Module 3 Forces & Motion

Unit 1 Motion

3.1 Motion

This section provides knowledge and understanding of key ideas used to describe and analyse the motion of objects in both one-dimension and in two-dimensions. It also provides learners with opportunities to develop their analytical and experimental skills.

The motion of a variety of objects can be analysed using ICT or data-logging techniques (HSW3). Learners also have the opportunity to analyse and interpret experimental data by recognising relationships between physical quantities (HSW5). The analysis of motion gives many opportunities to link to How Science Works. Examples relate to detecting the speed of moving vehicles, stopping distances and freefall (HSW2, 9, 10, 11, 12).

You are here! →

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- 2.1 Physical quantities and units
- 2.2 Making measurements and analysing data
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Module 3 – Forces and motion

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- 3.2 Forces in action
- 3.3 Work, energy and power
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Module 4 – Electrons, waves and photons

- 4.1 Charge and current
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3.1 Motion

- 3.1.1 Kinematics
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3.1.1 Kinematics

3.1.1 Kinematics

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) displacement, instantaneous speed, average speed, velocity and acceleration

(b) graphical representations of displacement, speed, velocity and acceleration

(c) Displacement–time graphs; velocity is gradient

(d) Velocity–time graphs; acceleration is gradient; displacement is area under graph.

What are average speed and instantaneous speed?

Average Speed

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

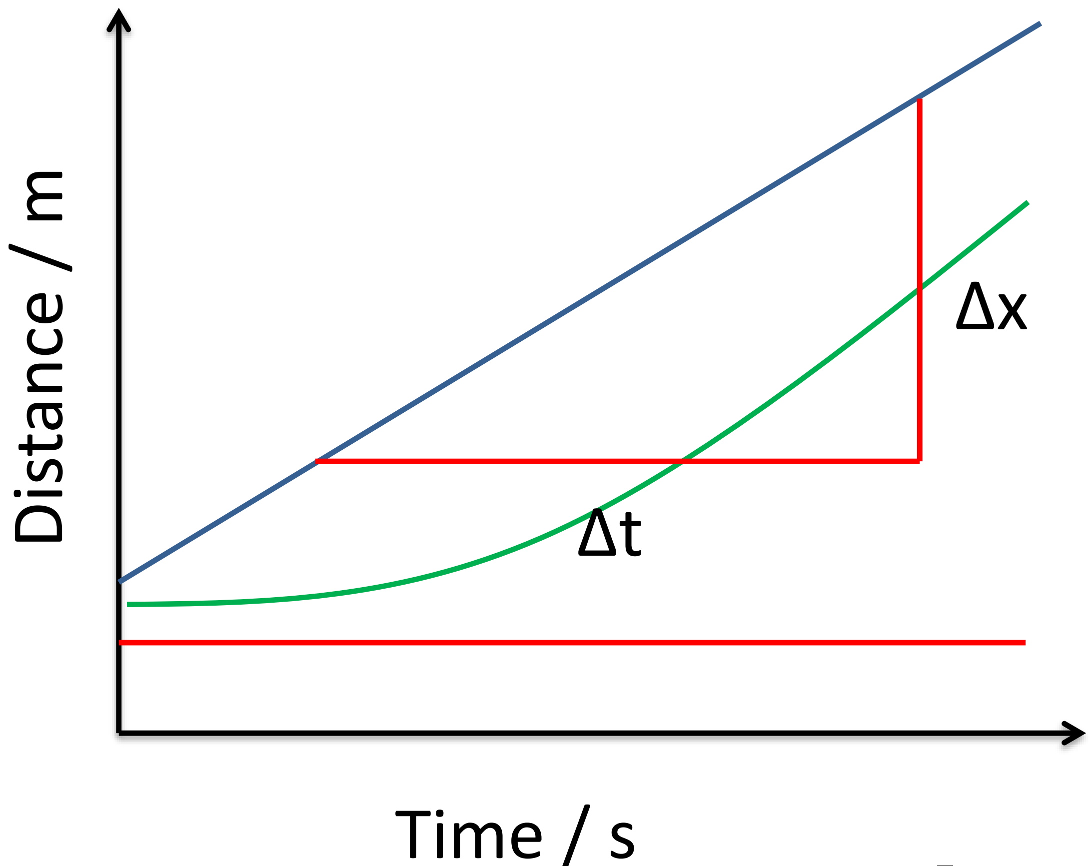
or

$$v = \frac{\Delta x}{\Delta t}$$

Where:
v is the quantity symbol for speed or velocity
x is the quantity symbol for distance
t is the quantity symbol for time
Δ is the greek letter Delta meaning "change in"

What is the unit for speed?

Distance – time graphs



Sketch:

- A stationary object
- An object moving with constant speed
- An accelerating object

What does the gradient of the line represent?

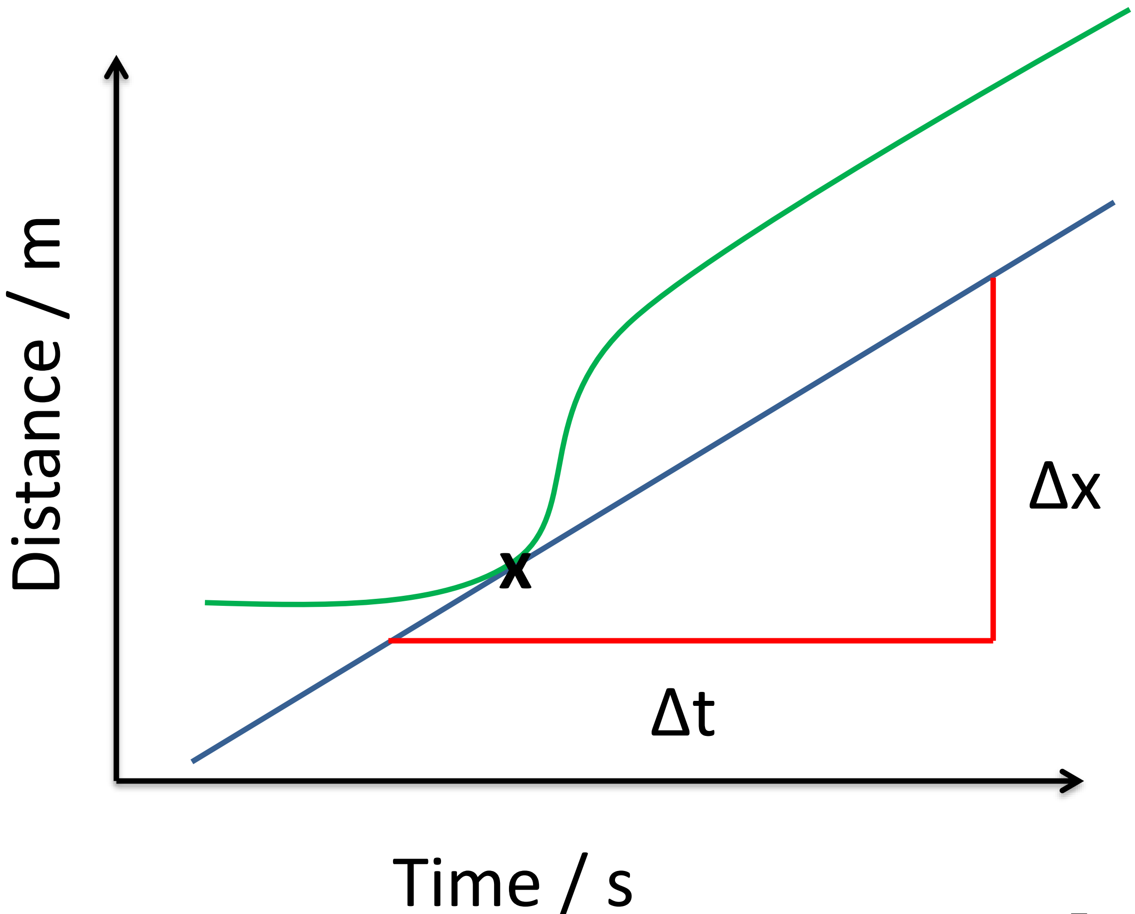
$$\text{gradient} = \frac{\Delta x}{\Delta t} = \text{speed}$$

Instantaneous Speed

- The speed of an object at a particular instant.

- We can find instantaneous speed by drawing a tangent onto a distance-time graph and then calculating its gradient.

Instantaneous Speed



Find the instantaneous speed at point X:

- Draw a large tangent at X
- Draw a large triangle on the tangent
- Calculate the gradient of the tangent

$$\text{gradient} = \frac{\Delta x}{\Delta t} = \text{speed}$$

So, that’s speed and distance sorted but what’s with velocity and displacement? Are they just posher words?

Definition - Speed

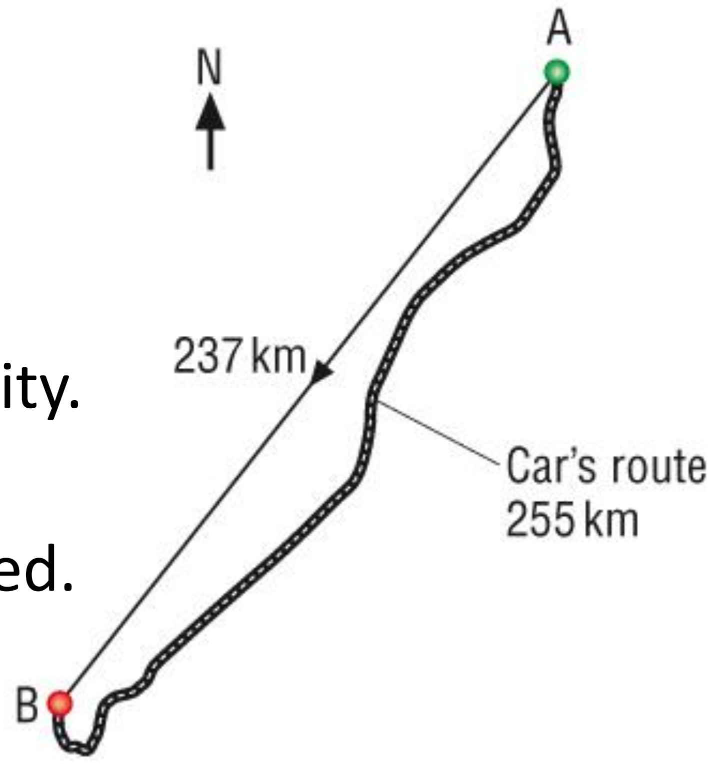
- How do we define speed?
  - Distance per unit time.

- Please note:
  - Speed is a scalar quantity.
  - It is defined by quantities, not units
    - So don’t define speed as metres per second or miles per hour.
  - Average speed is overall distance / overall time.
  - Instantaneous speed is the speed at a given instance in time.

Definition - Displacement

- How do we define displacement?
  - Distance moved in a stated direction.

- Please note:
  - Displacement is a vector quantity.
  - Displacement may not be the same as actual distance travelled.

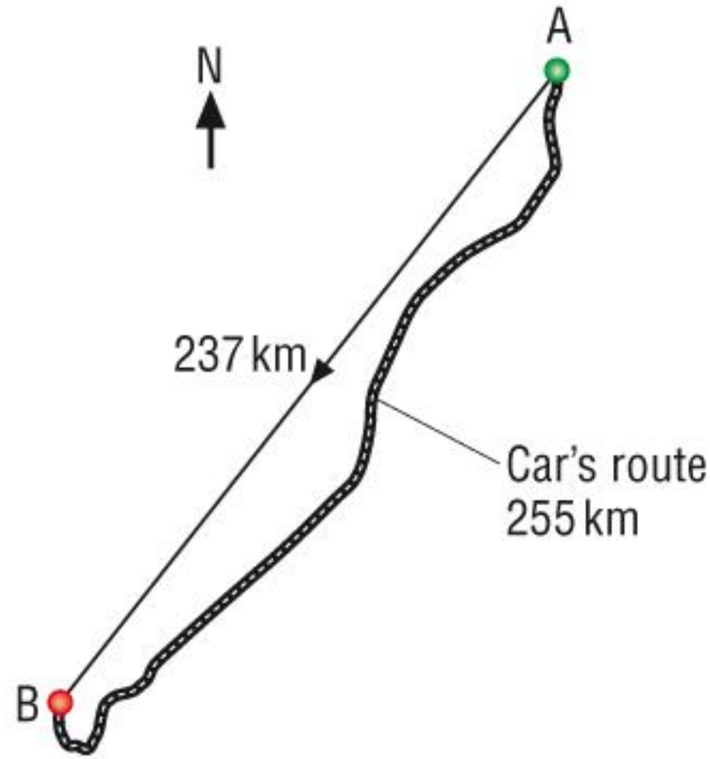


Definition – Velocity

- How do we define velocity?
  - Displacement per unit time.
- Please note:
  - Velocity is a vector quantity.
  - Displacement may not be the same as actual distance travelled.

If time taken is 3 hours...

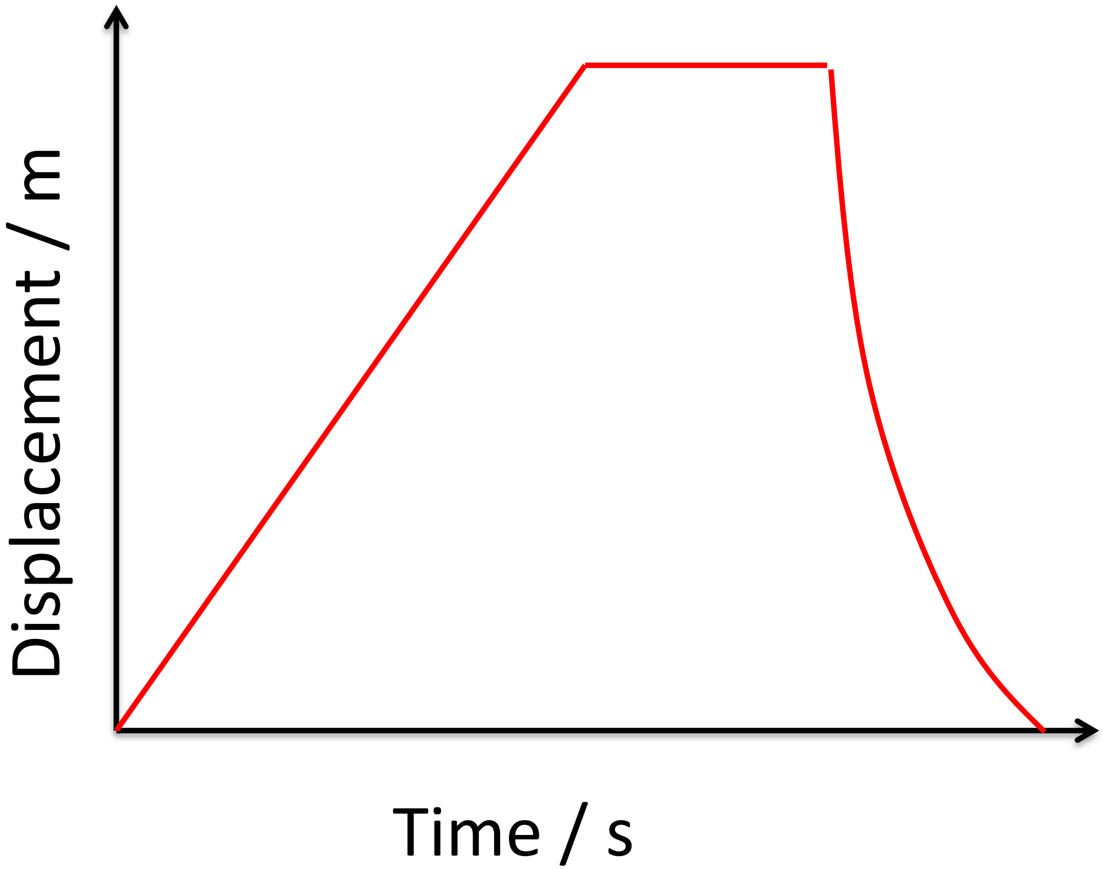
- What is the average speed?
  - 255km/3h = 85kmh^{-1}



- What is the average velocity?
  - 237km/3h = 79kmh^{-1} in a SW direction

What is this in SI units?

Displacement-Time Graphs



Describe the motion of the object as clearly as possible:

Maybe someone climbing a ladder and jumping off the top?

Definition – Acceleration

- How do we define acceleration?
  - The rate of change of velocity.

- Please note:
  - Acceleration is a vector quantity.
  - The units of acceleration can be confusing.
    - Change of velocity (ms^{-1}) per time (s)
    - Which becomes ms^{-2}

Using the acceleration equation

Acceleration (a) = Change in Velocity / Time (t)

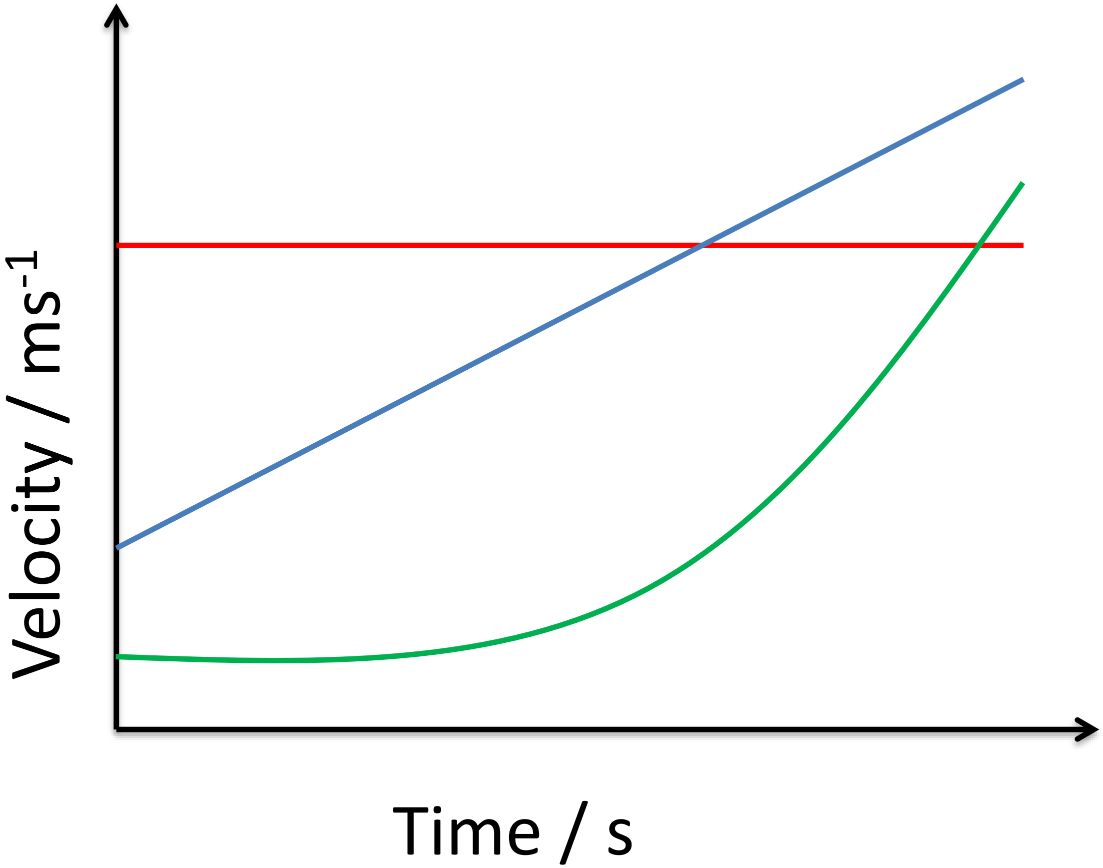
Or

a = (v – u) / t

Where v is final velocity and u is starting velocity.

- If v<u then the acceleration will be negative (a decrease in velocity).
- DO NOT CALL THIS A DECELERATION. It is negative acceleration.

Velocity-Time Graphs



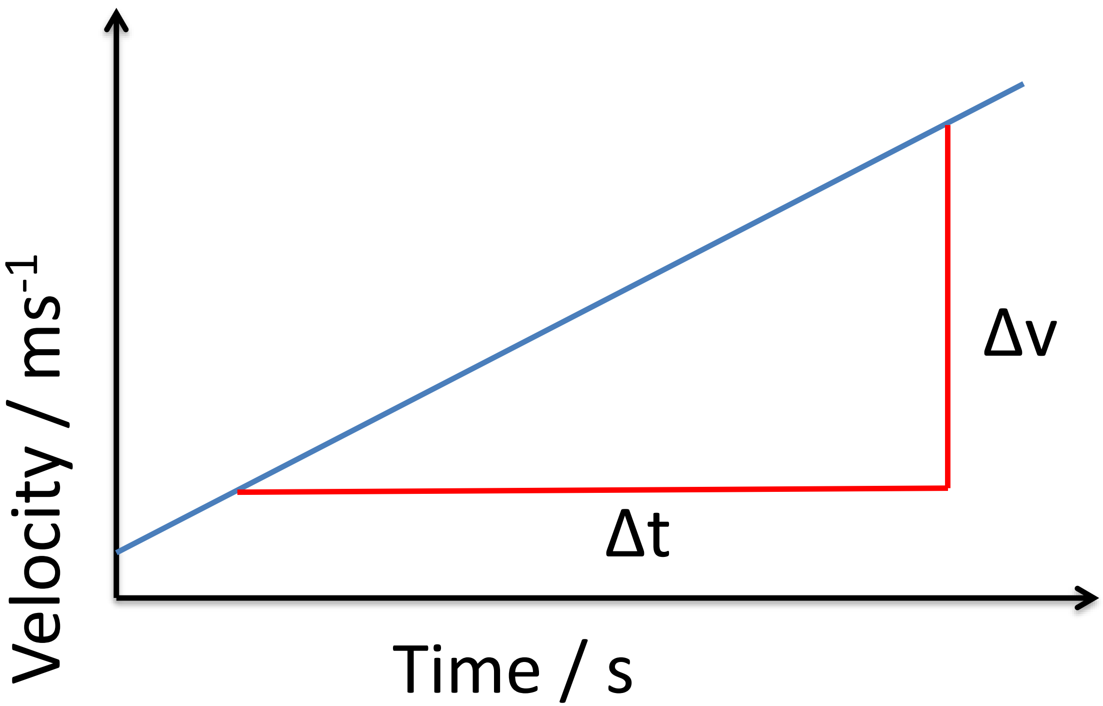
Sketch:

An object with constant velocity

An object with constant +ve acceleration

An object with changing acceleration

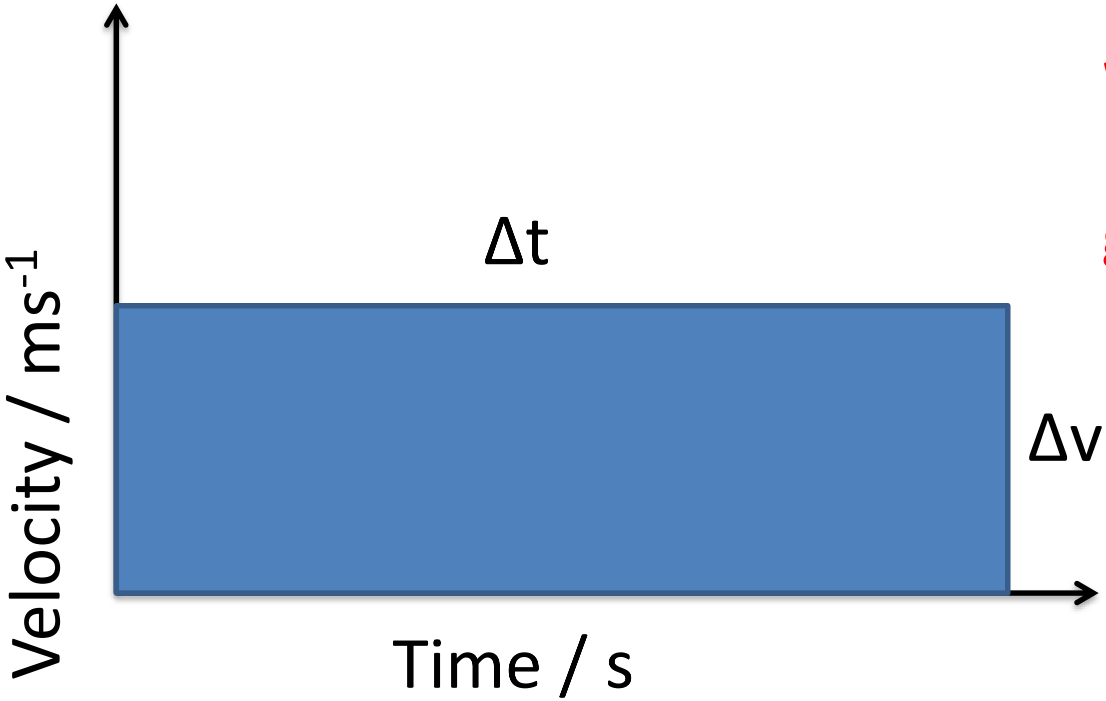
Velocity-Time Graphs



What does the gradient of a velocity – time graph represent?

$$\text{gradient} = \frac{\Delta v}{\Delta t} = \frac{v - u}{\Delta t} = \text{acceleration}$$

Velocity-Time Graphs



What does the area under a velocity – time graph represent?

$$\text{area} = \text{velocity} \times \text{time} = \text{displacement}$$

3.1.1 Kinematics (review)

3.1.1 Kinematics

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	displacement, instantaneous speed, average speed, velocity and acceleration
(b)	graphical representations of displacement, speed, velocity and acceleration
(c)	Displacement–time graphs; velocity is gradient
(d)	Velocity–time graphs; acceleration is gradient; displacement is area under graph.

3.1.2 Linear Motion

3.1.2 Linear motion

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) (i) the equations of motion for constant acceleration in a straight line, including motion of bodies falling in a uniform gravitational field without air resistance

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

$$s = ut + \frac{1}{2}at^2 \qquad v^2 = u^2 + 2as$$

(ii) techniques and procedures used to investigate the motion and collisions of objects

(b) (i) acceleration g of free fall

(ii) techniques and procedures used to determine the acceleration of free fall using trapdoor and electromagnet arrangement or light gates and timer

(c) reaction time and thinking distance; braking distance and stopping distance for a vehicle.

How can we predict motion with constant acceleration?

Constant Acceleration

- When dealing with constantly accelerating objects we always use the following algebraic symbols.
  - Do we use distance or displacement? Speed or acceleration?

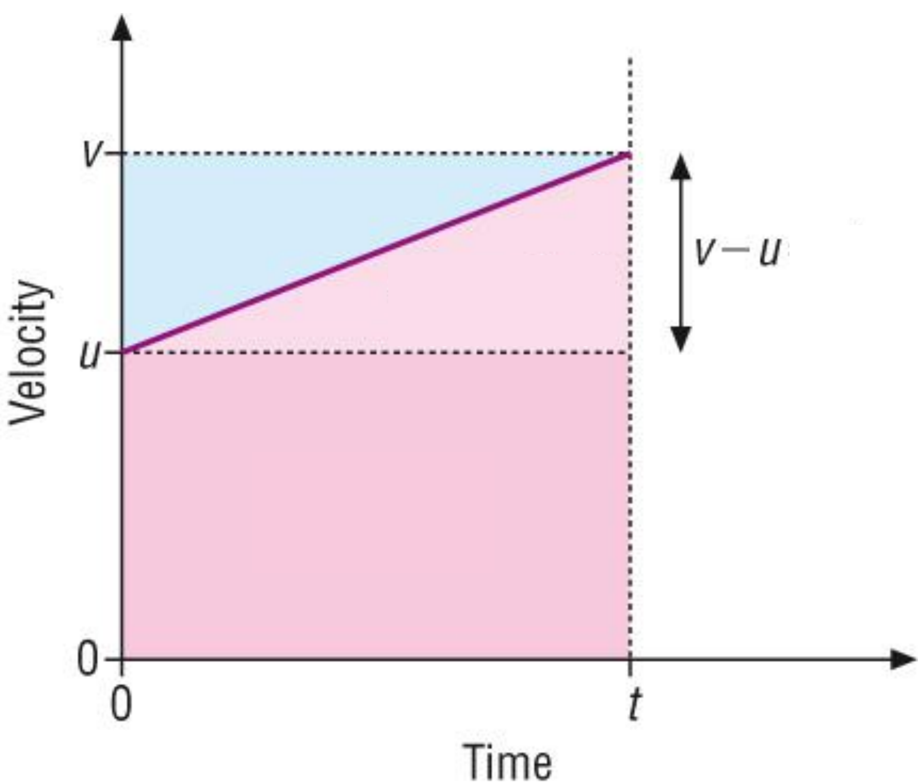
Symbol	Quantity	Alternative quantity	SI unit
s	distanced moved	displacement	metre
t	time interval		second
a	acceleration		m s^{-2}
u	speed at the start	velocity at the start	m s^{-1}
v	speed at the end	velocity at the end	m s^{-1}

Table 1 Standard algebraic symbols for constant acceleration

These are what we call the SUVAT quantities.

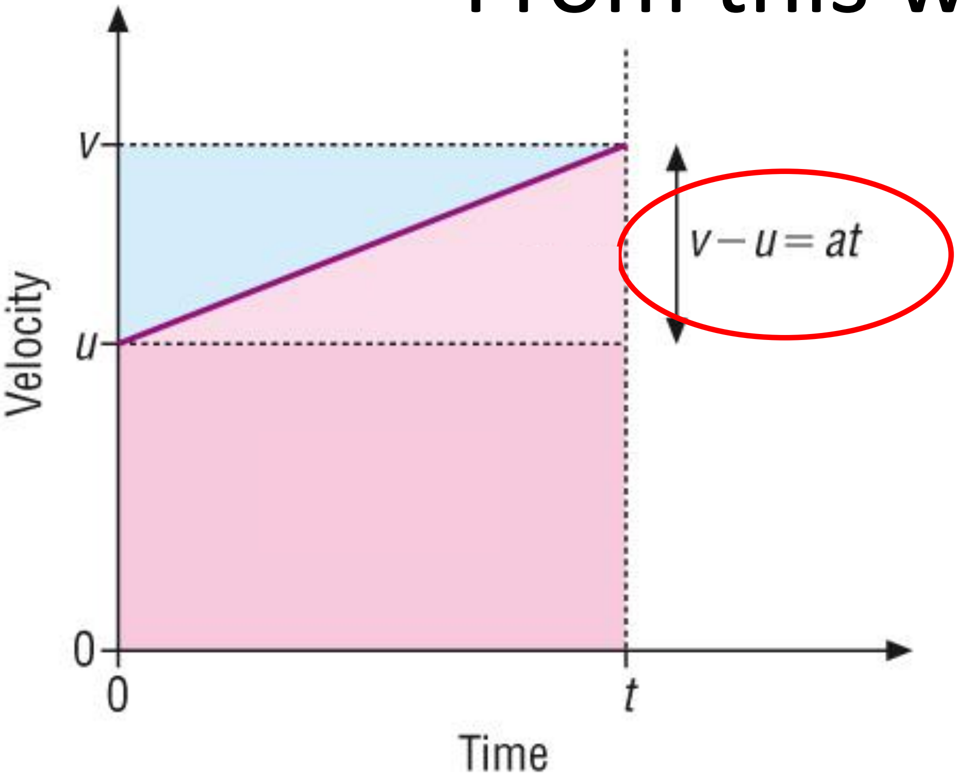
Acceleration Equations

- Remember: a=(v-u)/t
- This can be represented graphically as the gradient.



We may be asked to calculate these quantities where one of s, u, v, a or t is not given, so we need a set of equations relating these values...

From this we can get...



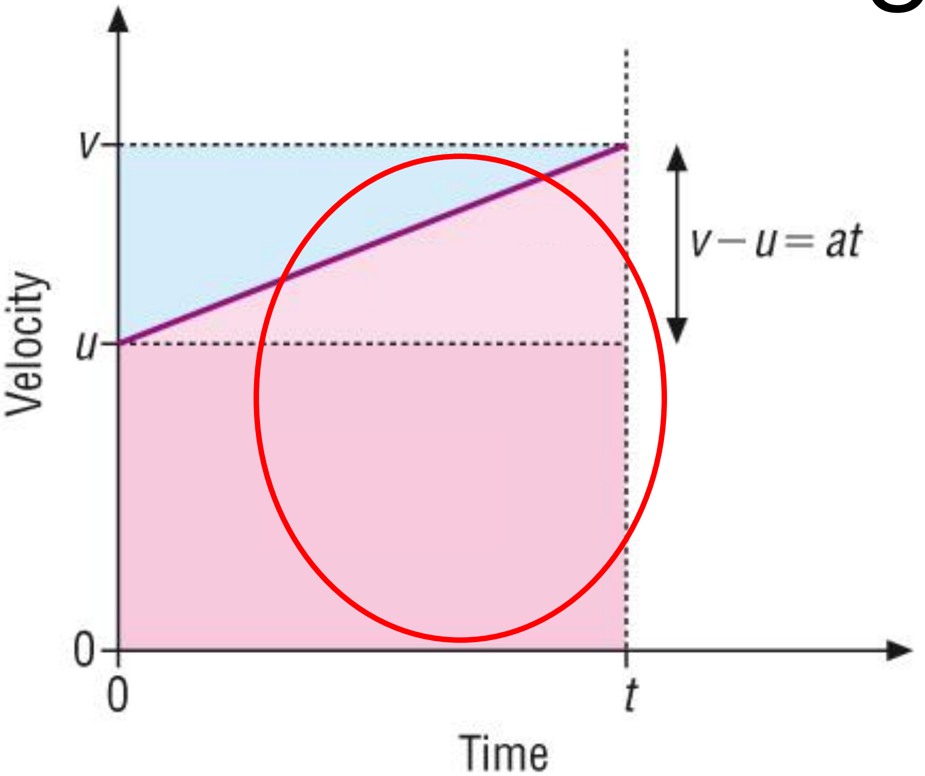
v-u=at

So

v=at+u

s is not represented.

Or...

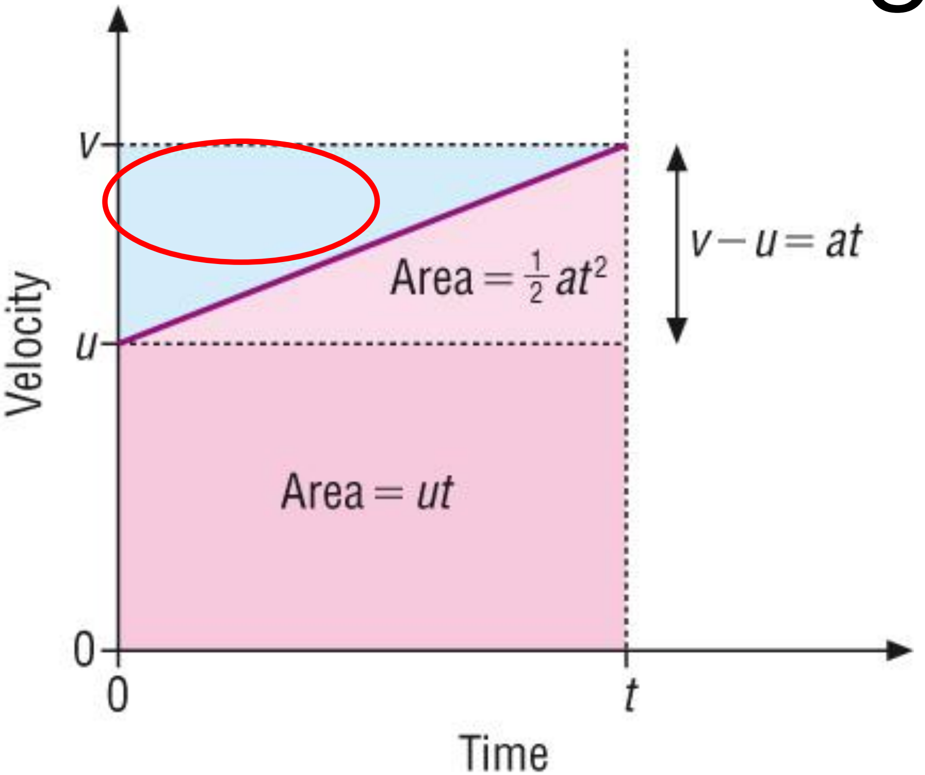


The distance travelled is the area under the graph, so...

$s=ut+at^2/2$

v is not represented.

Or...

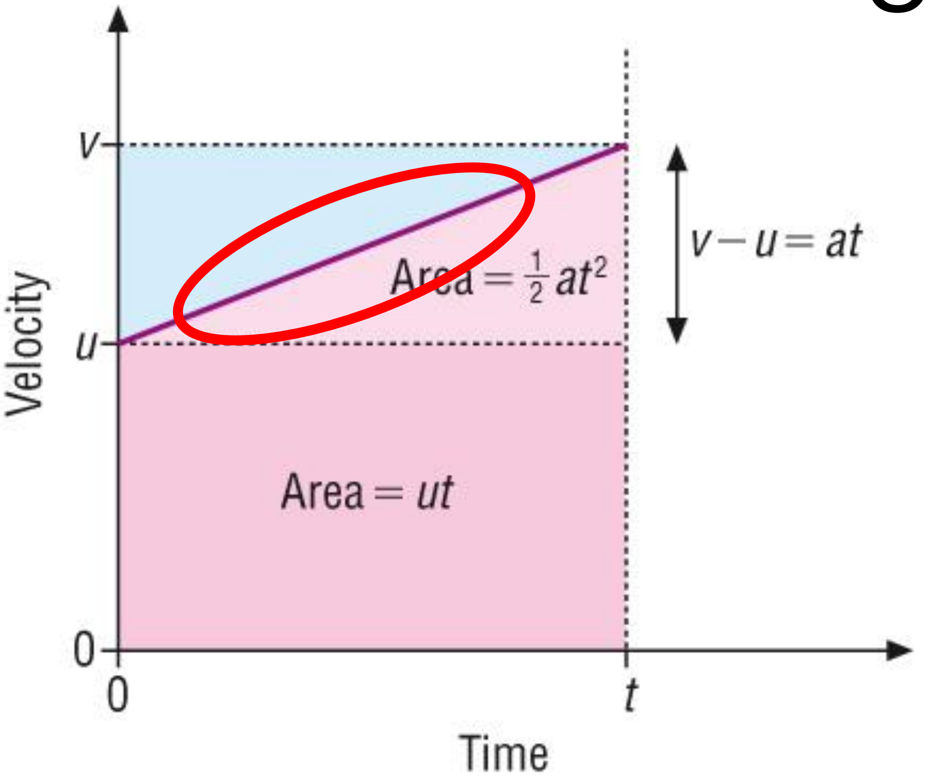


The distance travelled can also be seen as the whole rectangle minus the blue bit, so...

$s = vt - at^2/2$

u is not represented.

Or...



The distance travelled can equal the average velocity multiplied by time.

s=t(u+v)/2

a is not represented.

Finally...

Taking the previous equations of $v=u+at$ and $s=t(u+v)/2$...

We can rearrange the first one to make t the subject of the formula...

Then substitute this term into the second to get...

t is not represented.

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

So to summarise...

- SUVAT Equations are:

$v=u+at$

$s=t(u+v)/2$

$s=ut+at^2/2$

$s=vt-at^2/2$

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

These will be very useful to you.

Sometimes called kinematic equations

They **ONLY** apply during CONSTANT ACCELERATION

[Answer questions on p.34]

- Investigations of motion & collision of objects.

Why does the highway code worry about thinking distances and braking distances?

Car Stopping Distance

- Stopping distance is the total distance travelled after the driver sees a reason to stop until the car actually stops.

- Stopping distance has two components:
  - Thinking distance
    - The distance travelled during the time taken to see a hazard and apply the brakes.
  - Braking distance
    - The distance travelled while the brake is applied and the car is slowing.

Thinking Distance

- Thinking distance = initial velocity x reaction time

- The greater the speed or reaction time the further the thinking distance.
  - Reaction times can be increased by alcohol, tiredness, distractions or drugs

Braking distance

- Using $v^2=u^2+2as$ and rearranging to $s=-u^2/2a$ we can see that braking distance is related to initial velocity and rate of negative acceleration.
  - Acceleration can be affected by tyre conditions and weather.

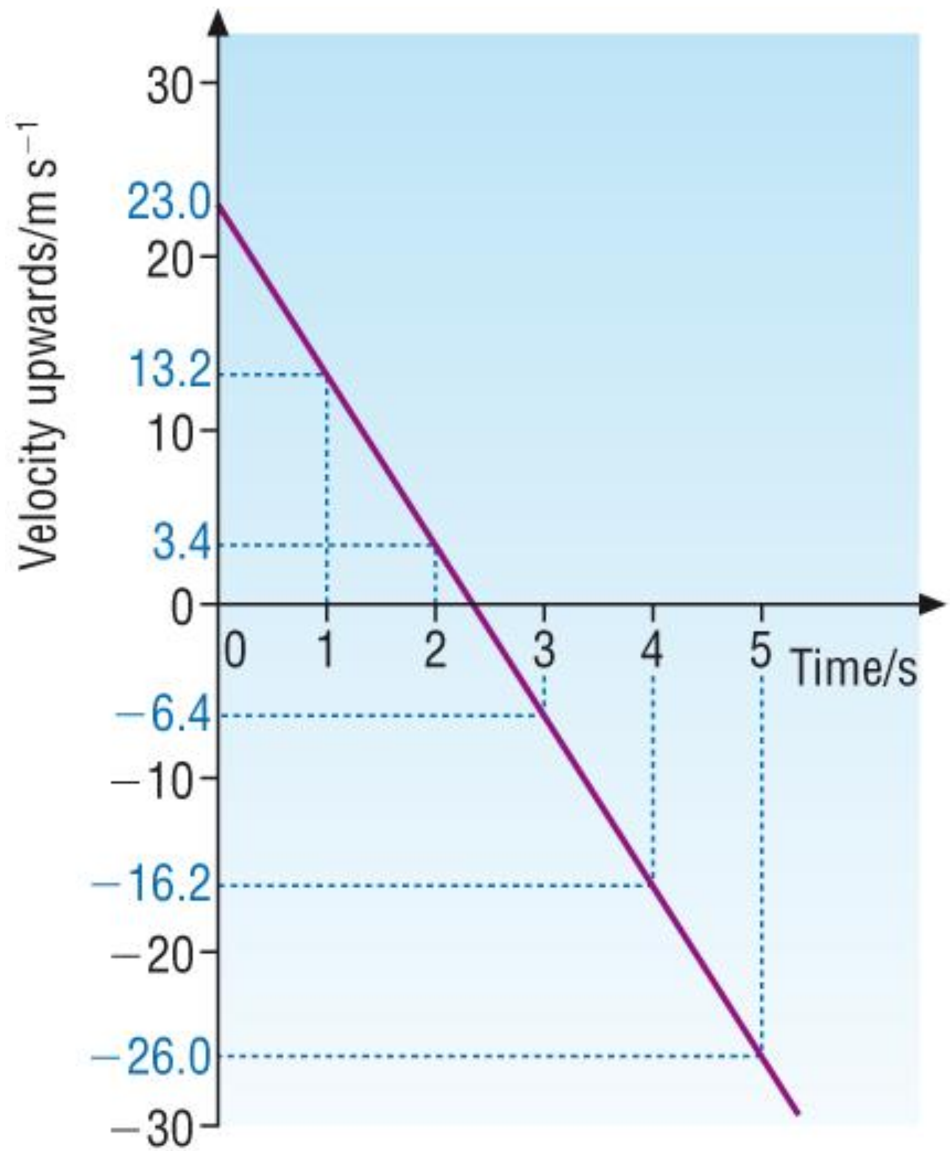
How can we measure the acceleration due to gravity?

Free Fall

- A free falling object on Earth has an acceleration of g = 9.8118ms^{-2}.
  - This value is not constant.
  - g decreases with altitude (distance from centre).
    - So g decreases at the top of a mountain.
    - Also, Earth is not completely spherical (it's squashed slightly N-S).
      - At the North pole g = 9.8322ms^{-2}
      - At the Equator g = 9.7803ms^{-2}
  - For the purposes of this section we assume that g is constant at 9.8118ms^{-2} and that air resistance is negligible.

Using g

- The acceleration of freefall is always vertically downwards (towards the centre of Earth).
  - If an object is dropped, it accelerates constantly downwards.
  - If an object is thrown upwards, it still accelerates constantly downwards.

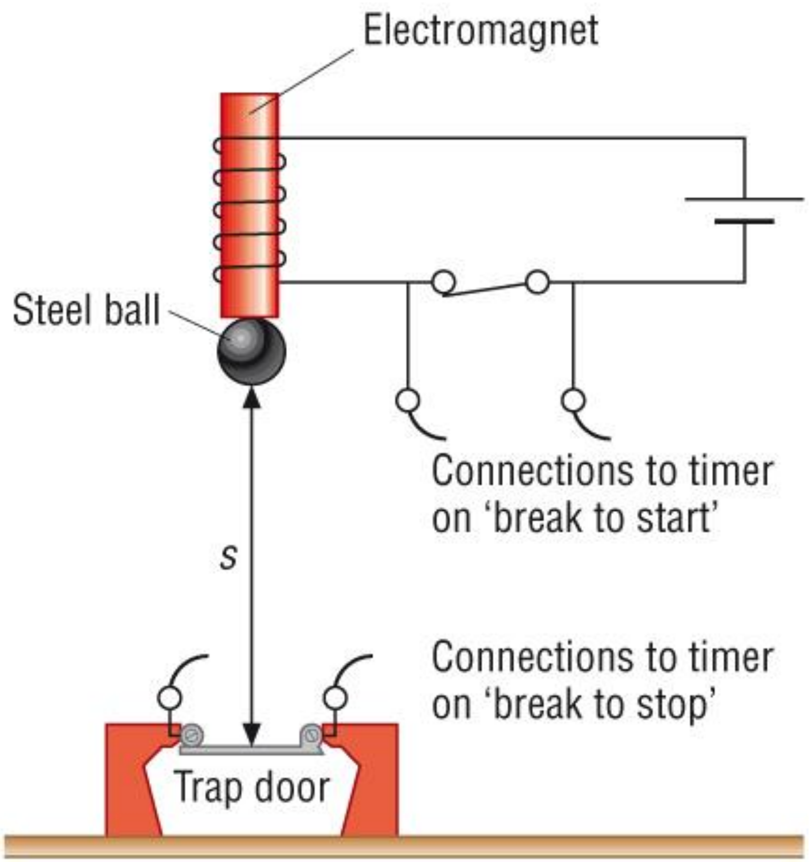


Measuring g

- Two approaches can be used to measure the acceleration of freefall:

1. Direct approaches
   - (eg. Timing a falling object, use of light gates, video recording of a falling object against a metre rule)
2. Indirect approaches
   - (eg. Measuring the time taken for a pendulum to complete a full swing, plotting a distance-time^2 graph)

The Direct Approach



- The distance the ball falls (s) is measured.
- The time (t) is taken from the timer.
- Use $s=ut+at^2/2$
  - u = 0 as the ball starts from rest.
  - So $s=gt^2/2$ and thus $g=2s/t^2$
  - A graph of s against t^2 will have a gradient of g/2

Uncertainty

- If you tried this experiment several times you would get several answers for the value of g.
- Why?
- Systematic uncertainty could come from:
  - Too large a current through the electromagnet causing a delay releasing the ball – set the current as low as possible.
  - The fall distance is too large (or ball too small) and air resistance is having an effect.
  - Measurement of fall distance is imprecise.

Plotting a distance-time^2 graph

- Measure the distance an object falls in a series of different times.
- Using $s=ut+at^2/2$, and since the object starts at rest, we can derive $s=gt^2/2$.
- Plotting distance (s) against time^2 (t^2) we will get a straight line with gradient g/2.

- Try it and estimate the percentage uncertainty.

3.1.2 Linear Motion (review)

3.1.2 Linear motion

Learning outcomes

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3.1.3 Projectile Motion

3.1.3 Projectile motion

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

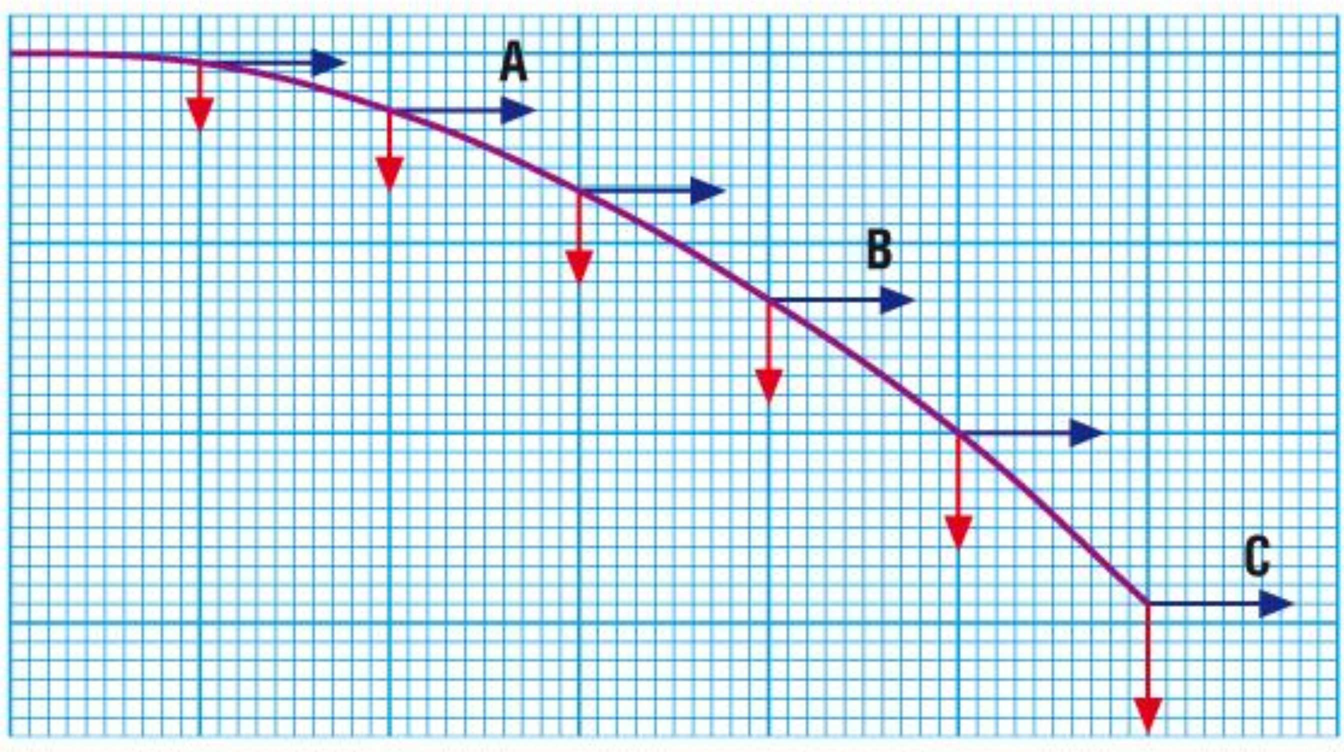
(a) independence of the vertical and horizontal motion of a projectile

(b) two-dimensional motion of a projectile with constant velocity in one direction and constant acceleration in a perpendicular direction.

Can we predict the motion of projectiles?

Using g

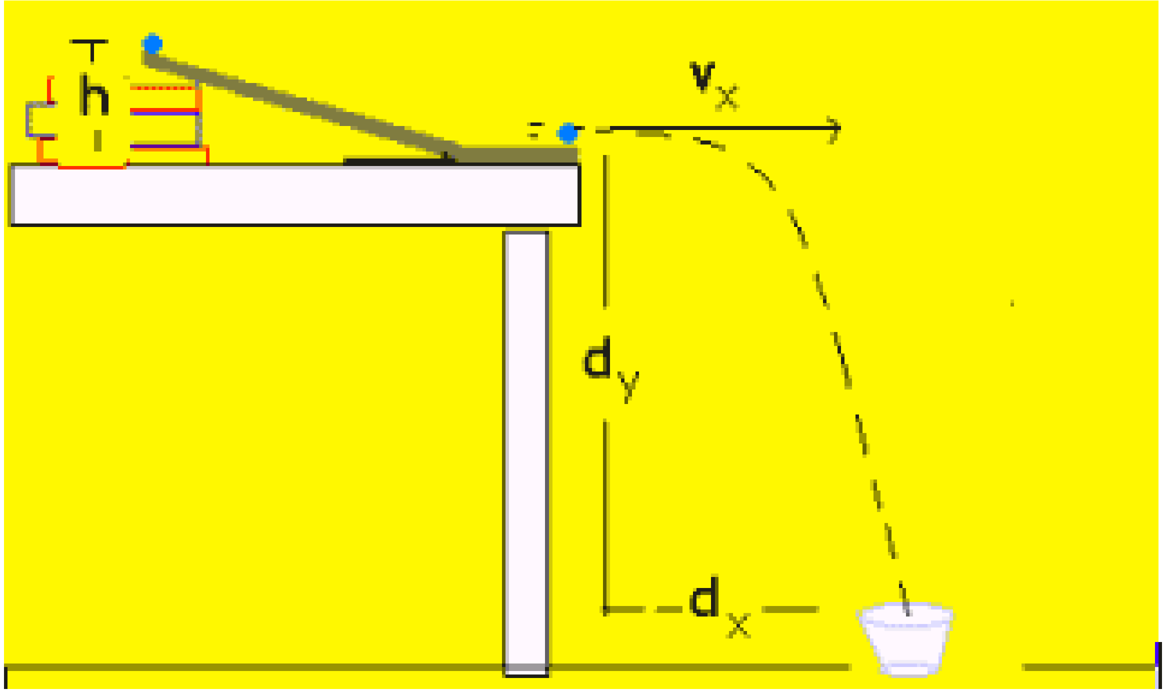
- If an object is thrown horizontally, the horizontal velocity of the object remains constant while it is accelerating downwards.



Answering questions about Freefall

- You need to treat the horizontal movement and vertical movement separately.
  - The SUVAT equations can then be applied to each.
- Take extra care with + and – signs.
- Do not keep rounding numbers throughout your calculations.
  - Rounding should only be done at the end.
  - Round to just one more significant figure than that given in the question.

- Practical (Projectile motion down a ramp)



For various launch heights, h, calculate the expected horizontal range, d_x, then place a cup on the floor at that position and see how correct you are.

How do you calculate dx?

Calculating the vectors

Vector calculations

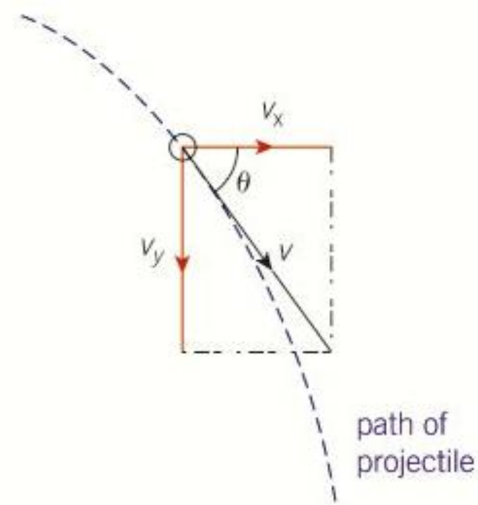
The path described by the cannonball in the worked example is curved because the vertical component of its velocity increases with time whilst the horizontal component is unaffected.

The magnitude of the actual velocity v of the cannonball, or any other projectile, can be calculated from the vertical and horizontal components v_x and v_y of this velocity. You just use Pythagoras' theorem (Figure 4).

$$\text{Actual velocity } v = \sqrt{v_x^2 + v_y^2}$$

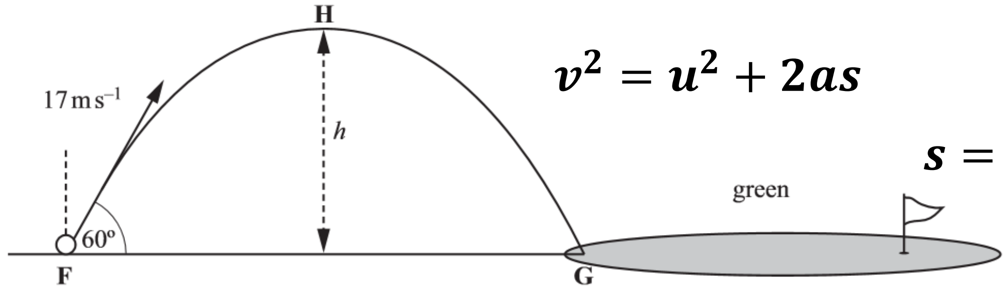
The angle θ made by the velocity to the horizontal is given by

$$\theta = \tan^{1} \frac{v_y}{v_x}$$



▲ **Figure 4** *The velocity v of a projectile has vertical and horizontal components*

Calculate the horizontal range of the golf ball, s_x, for each launch angle, and suggest which angle provides the longest shot.



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

$$s = vt - \frac{at^2}{2}$$

Initial velocity/ u	Launch angle /o	u_x /ms^{-1}	u_y /ms^{-1}	H_{max} /m	Time, t /s	s_x /m
17ms^{-1}	0					
	15					
	30					
	45					
	60					
	75					
	90					

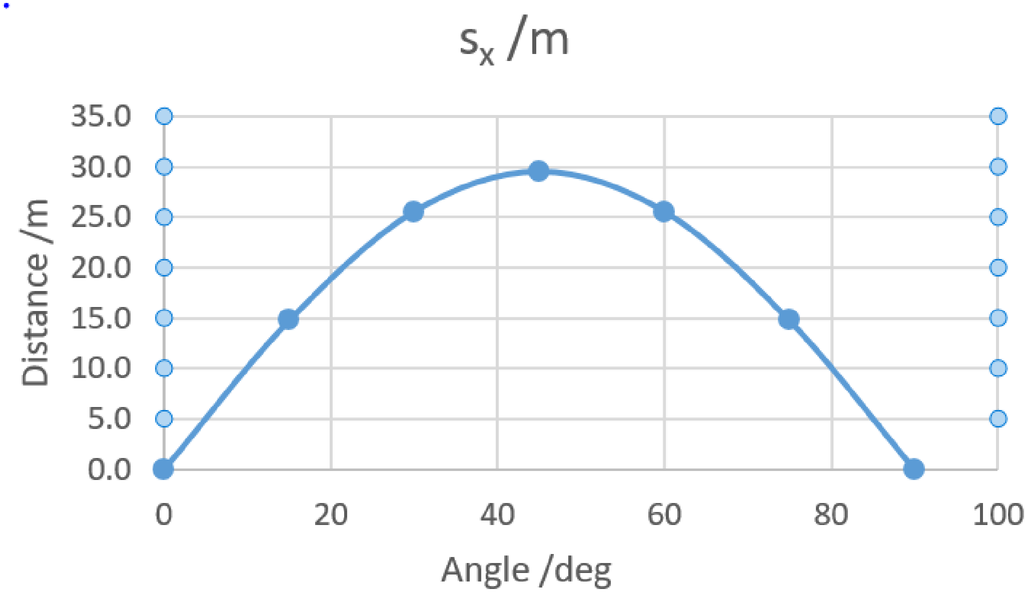
$17\cos\theta$ $\quad$ $17\sin\theta$ $\quad$ $\frac{-u_y^2}{-2a}$ $\quad$ $2\text{x}\sqrt{2H_{max}/a}$ $\quad$ $u_x t$

u /ms^{-1}	Angle /deg	u_x /ms^{-1}	u_y /ms^{-1}	H_{max} /m	t /s	s_x /m
17	0	17.0	0.0	0.0	0.00	0.0
	15	16.4	4.4	1.0	0.90	14.7
	30	14.7	8.5	3.7	1.73	25.5
	45	12.0	12.0	7.4	2.45	29.5
	60	8.5	14.7	11.0	3.00	25.5
	75	4.4	16.4	13.7	3.35	14.7
	90	0.0	17.0	14.7	3.47	0.0

In practice, a Driver provides the longest shot with a launch angle (club face) of just 11-12 degrees.

How come?

- **Air resistance increases with the square of the velocity.**
- **Ball spin produces uplift.**
- **Ball is struck as the club head is on its way upwards.**



3.1.3 Projectile Motion (review)

3.1.3 Projectile motion

Learning outcomes

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Module 3 – Forces and motion

Complete! → 3.1 Motion
3.2 Forces in action
3.3 Work, energy and power
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3.5 Newton's laws of motion and momentum

Module 4 – Electrons, waves and photons

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