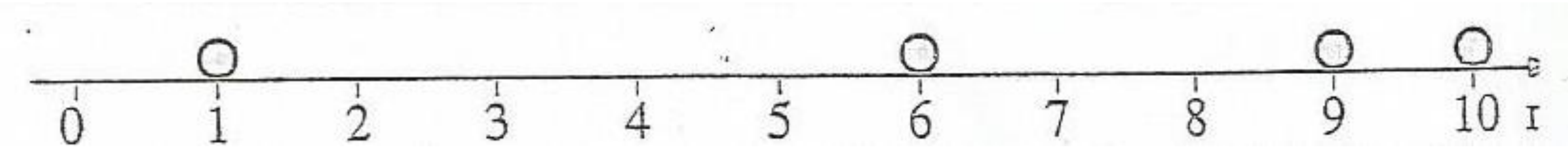


Changing velocity by **speeding up** at a constant rate

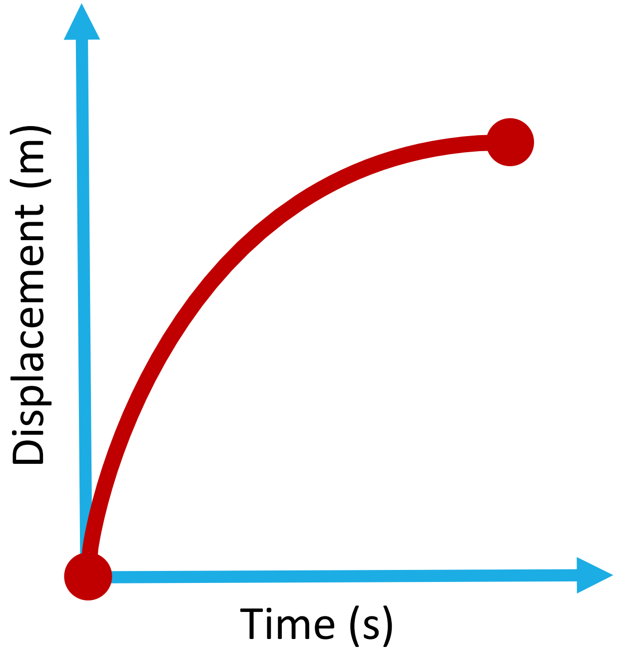


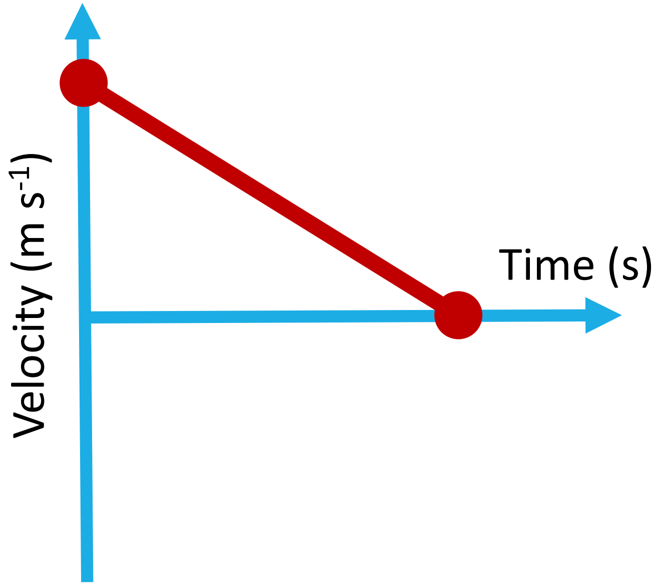


Constant Negative Acceleration



Changing velocity by **slowing down** at a constant rate





Motion Variables

Displacement	Initial Velocity	Final Velocity	Acceleration	Time
s	**u**	**v**	**a**	**t**

Whenever we are describing the motion of an accelerating object, there are five variables that we need to take into account

Note: The variables used in IB Physics vary slightly from other nomenclature standards

Calculating Acceleration

$$acceleration = \frac{final\ velocity - initial\ velocity}{change\ in\ time}$$

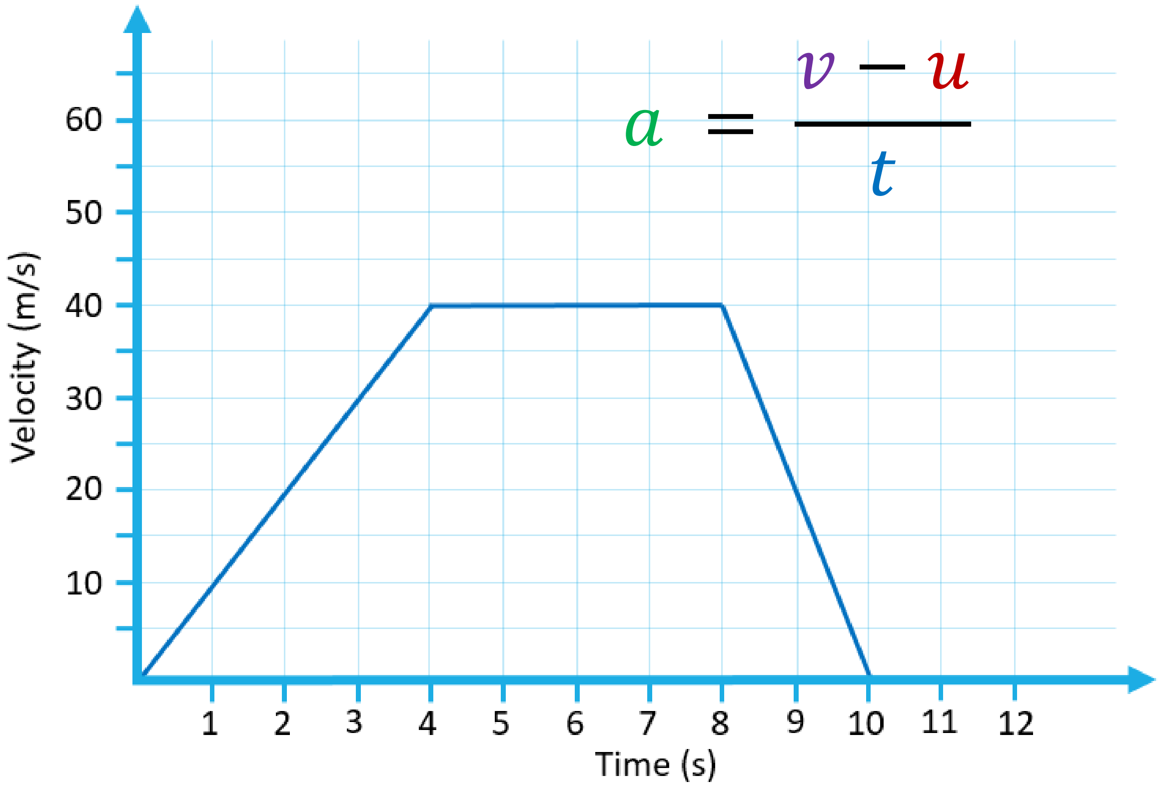
Symbols

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

Units

$$ms^{-2} = \frac{ms^{-1} - ms^{-1}}{s}$$

Think about this unit…



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

m/s/s

m/s^2

$m\ s^{-2}$

Try This | 1

What is the acceleration of a car that accelerates from 15 m s^{-1} to 35 m s^{-1} in 10 seconds?

u	15 ms^{-1}
v	35 ms^{-1}
a	?
t	10 s

$$a = \frac{v - u}{t} = \frac{35 - 15}{10}$$

$$\mathbf{a = 2\ ms^{-2}}$$

Try This | 2

Find the average acceleration of a northbound train that slows down from 12 m s^{-1} to a complete stop in 8 sec

**Tip: You <u>can</u> get a negative value!*

u	12 ms^{-1}
v	0 ms^{-1}
a	?
t	8 s

$$a = \frac{v-u}{t} = \frac{0-12}{8}$$

$$a = -\mathbf{1.5\ ms^{-2}}$$

Solve for v

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

$$v = u + at$$

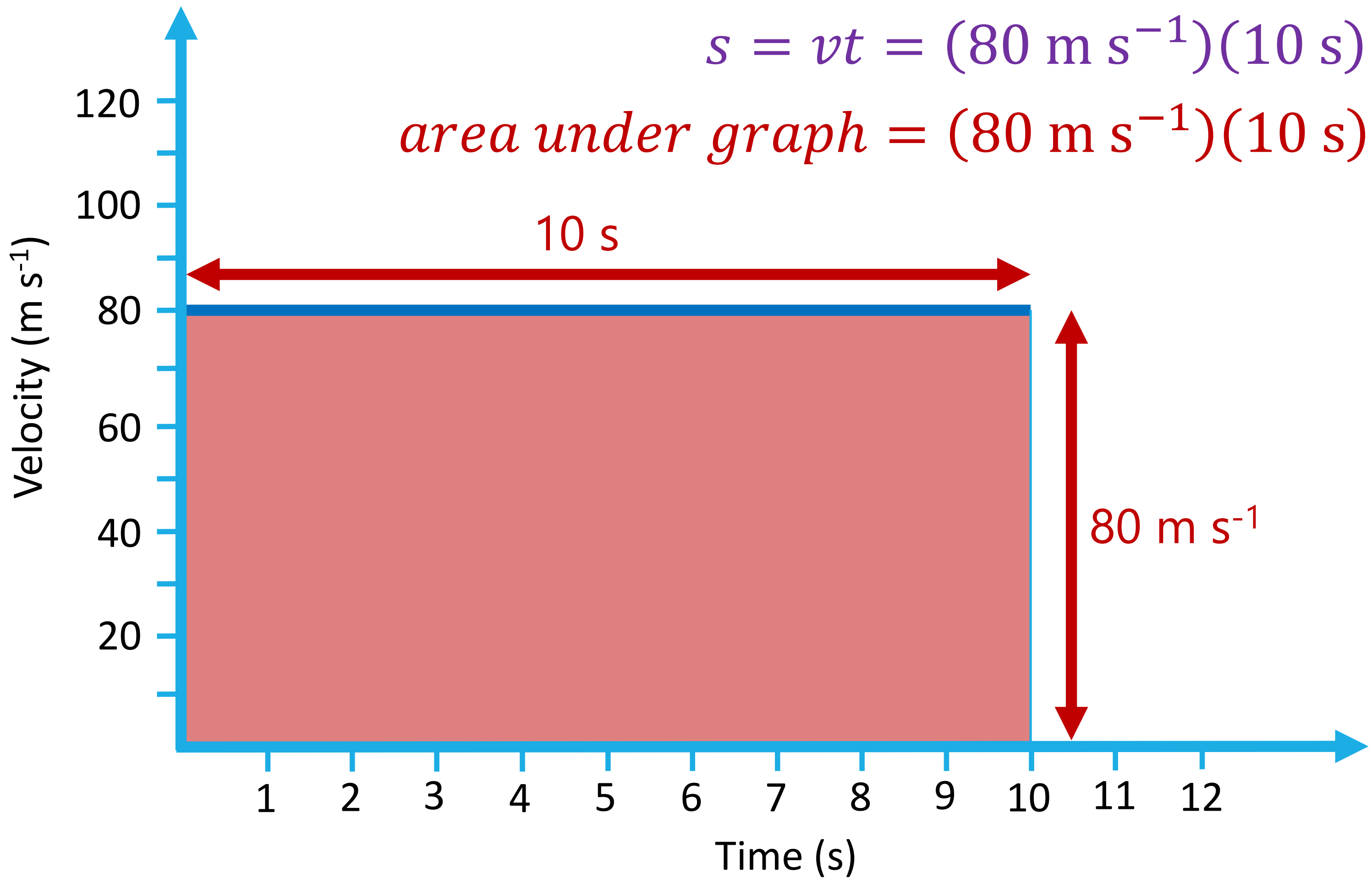
Physics Data Booklet

Sub-topic 2.1 – Motion
$v = u + at$
$s = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2as$
$s = \frac{(v + u)t}{2}$

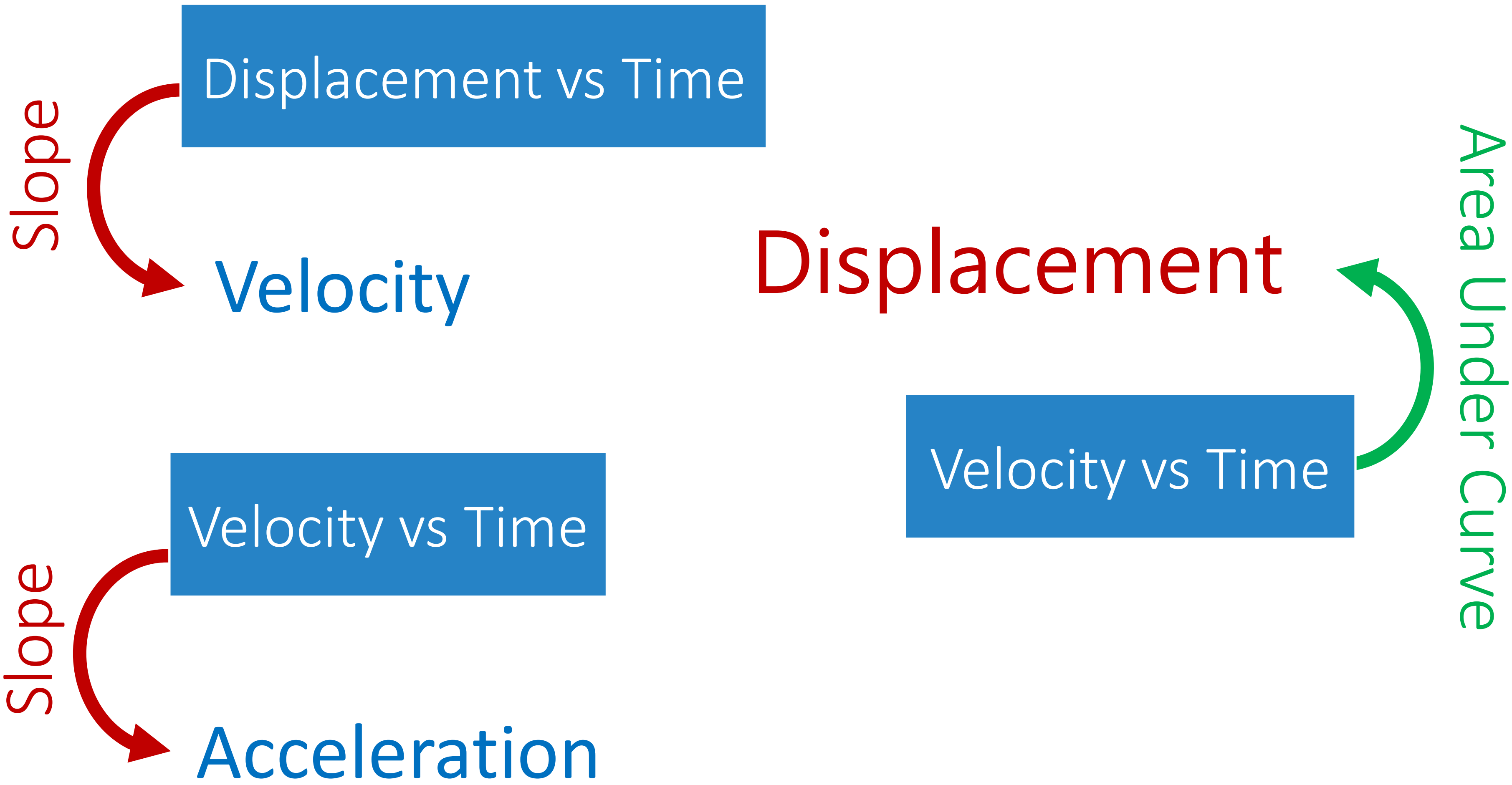
How far have I gone?

$$s = vt = (80\ \mathrm{m\ s^{-1}})(10\ \mathrm{s}) = 800\ \mathrm{m}$$

$$area\ under\ graph = (80\ \mathrm{m\ s^{-1}})(10\ \mathrm{s}) = 800\ \mathrm{m}$$

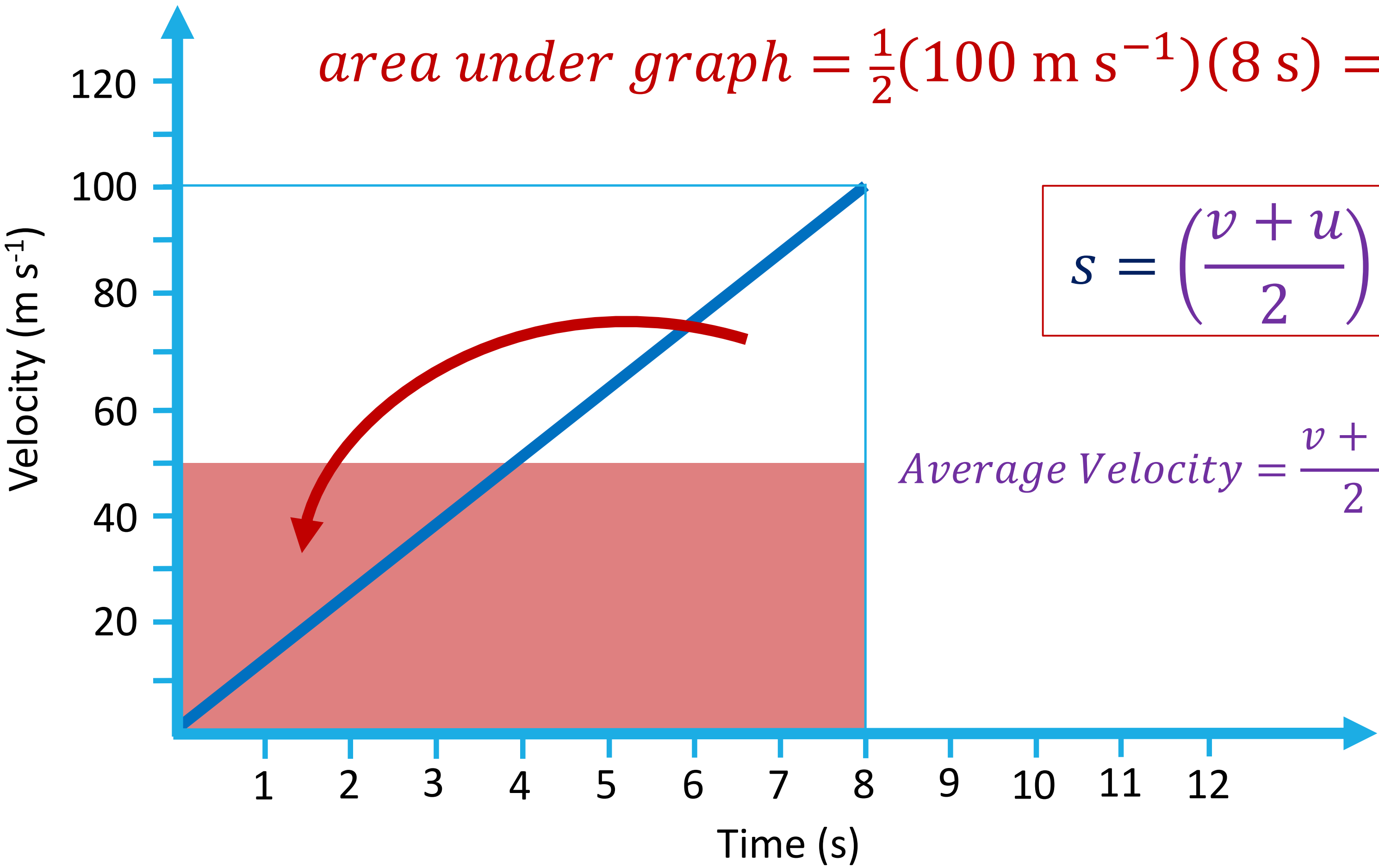


Use the graphs to tell you MORE!



How far have I gone?

$$area\ under\ graph = \frac{1}{2}(100\ \mathrm{m\ s^{-1}})(8\ \mathrm{s}) = 400\ \mathrm{m}$$



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

$$Average\ Velocity = \frac{v+u}{2}$$

Physics Data Booklet

Sub-topic 2.1 – Motion
$v = u + at$
$s = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2as$
$s = \frac{(v+u)t}{2}$

Try This | 3

You speed up with a uniform acceleration from 0 m/s to 30 m/s in 5 seconds. How far have you gone?

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

$$s = \frac{(30+0)(5)}{2} = \mathbf{75\ m}$$

s	?
u	0 m s^{-1}
v	30 m s^{-1}
a	-------
t	5 s

What if I don't know v?

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

$$v = u + at$$

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

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

Physics Data Booklet

Sub-topic 2.1 – Motion
$v = u + at$
$s = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2as$
$s = \frac{(v + u)t}{2}$

Try This | 4

If a plane on a runway is accelerating at 4.8 m s^{-2} for 15 seconds before taking off, how long should the runway be?

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

$$= (0)(15) + \frac{1}{2}(4.8)(15)^2$$

$$s = 540\ \text{m}$$

s	?
u	0 m s^{-1}
v	--------
a	4.8 m s^{-2}
t	15 s

One more equation

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

Equations

Units	m	$m\ s^{-1}$	$m\ s^{-1}$	$m\ s^{-2}$	s
$v = u + at$		u	v	a	t
$s = ut + \frac{1}{2}at^2$	s	u		a	t
$v^2 = u^2 + 2as$	s	u	v	a	
$s = \frac{(v+u)t}{2}$	s	u	v		t

Try This | 5

A driver slams on the brakes and skids for 3 seconds before coming to a stop. You go and measure that the skid marks show a deceleration over 9 m. What was the initial speed of the car?

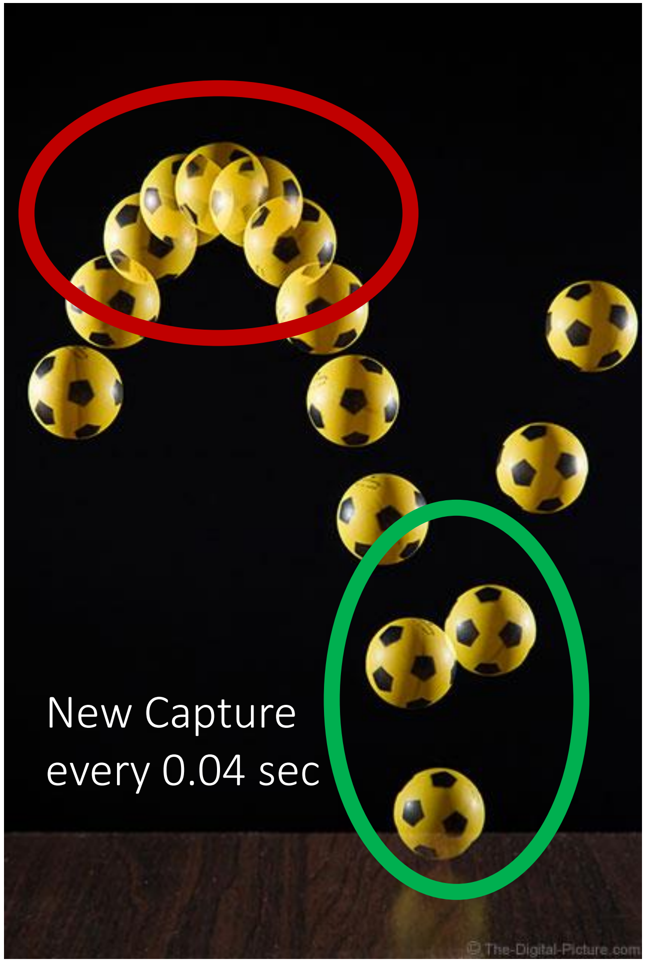
$$s = \frac{(v+u)t}{2}$$

$$u = \frac{2s}{t} - v = \frac{2(9)}{(3)} - 0$$

$$u = 6 \text{ m s}^{-1}$$

s	9 m
u	?
v	0 m s^{-1}
a	---
t	3 s

Stroboscopic Photographs

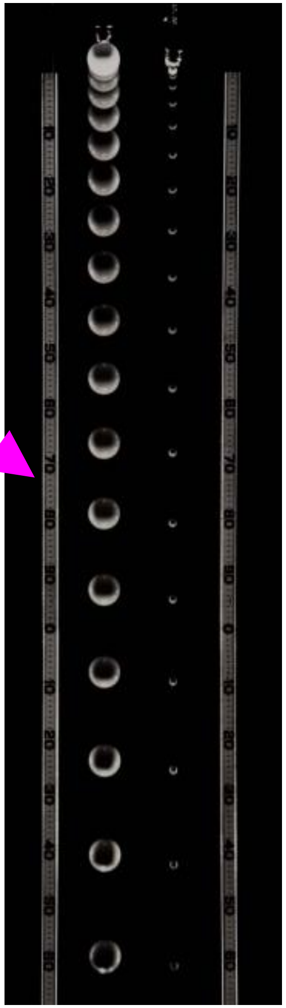


In a stroboscopic photograph, a new snapshot is captured every ___ seconds and combined to show the motion over a period of time.

Circle the part of the motion where this soccer ball is moving the FASTEST

Circle the part of the motion where this soccer ball is moving the SLOWEST

Stroboscopic Photographs

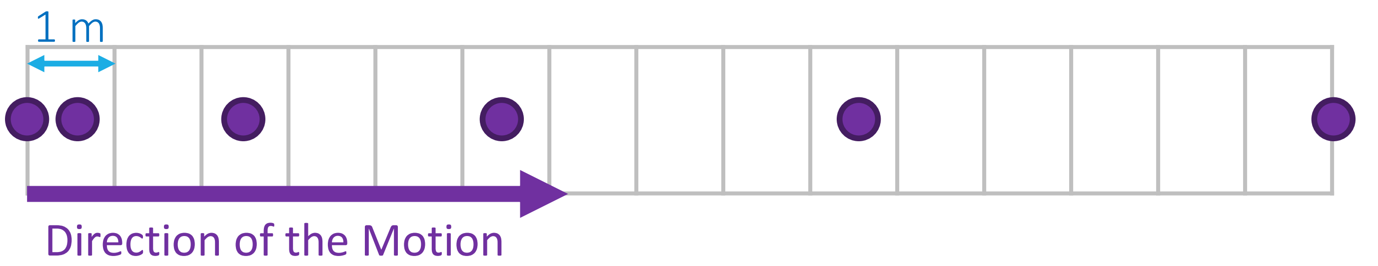


Constant Velocity or Accelerating?

How do you know?

More spacing between pictures = moving faster

Constant Acceleration



Time (s)	Displacement (m)
0 s	0.0 m
1 s	0.6 m
2 s	2.4 m
3 s	5.4 m
4 s	9.6 m
5 s	15 m

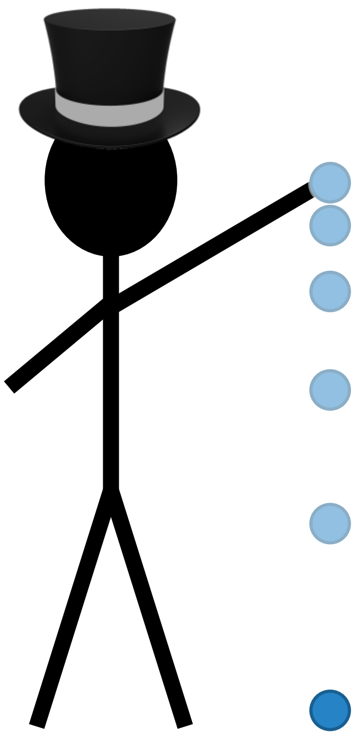
$$s = ut + \frac{1}{2}at^2$$

$$15 = (0)(5) + \frac{1}{2}a(5)^2$$

$$a = 1.2 \text{ m}$$

s	15 m
u	0 m s^{-1}
v	---
a	?
t	5 s

2.3



Freefall

IB PHYSICS | UNIT 2 | MOTION

Warm Up

A car traveling in a straight line has a velocity of +4.8 m s^{-1}. After an acceleration of 0.65 m s^{-2}, the car's velocity is +9.9 m s^{-1}. Over what time interval did the acceleration occur?

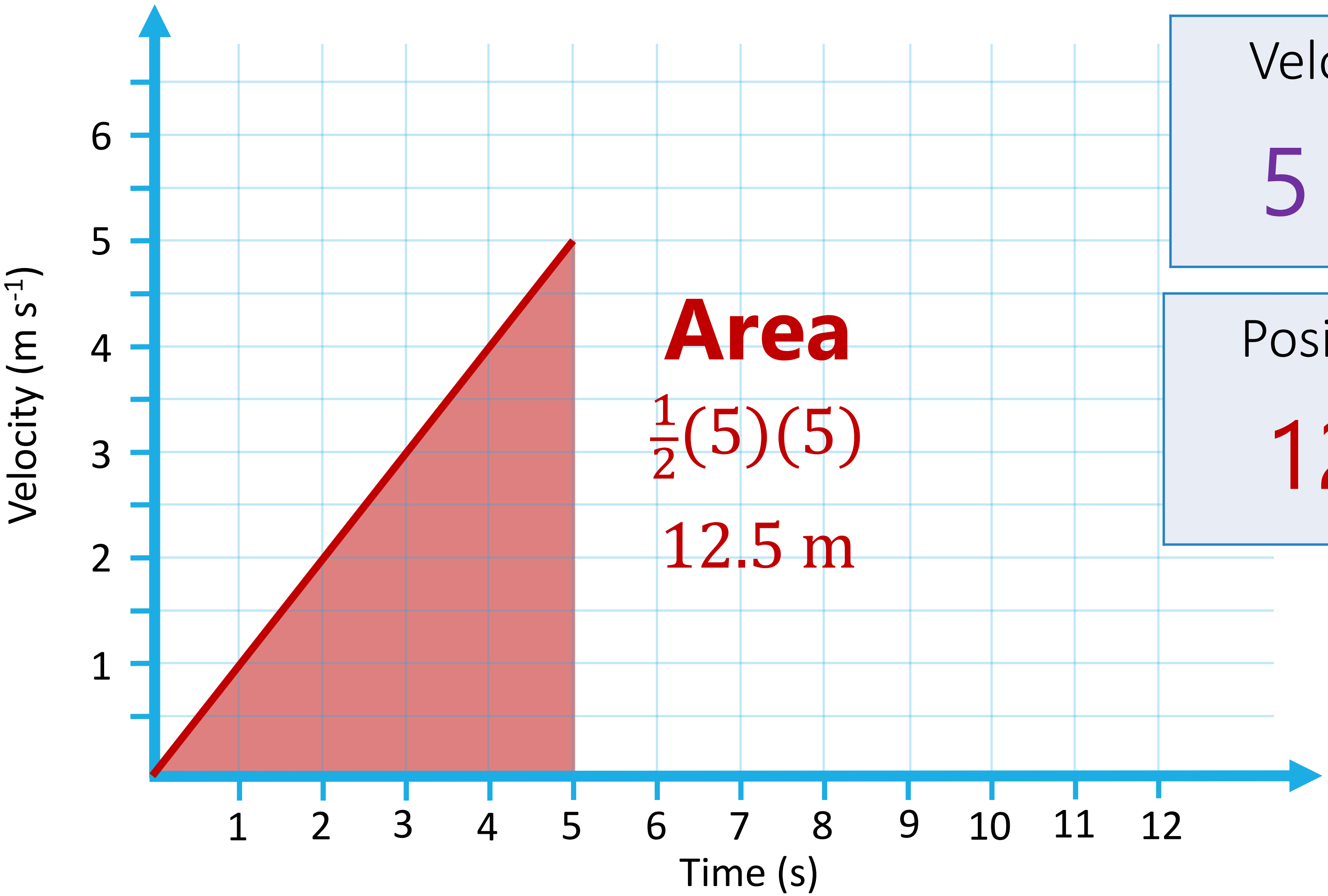
$$v = u + at$$

$$9.9 = 4.8 + (0.65)t$$

$$t = 7.85 \text{ s}$$

s	---
u	4.8 m s^{-1}
v	9.9 m s^{-1}
a	0.65 m s^{-2}
t	?

Warm Up



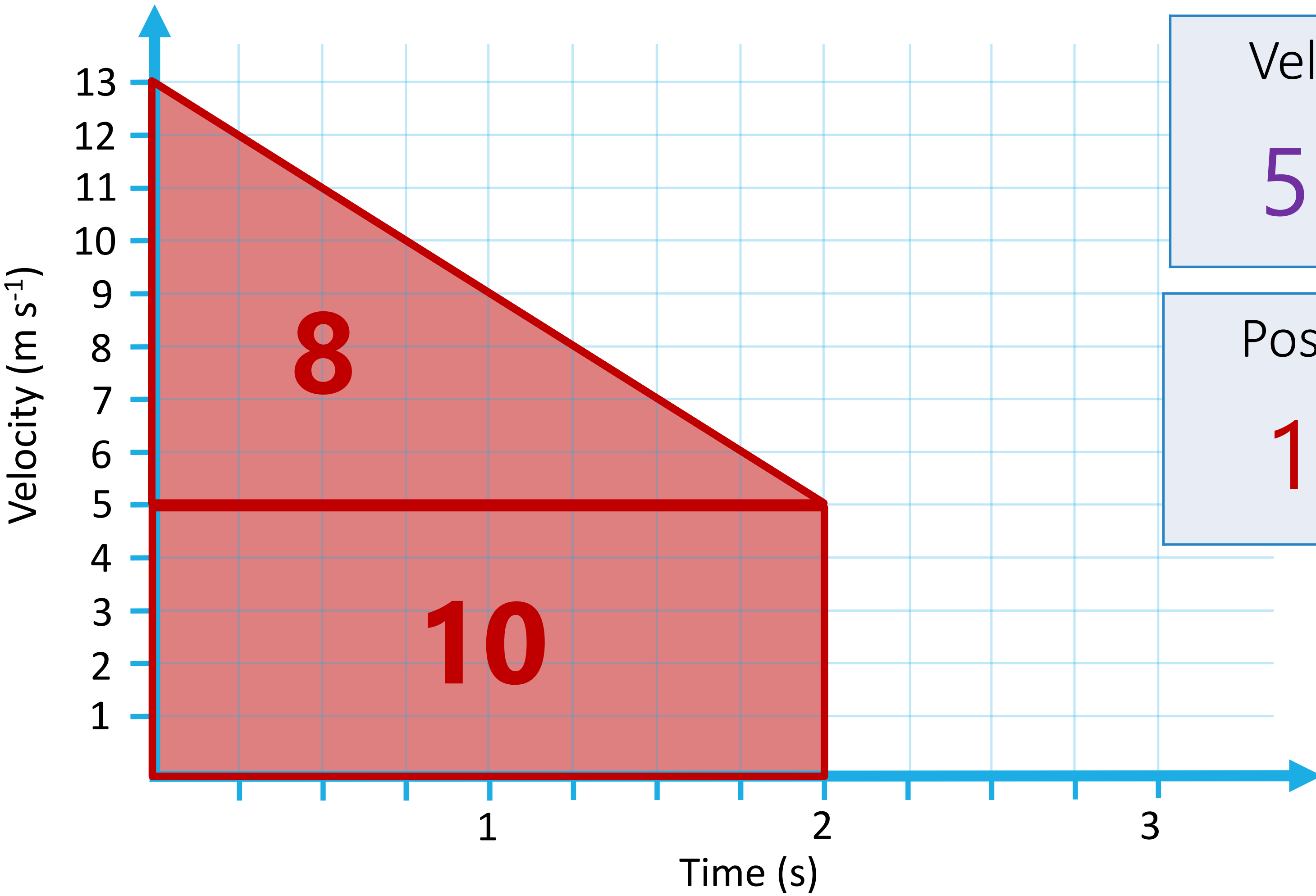
Velocity at 5 s

5 m s^{-1}

Position at 5 s

12.5 m

Warm Up



Velocity at 2 s

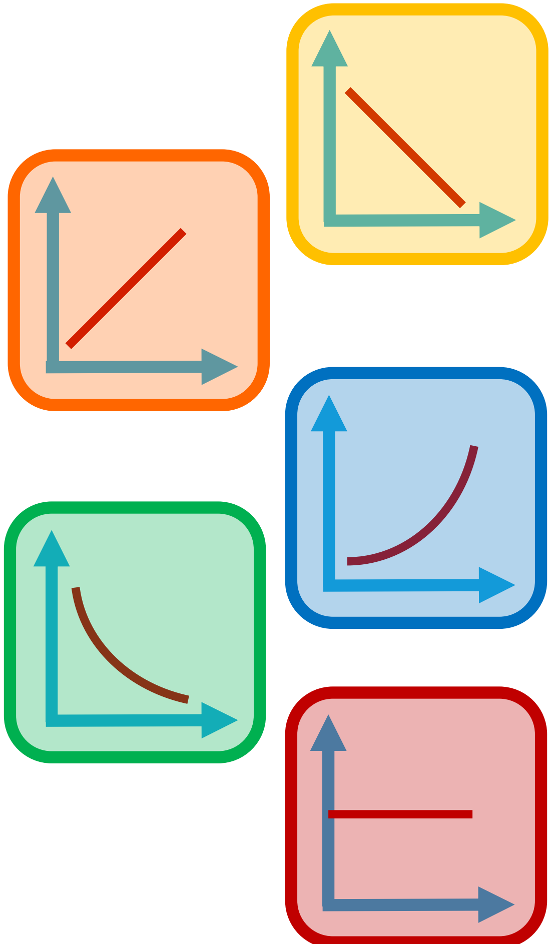
5 m s^{-1}

Position at 2 s

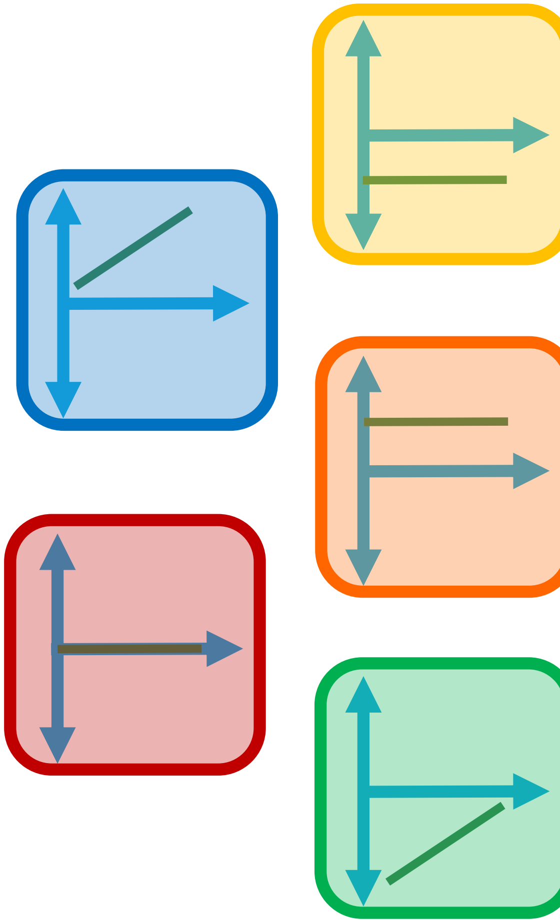
12.5 m

Warm Up – Match these Graphs!

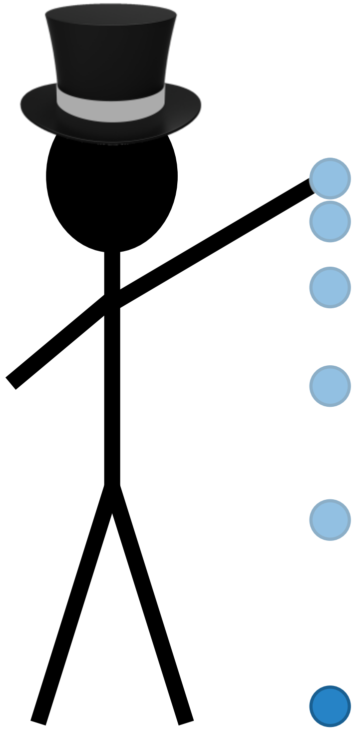
Displacement vs Time



Velocity vs Time



What is Free Fall?



The only force acting on the object is gravity

No Air Resistance

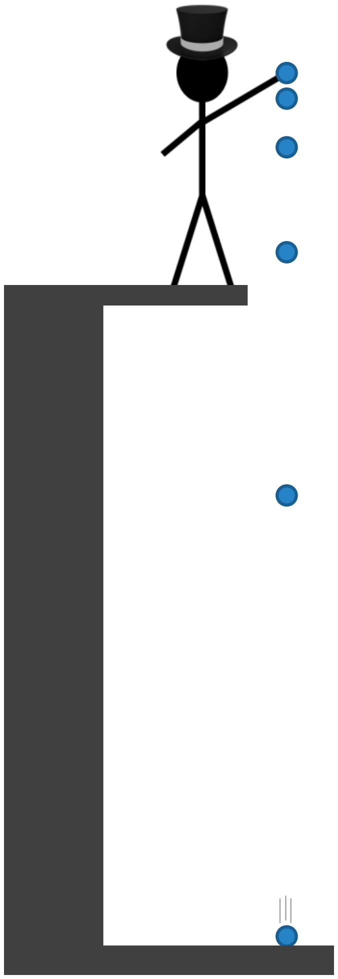
Acceleration due to Gravity

$-9.81\ m\ s^{-2}$

negative

Remember Direction!

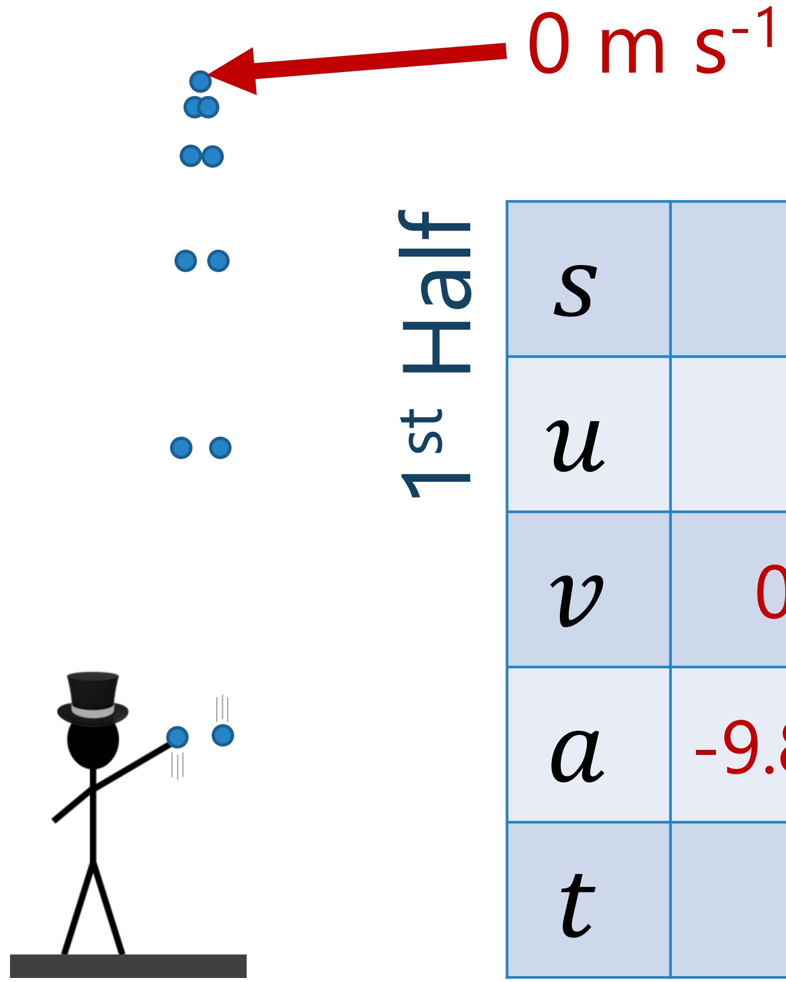
What if you drop something?



What do you know?

s	
u	0 m s^{-1}
v	
a	-9.81 m s^{-2}
t	

What if you throw something up?



What do you know?

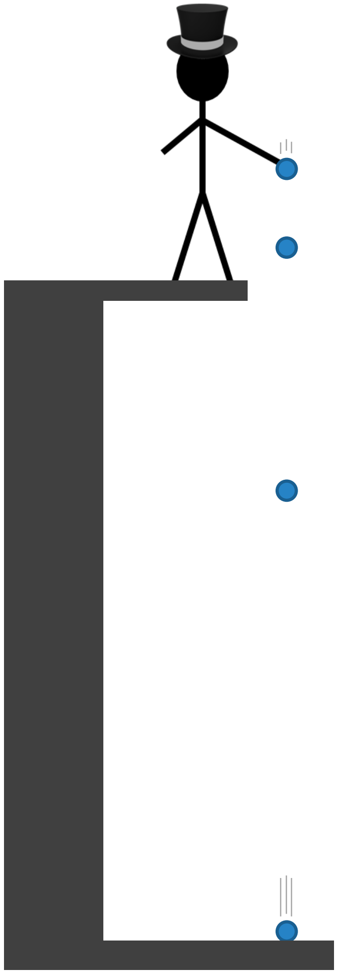
1st Half

s	
u	
v	$0\ m\ s^{-1}$
a	$-9.81\ m\ s^{-2}$
t	

2nd Half

s	
u	$0\ m\ s^{-1}$
v	
a	$-9.81\ m\ s^{-2}$
t	

What if you throw something down?



What do you know?

s	
u	
v	
a	-9.81 m s^{-2}
t	

Reminder of our Equations

Units	m	$m\,s^{-1}$	$m\,s^{-1}$	$m\,s^{-2}$	s
$v = u + at$		u	v	a	t
$s = ut + \frac{1}{2}at^2$	s	u		a	t
$v^2 = u^2 + 2as$	s	u	v	a	
$s = \frac{(v+u)t}{2}$	s	u	v		t

Dropping a marble

If you drop a marble off of the Empire State Building (~380 m), how fast will it be going once it reaches the ground?

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

$$v = \sqrt{0^2 + 2(-9.81)(-380)}$$

$$v = -86.3\ \mathrm{m\ s^{-1}}$$

*The negative indicates a downward direction

s	-380 m
u	0 m s^{-1}
v	?
a	-9.81 m s^{-2}
t	---

Shooting a Basket

What is the vertical velocity of a basketball required to reach the rim of the basketball hoop? (~3.0 m high)

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

$$0^2 = u^2 + 2(-9.81)(3)$$

$$u = 7.67 \text{ m s}^{-1}$$

s	3 m
u	?
v	0 m s^{-1}
a	-9.81 m s^{-2}
t	---

Flipping a Coin

You flip a coin and catch it. It is in the air for a total of 0.6 seconds. How high did it go?

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

$$s = \frac{1}{2}(-9.81)(0.3)^2$$

$$s = 0.441\ \text{m}$$

s	?
u	0 m s^{-1}
v	---
a	-9.81 m s^{-2}
t	0.3 s

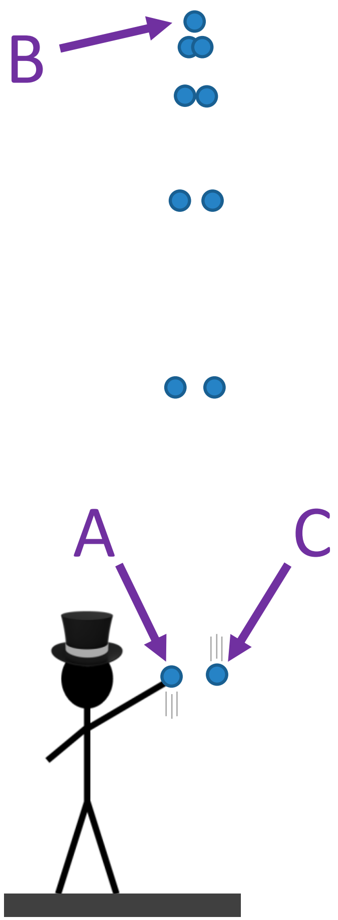
Half the time

2.4

Graphing Motion

IB PHYSICS | UNIT 2 | MOTION

Warm Up



A

Velocity	$+5\ m\ s^{-1}$
Acceleration	$-9.81\ m\ s^{-2}$

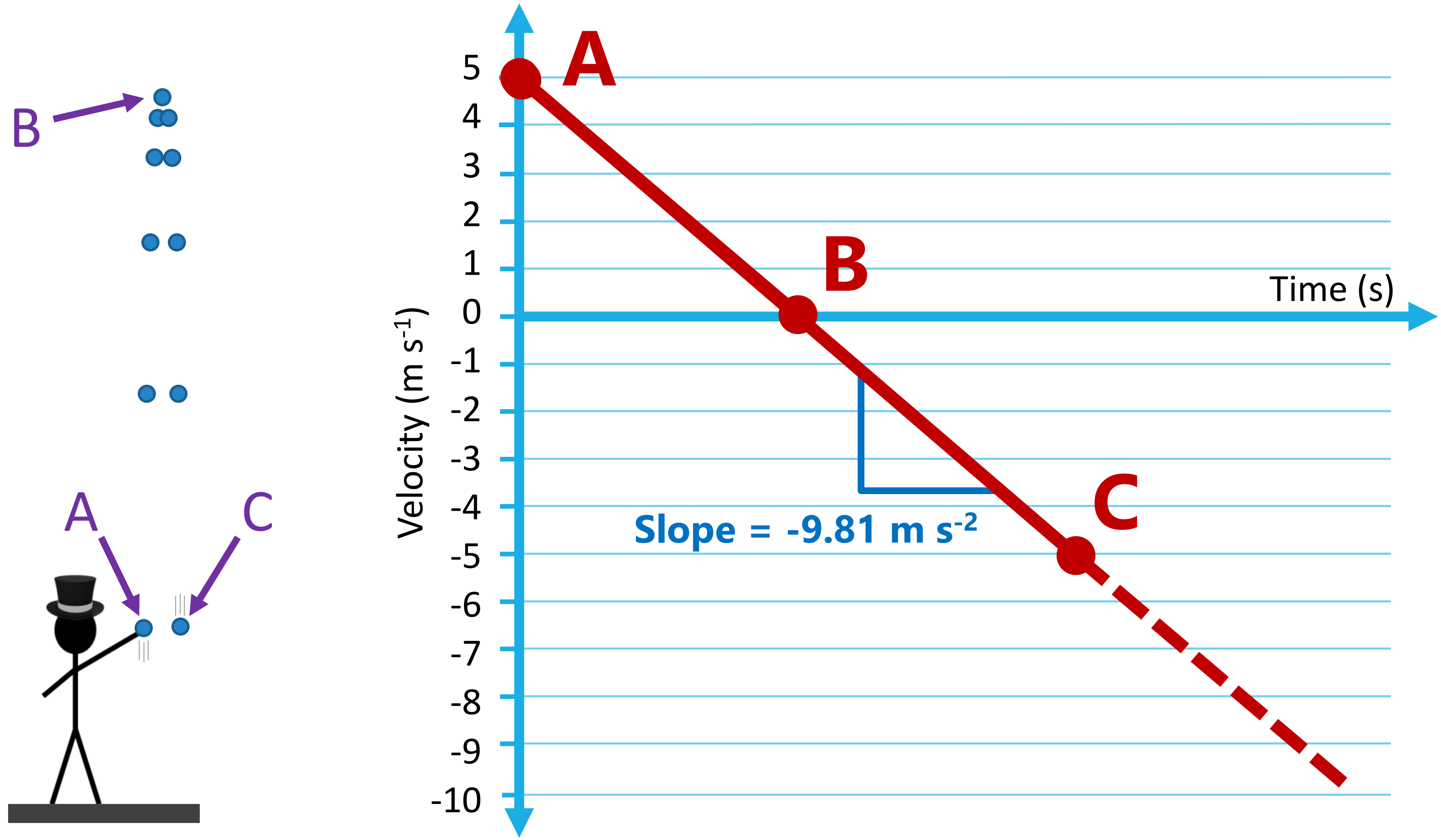
B

Velocity	$0\ m\ s^{-1}$
Acceleration	$-9.81\ m\ s^{-2}$

C

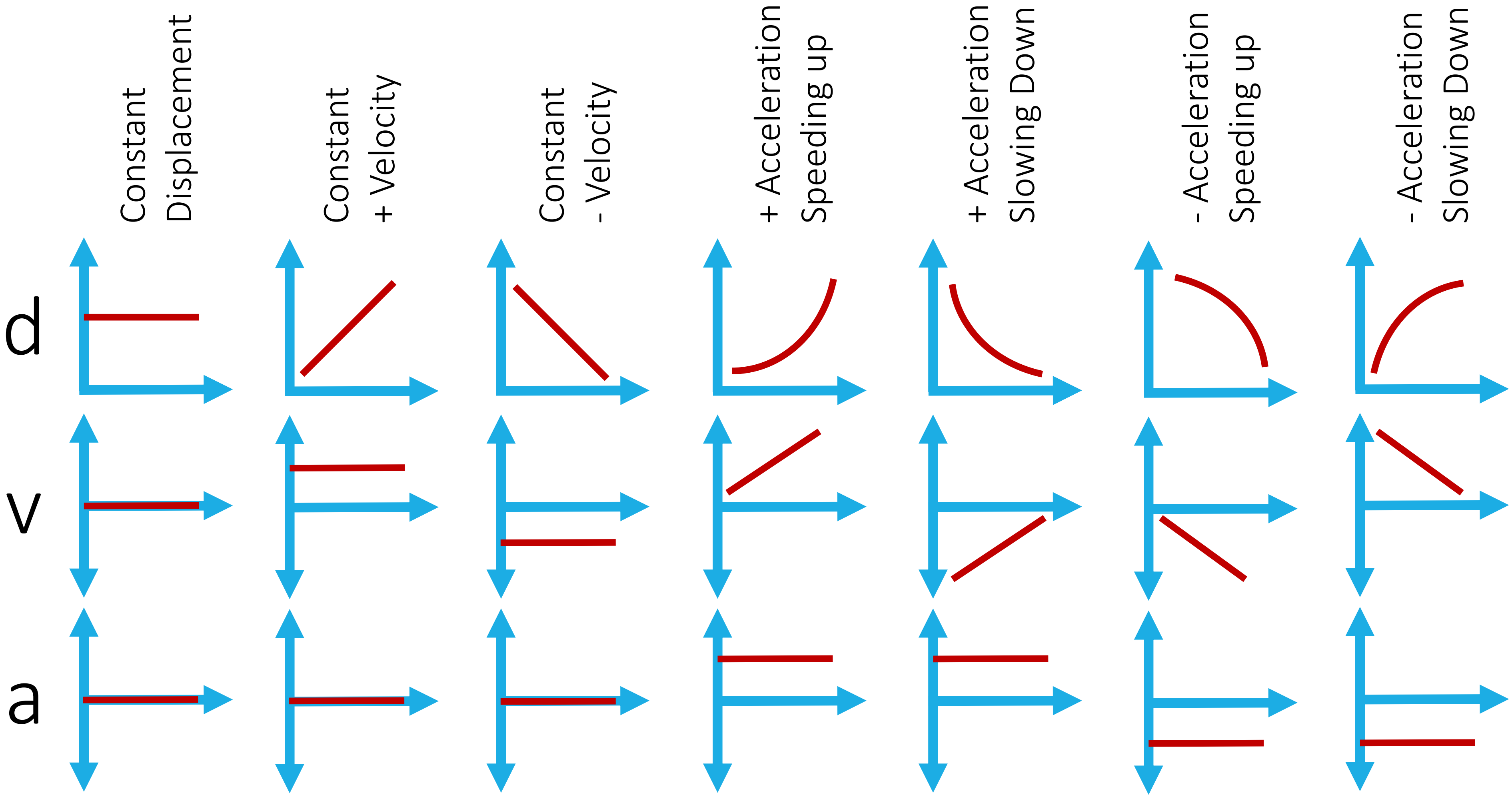
Velocity	$-5\ m\ s^{-1}$
Acceleration	$-9.81\ m\ s^{-2}$

Warm Up



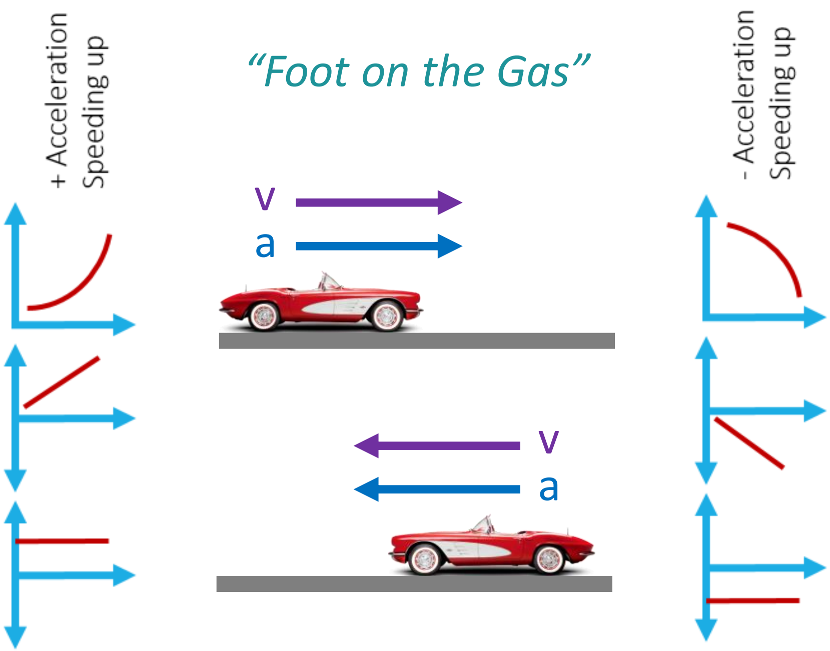
B
A
C
A
B
C
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Velocity (m s-1)
Time (s)
Slope = -9.81 m s-2

Motion Graphs Guide

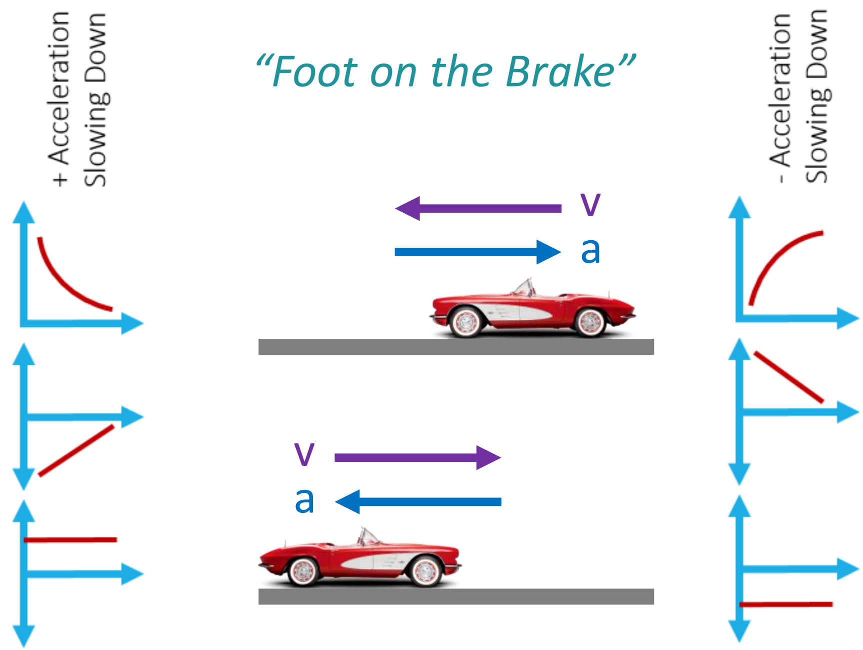


Acceleration | Slowing or Speeding?

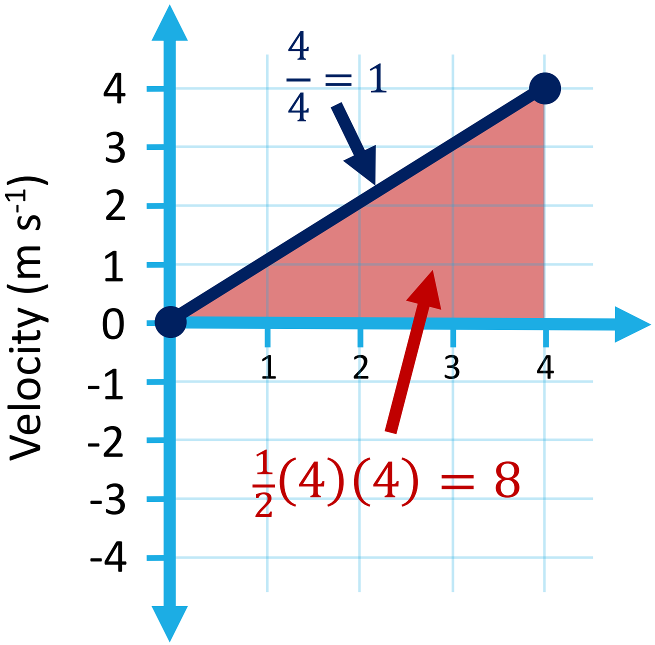
When the acceleration is in the **same** direction as the velocity the object is speeding up



When the acceleration is in the **opposite** direction as the velocity the object is slowing down



Information from a V vs T graph



What is the velocity at 4 seconds?

$4\ m\ s^{-1}$

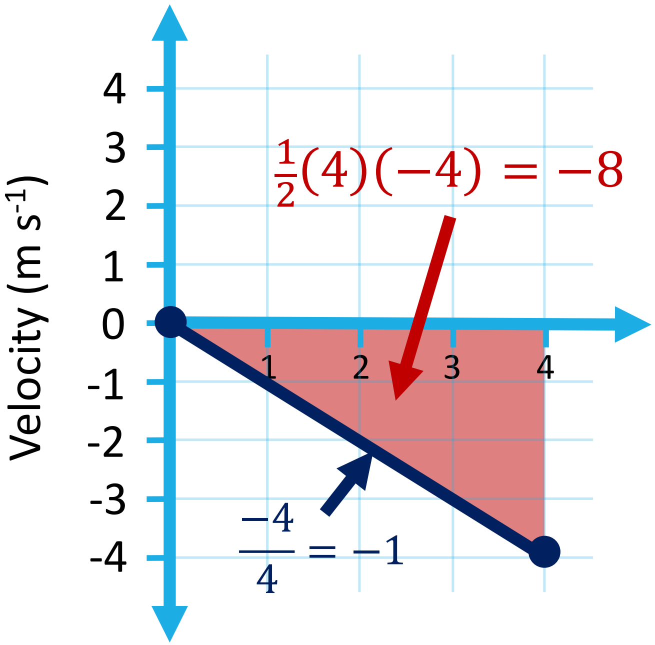
What is the acceleration from 1 s – 4 s?

Slope = $1\ m\ s^{-2}$

What is the displacement after 4 s?

Area = 8 m

Information from a V vs T graph



What is the velocity at 4 seconds?

-4 m s^{-1}

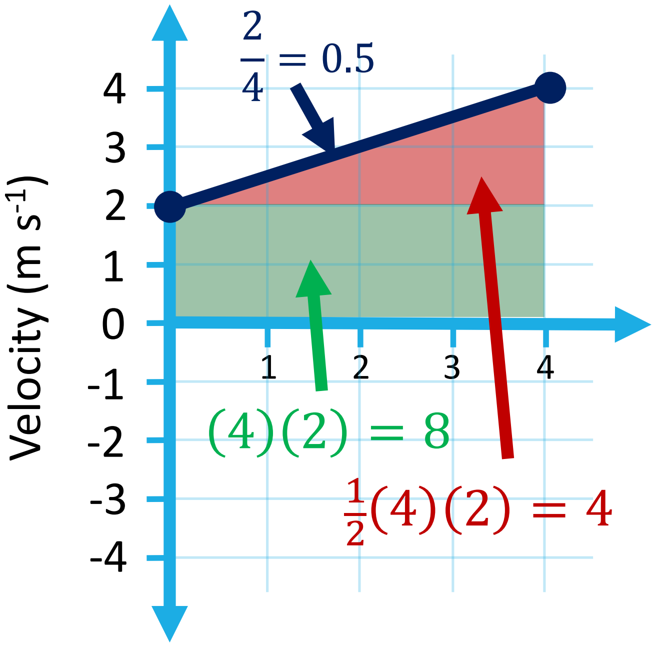
What is the acceleration from 0 s – 4 s?

Slope = -1 m s^{-2}

What is the displacement after 4 s?

Area = -8 m

Information from a V vs T graph



What is the velocity at 4 seconds?

4 m s^{-1}

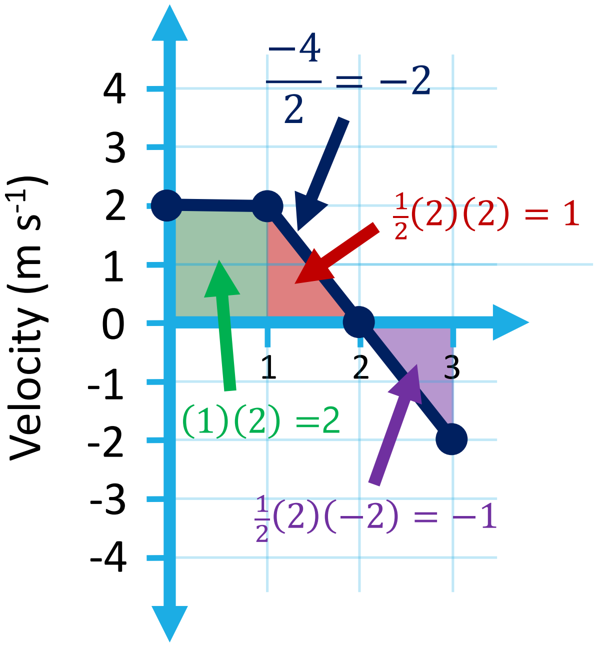
What is the acceleration from 0 s – 4 s?

Slope = 0.5 m s^{-2}

What is the displacement after 4 s?

Area = 12 m

Information from a V vs T graph



What is the velocity at 3 seconds?

$-2\ \text{m s}^{-1}$

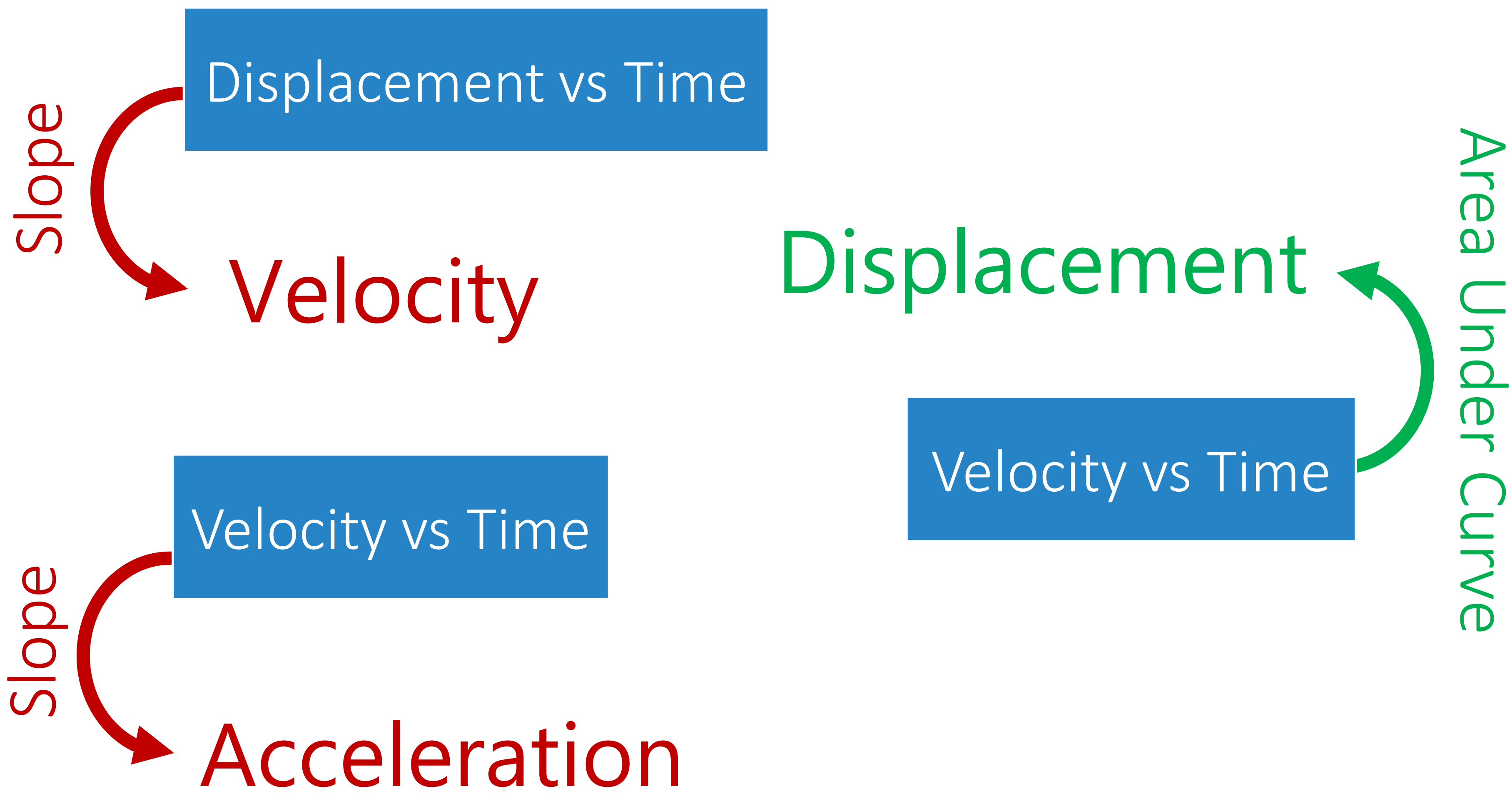
What is the acceleration from 1 s – 3 s?

Slope = $-2\ \text{m s}^{-2}$

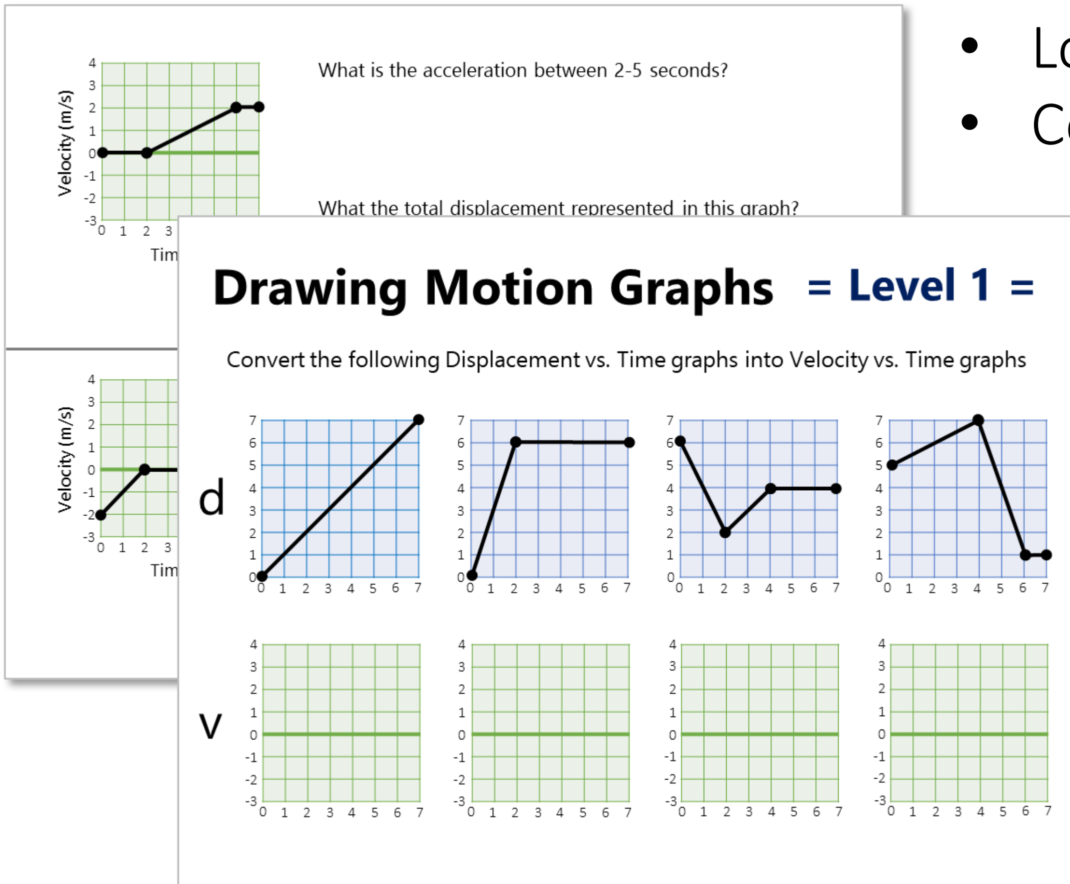
What is the displacement after 3 s?

Area = 2 m

Use the graphs to tell you MORE!



Time to Practice…



- Lots of examples posted
- Complete the missing graphs
  - Check answers with the KEY
  - Make sure you try at least one per page because they get increasingly more difficult

2.5

Horizontal Projectiles

IB PHYSICS | UNIT 2 | MOTION

Reminder of our Equations

Units	m	$m\,s^{-1}$	$m\,s^{-1}$	$m\,s^{-2}$	s
$v = u + at$		u	v	a	t
$s = ut + \frac{1}{2}at^2$	s	u		a	t
$v^2 = u^2 + 2as$	s	u	v	a	
$s = \frac{(v+u)t}{2}$	s	u	v		t

Dropping the Ball

How much time will it take this ball to hit the ground when dropped? The impact velocity?

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

$$-25 = \frac{1}{2}(-9.81)t^2$$

$$t = 2.26\ \mathrm{s}$$

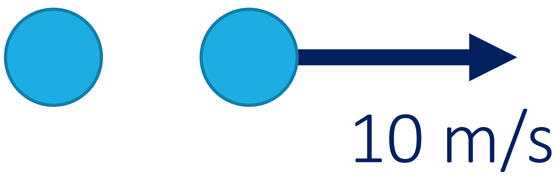
$$v^2 = \cancel{u^2} + 2as$$

$$v = \sqrt{2as} = \sqrt{2(-9.81)(-25)}$$

$$v = -22.2\ \mathrm{m\ s^{-1}}$$

s	-25 m
u	0 m s^{-1}
v	?
a	-9.81 m s^{-2}
t	?

Air Time - Comparison



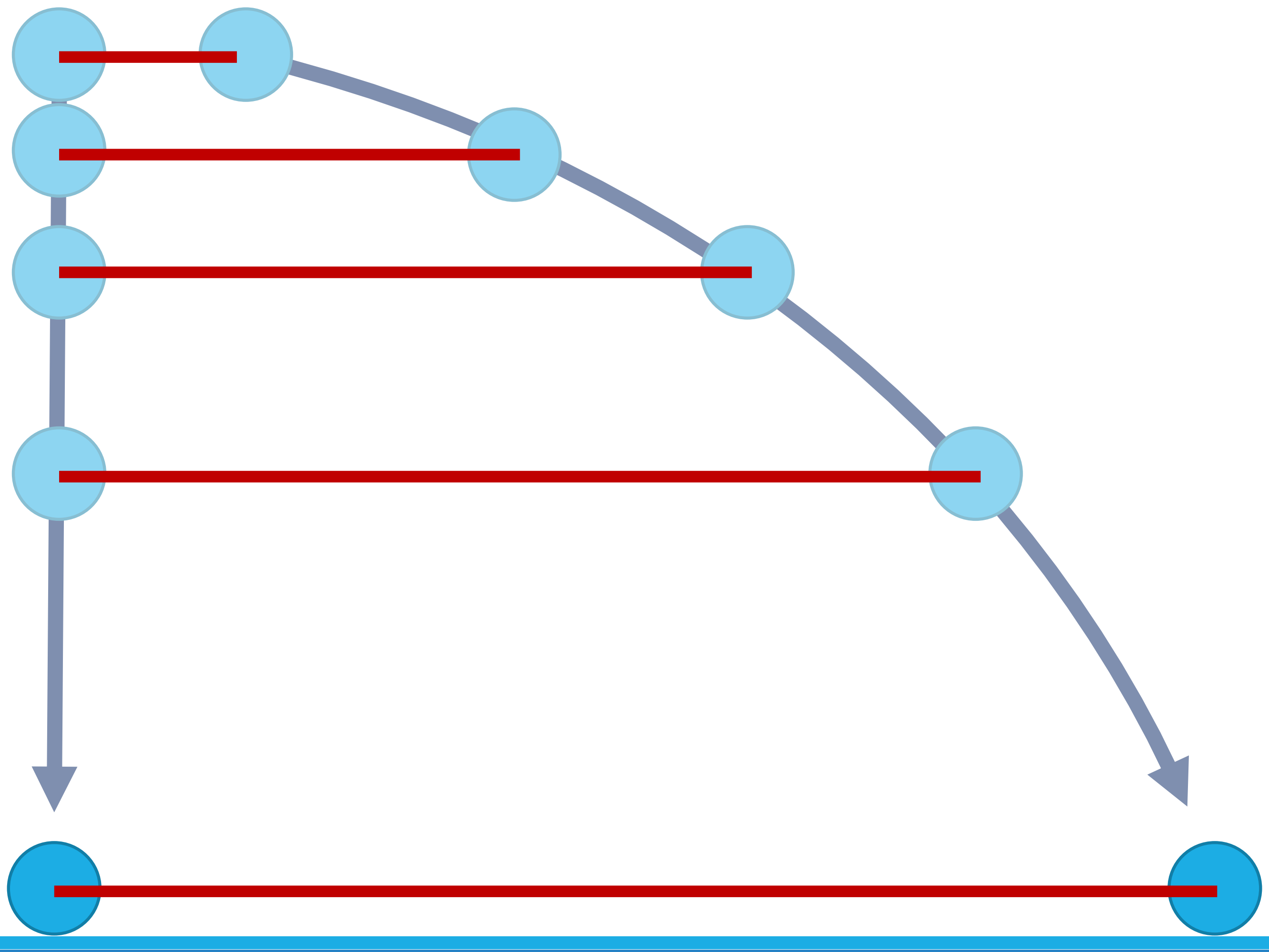
Which ball will have more air time?

The ball's hit the ground at exactly the same time

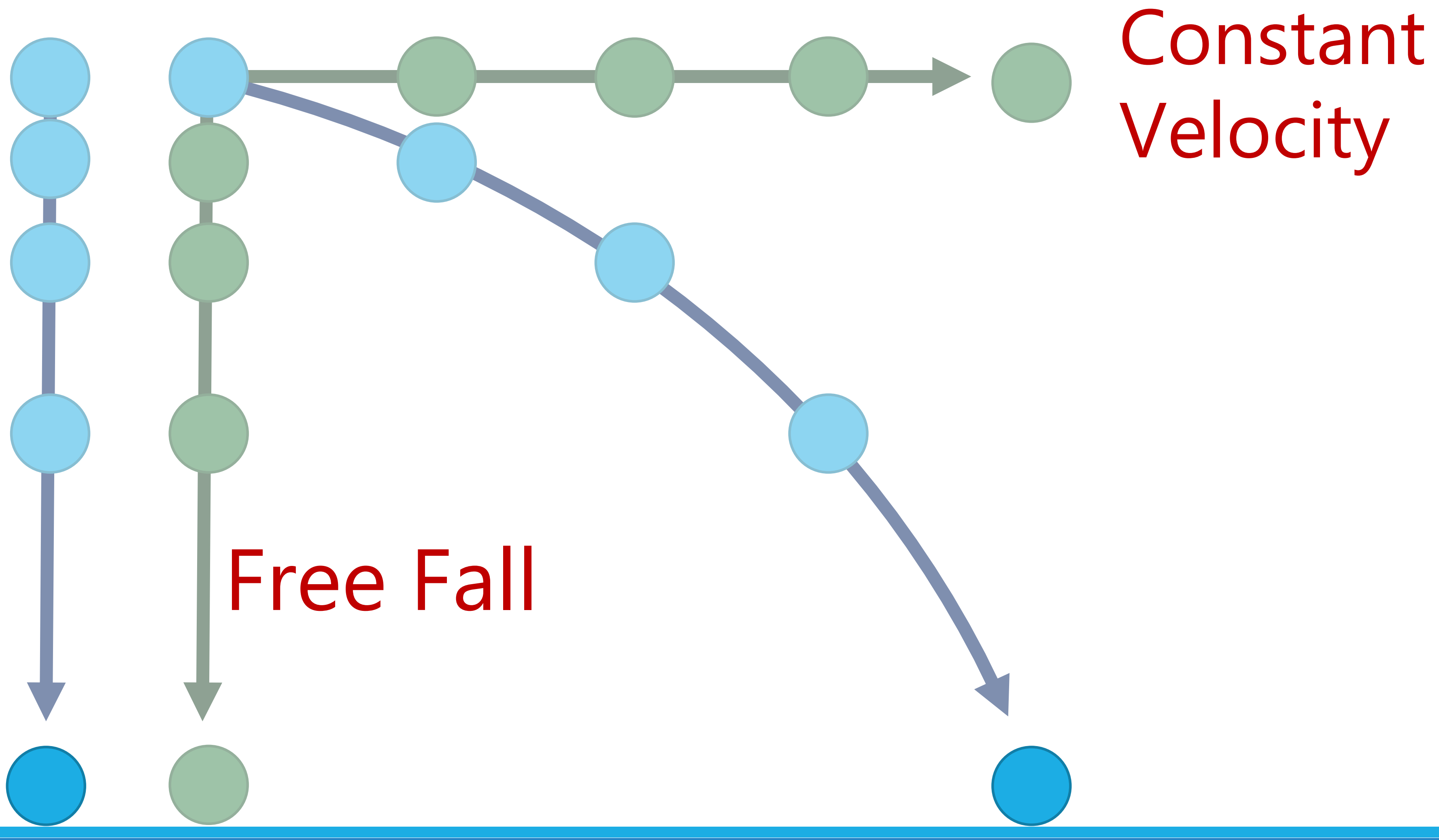
Bullet Fired vs Bullet Dropped

Bullet Fired vs Bullet Dropped - Mythbusters for the Impatient

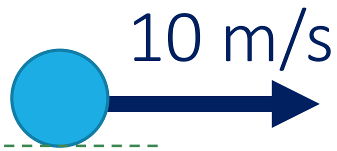
Air Time - Comparison



X and Y Components



Horizontal Projectile



From Previous Problem →

Vertical Only	
s	-25 m
u	0 m s^{-1}
v	-22.2 m s^{-1}
a	-9.81 m s^{-2}
t	2.26 s

How far does the ball travel?

$$s = vt = (10\text{ m s}^{-1})(2.26\text{ s})$$

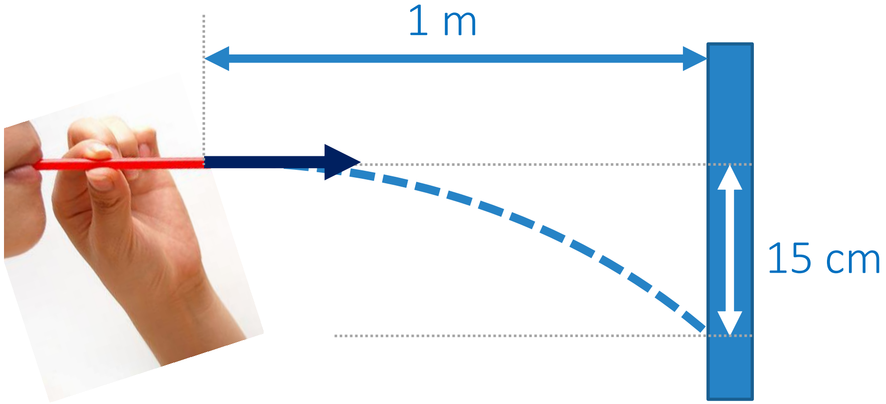
$$s = 22.6\text{ m}$$

2-D Problem Solving Steps

1. Start with "suvat" in the vertical direction and pretend it's just a freefall problem
2. The air time is the same for horizontal motion
3. Solve for horizontal using v = s/t

Vertical Only	
s	
u	
v	
a	
t	

Try This



$$s = \cancel{u}t + \frac{1}{2}at^2$$

$$-0.15 = \frac{1}{2}(-9.81)t^2$$

$t = 0.175\ \mathrm{s}$

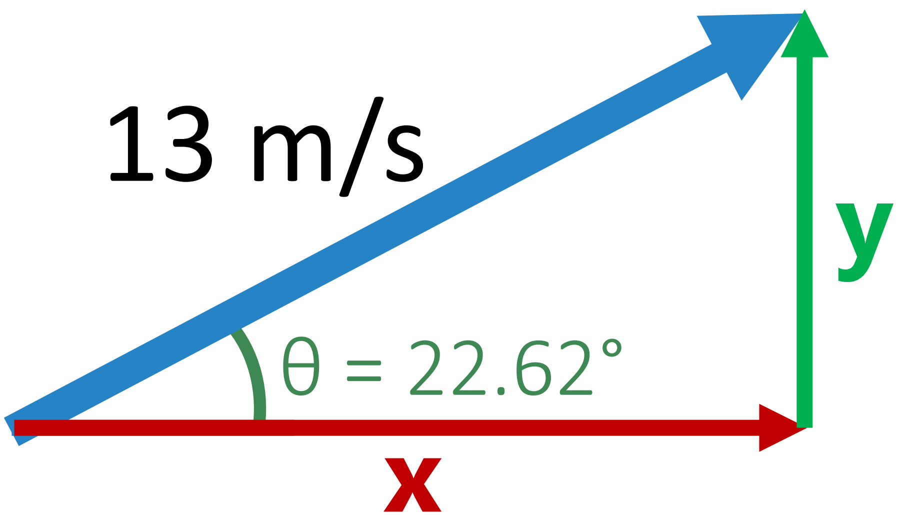
$$v = \frac{s}{t} = \frac{1\ \mathrm{m}}{0.175\ \mathrm{s}}$$

Horizontal Motion

$v = 5.71\ \mathrm{m\ s^{-1}}$

Vertical Only	
s	-0.15 m
u	0 m s^{-1}
v	---
a	-9.81 m s^{-2}
t	0.175 s

Vector Components



All vectors can be broken down into x and y components

x = 13 cos(22.62) = 12

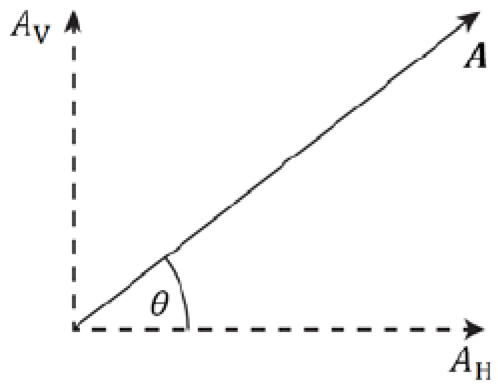
y = 13 sin(22.62) = 5

$$sin\theta = \frac{y}{13} \quad cos\theta = \frac{x}{13}$$

X-Component	12 m s^{-1}
Y-Component	5 m s^{-1}

Data Booklet Resource

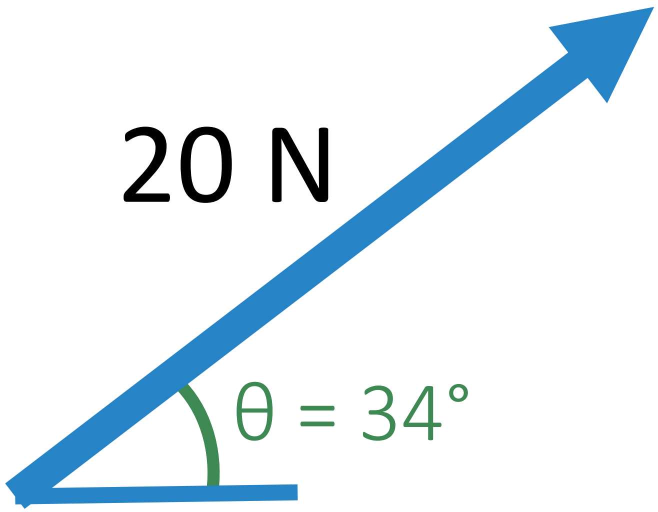
Sub-topic 1.3 – Vectors and scalars



$A_H = A\cos\theta$

$A_V = A\sin\theta$

Try this



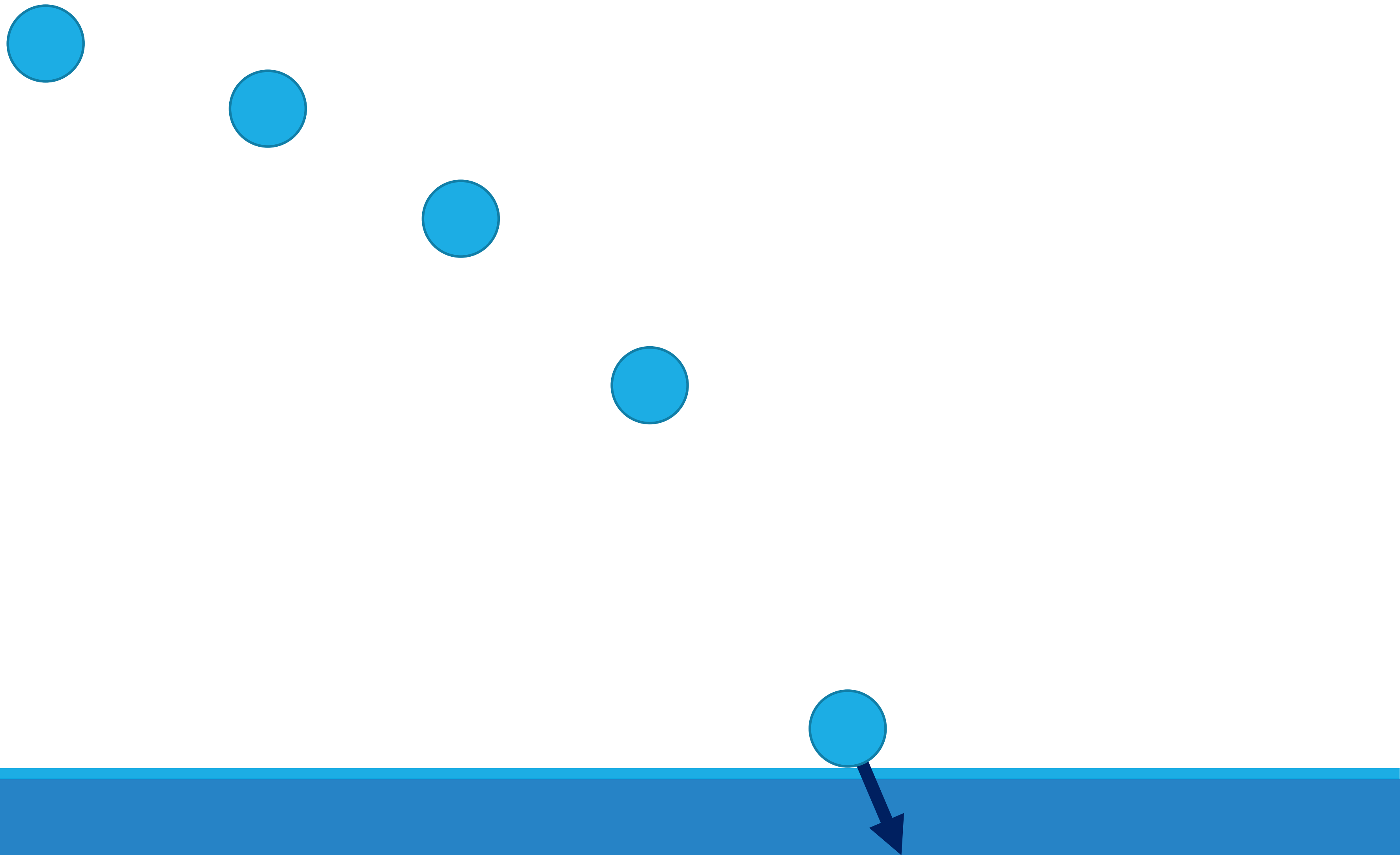
What are the x and y components of a 20 N force applied 34° from horizontal?

$$x = 20\cos(34) = 16.6$$

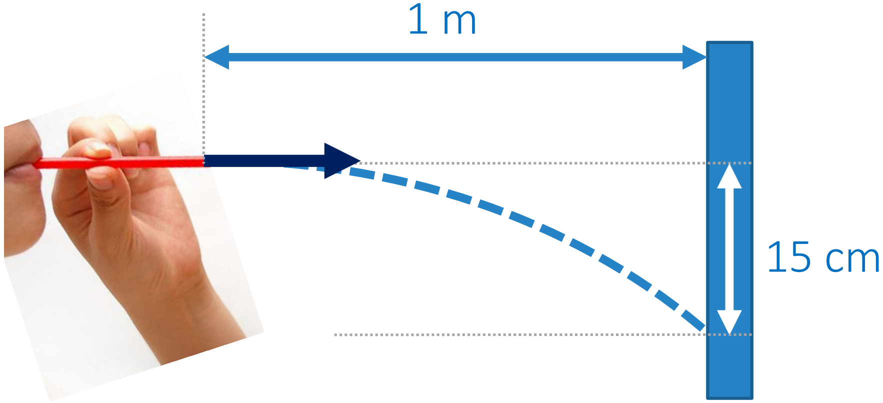
$$y = 20\sin(34) = 11.2$$

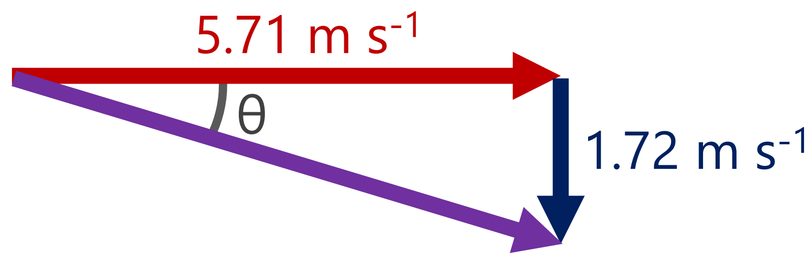
X-Component	16.6 N
Y-Component	11.2 N

Impact Velocity and Angle?



Impact Velocity and Angle





Horizontal Velocity:

From previous problem → $v_x = 5.71\ \mathrm{m\ s^{-1}}$

Vertical Velocity:

$$v^2 = \cancel{u^2} + 2as$$

$$v = \sqrt{2as} = \sqrt{2(-9.81)(-0.15)}$$

$$v_y = -1.72\ \mathrm{m\ s^{-1}}$$

Impact Velocity:

$$v = \sqrt{5.71^2 + 1.72^2}$$

$$v = 5.96\ \mathrm{m\ s^{-1}}$$

Impact Angle:

$$\theta = tan^{-1}(1.72/5.72)$$

$$\theta = 16.8\ °$$

2.6

Projectiles at an Angle

IB PHYSICS | UNIT 2 | MOTION

Reminder of our Equations

Units	m	$m\,s^{-1}$	$m\,s^{-1}$	$m\,s^{-2}$	s
$v = u + at$		u	v	a	t
$s = ut + \frac{1}{2}at^2$	s	u		a	t
$v^2 = u^2 + 2as$	s	u	v	a	
$s = \frac{(v+u)t}{2}$	s	u	v		t

2-D Problem Solving Steps

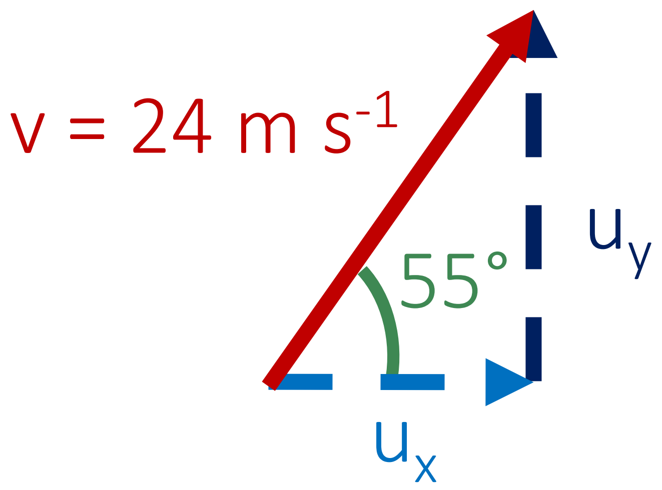
1. Start with "suvat" in the vertical direction and pretend it's just a freefall problem

2. The air time is the same for horizontal motion

3. Solve for horizontal using v = s/t

Vertical Only	
s	
u	
v	
a	
t	

Remember Vectors?

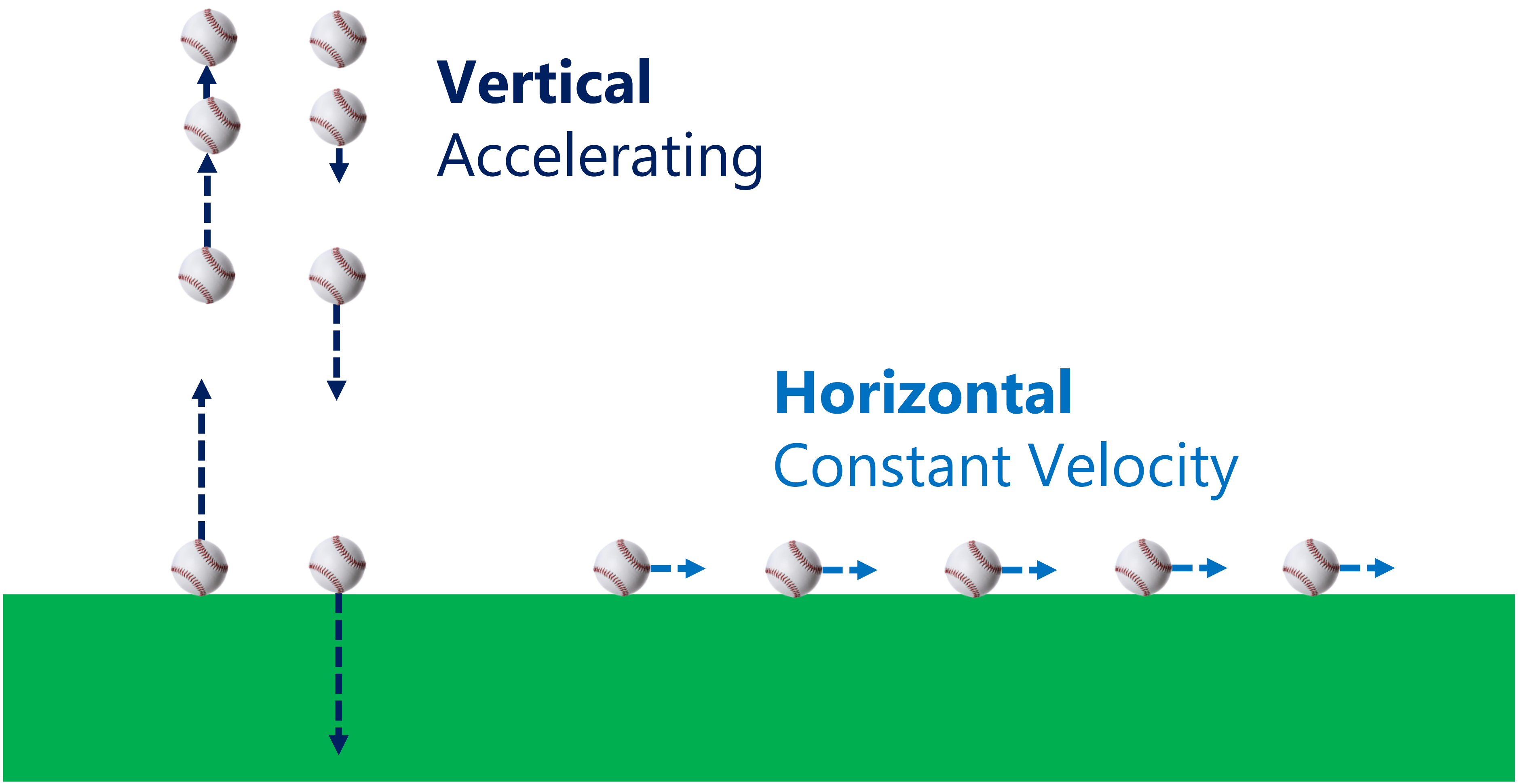


u_x	13.8 m s^{-1}
u_y	19.7 m s^{-1}

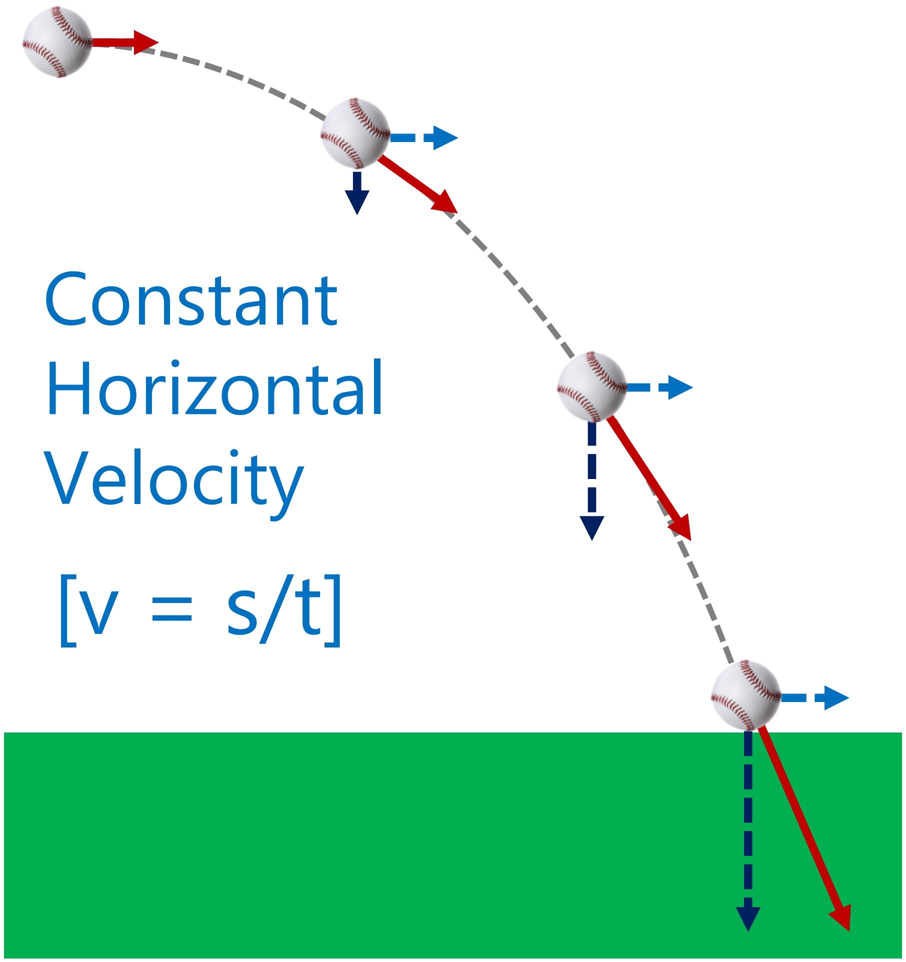
$$u_x = 24\cos(55) = 13.8$$

$$u_y = 24\sin(55) = 19.7$$

One Dimensional Motion



Horizontal Projectile

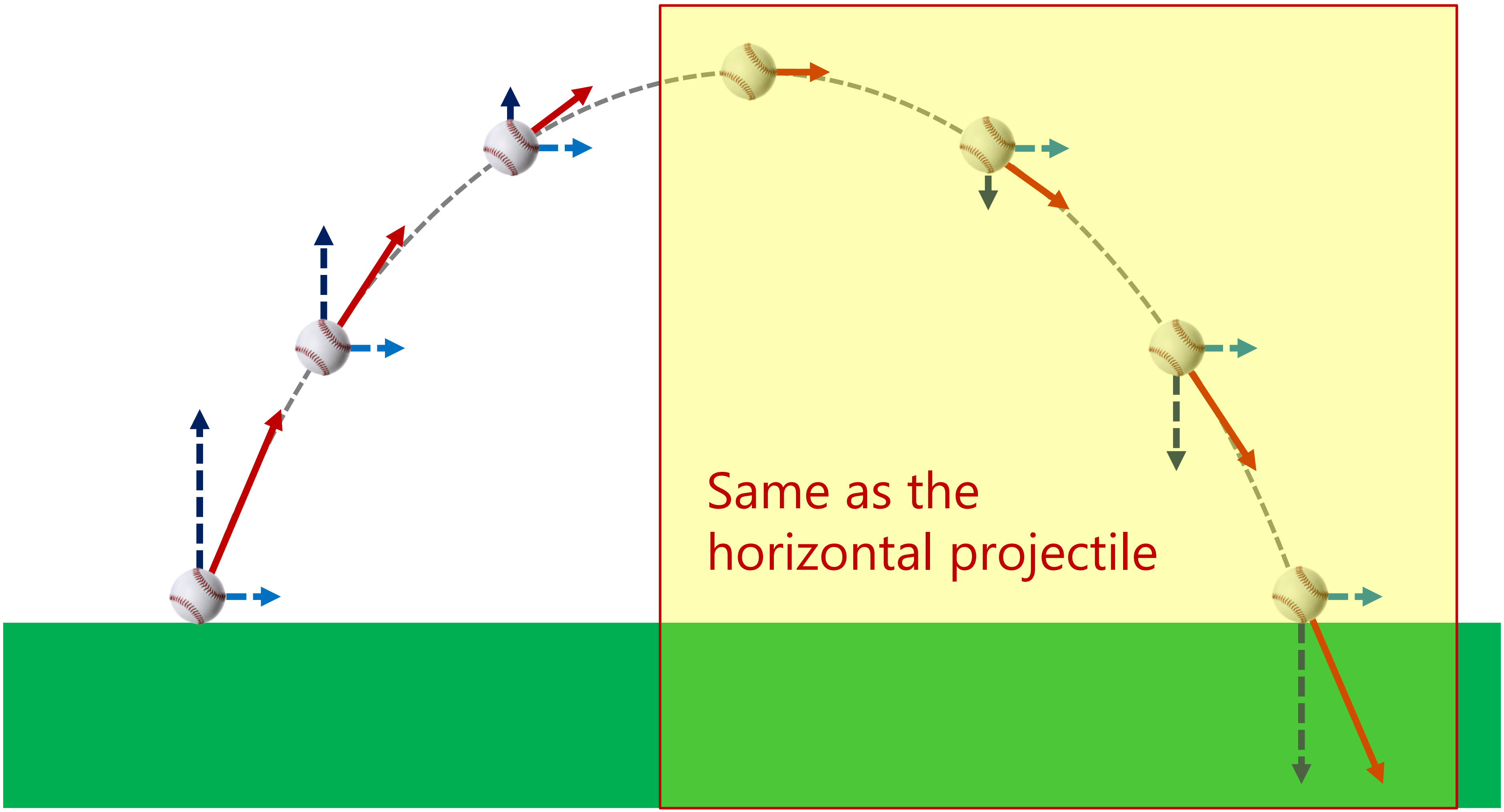


Constant Horizontal Velocity

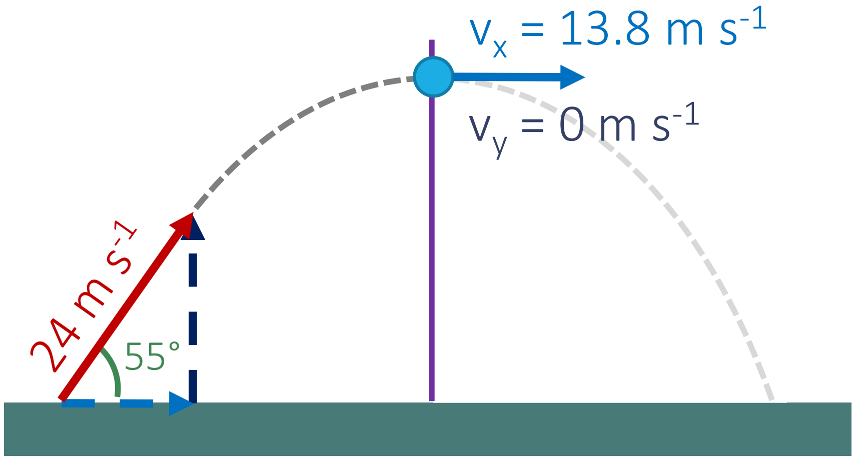
[v = s/t]

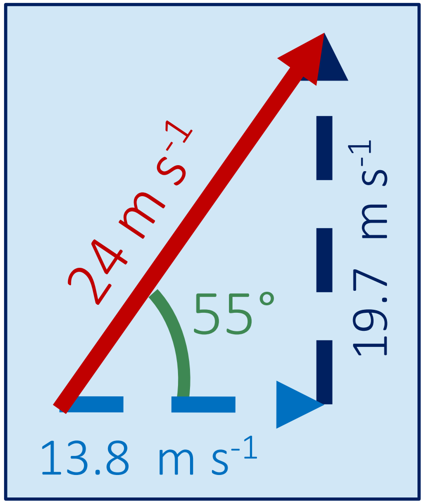
Vertical Only	
s	
u	0 m s^{-1}
v	
a	-9.81 m s^{-2}
t	

Two Dimensional Projectile



Projectile – First Half





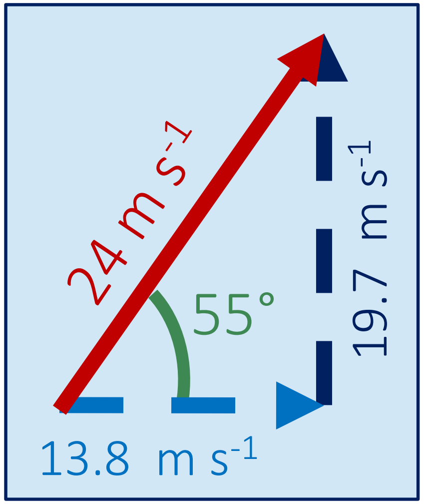
$$v = u + at$$
$$0 = 19.7 + (-9.81)t$$
$$t = 2.01 \text{ s}$$

$$v^2 = u^2 + 2as$$
$$0^2 = 19.7^2 + 2(-9.81)s$$
$$s = 19.8 \text{ m}$$

1st Half Vertical	
s	19.8 m
u	19.7 m s^{-1}
v	0 m s^{-1}
a	-9.81 m s^{-2}
t	2.01 s

Projectile – Full Thing

Total Time	4.02 s
$Displacement_x$	55.5 m

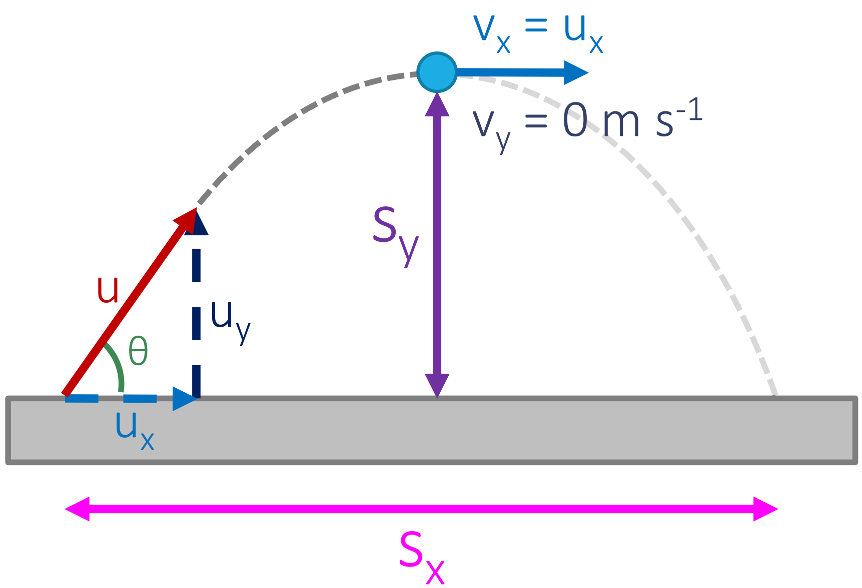


First Half = 2.01 s

Total Time = 2.01 × 2 = **4.02 s**

s = vt = (13.8)(4.02) = **55.5 m**

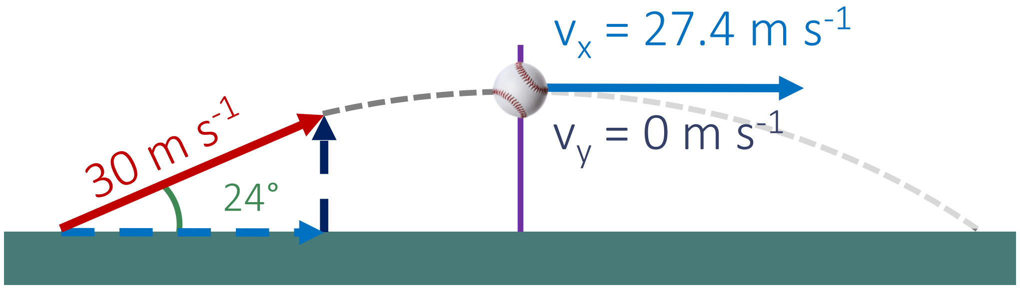
Projectile – In General



Total Time	2t
$Displacement_x$	$u_x(2t)$

1st Half Vertical	
s	Total Height
u	u_y
v	$0\ m\ s^{-1}$
a	$-9.81\ m\ s^{-1}$
t	

Try This...



You hit a baseball at 24° above the horizontal as a speed of 30 m s^{-1}. How far does the ball travel before it hits the ground?

u_x = 30 cos(24) = 27.4 m s^{-1}

u_y = 30 sin(24) = 12.2 m s^{-1}

$v = u + at$

$0 = 12.2 + (-9.81)t$

$t = 1.24\ \mathrm{s}$

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

$0^2 = 12.2^2 + 2(-9.81)s$

$s = 7.56\ \mathrm{m}$

Horizontal:

Total Time = 2(1.24) = 2.48 s

s = vt = (27.4)(2.48)

s = 68 m

1st Half Vertical	
s	7.56 m
u	12.2 m s^{-1}
v	0 m s^{-1}
a	-9.81 m s^{-2}
t	1.24 s