Edexcel International A Level (IAL) Maths: Mechanics 1

Your notes

Constant Acceleration in 1D

Contents

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Your notes

Deriving the suvat Formulae

What is suvat?

- **suvat** is an acronym for the five quantities used when **modelling motion** in a **straight-line** with **constant acceleration**
  - **s** – displacement (from the starting point)
  - **u** – initial velocity
  - **v** – final velocity
  - **a** – acceleration
  - **t** – time
- All except time are **vector** quantities and can be **negative**
  - time is a **scalar** quantity

What are the suvat (constant acceleration) equations?

- The **five** equations for motion in a **straight line** are:

$$v = u + at$$

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

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

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

$$s = vt - \frac{1}{2}at^2$$

- The equations can **only be used** when the motion has **constant acceleration**
- All equations connect four of the five quantities
  - Knowing any **three** allows a **fourth** to be found
- The equations are **not provided** in the exam so you need to memorise them

How do I derive the suvat equations?

- The **four** equations that involve time can be derived from a **velocity-time** graph
  - The velocity-time graph will be a **straight line** as the **acceleration** is **constant**
  - The fifth equation can be found by choosing any two of the equations and eliminating the t variable (see the worked example)

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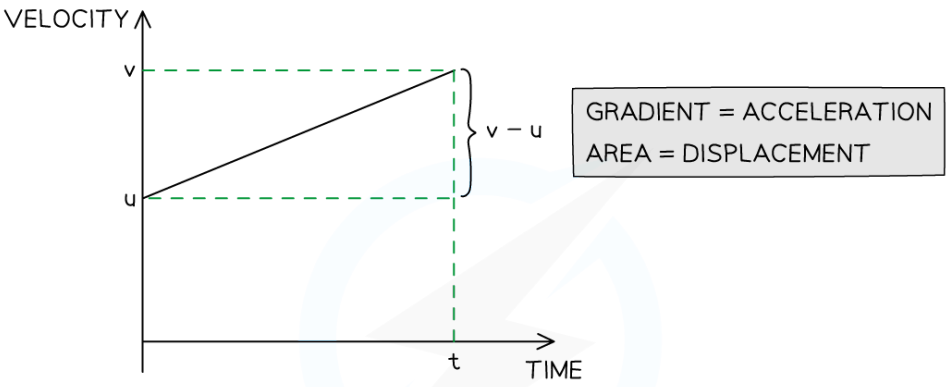

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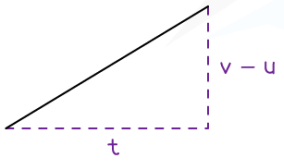
- USING GRADIENT = ACCELERATION



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

$$v - u = at$$

$$v = u + at$$

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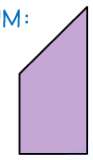
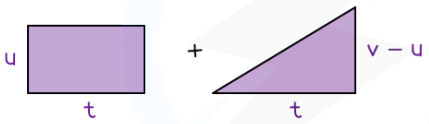
- USING DISPLACEMENT = AREA

TRAPEZIUM:



$$S = \frac{1}{2}(u+v)t$$

RECTANGLE + TRIANGLE:

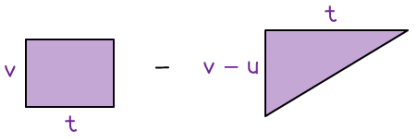


$$S = ut + \frac{1}{2}(v-u)t$$

$$S = ut + \frac{1}{2}(at)t$$

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

RECTANGLE − TRIANGLE:



$$S = vt - \frac{1}{2}(v-u)t$$

$$S = vt - \frac{1}{2}(at)t$$

$$S = vt - \frac{1}{2}at^2$$

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Worked Example

Use the constant acceleration equations

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

to show that

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

Answer:

We need to eliminate the 't'

Step 1: Rearrange $v = u + at$

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

Step 2: Substitute into $s = \frac{1}{2}(u + v)t$

$$S = \frac{1}{2}(u + v)\left(\frac{v - u}{a}\right)$$

Step 3: Rearrange into the required form

$2as = (u + v)(v - u)$ by multiplying by 2a

$2as = v^2 - u^2$ by expanding

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

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Examiner Tips and Tricks

- If asked to derive any of the formulae there may be a velocity-time graph provided. Make sure you show each step and state any reasons such as the gradient of the graph being the acceleration.
- If the question does not ask you to derive the formulae then you can use them freely without proof.

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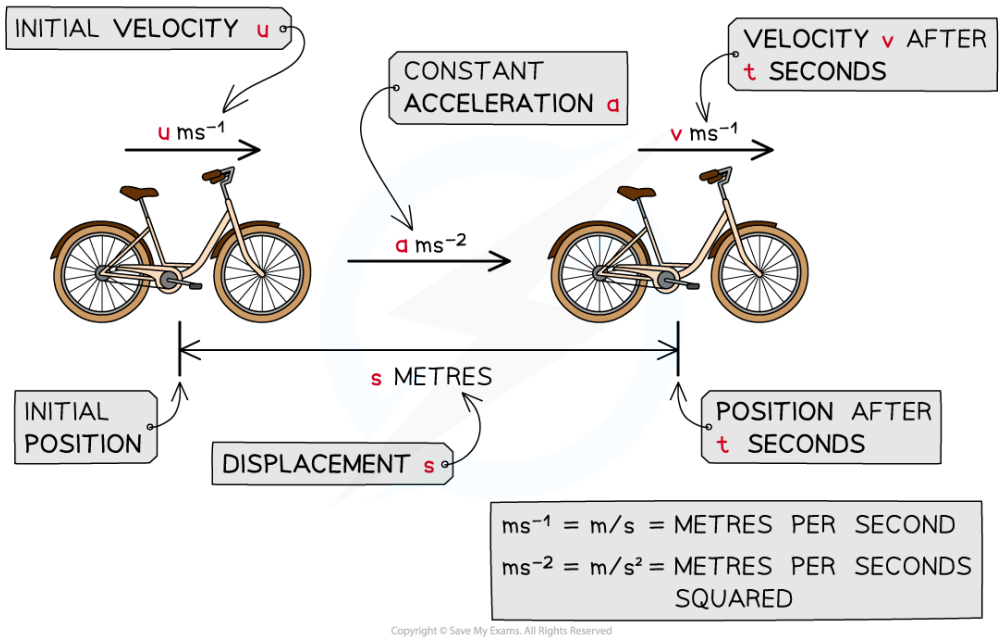
suvat in 1D

What are the suvat equations (constant acceleration formulae)?

- For constant acceleration there are **five suvat formulae:**

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



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How do I find suvat values from a question?

- Common phrases for **displacement**:
  - "...returns to its starting position ..." is a way of saying **s = 0**
- Common phrases for **velocity**:
  - "... initially at rest ...", "... stationary ..." are ways of saying **u = 0**

- "... comes to rest ..." is a way of saying **v = 0**

- Common phrases for **acceleration**:
  - "... falls freely ..." is a way of saying **a = ± g** (see the gravity section)
- Sometimes you will need to use other techniques (such as **Newton's Laws of Motion**) to find the **acceleration**

Your notes

How do I solve problems involving constant acceleration?

- **Step 1**: **Sketch** (or add to) a **diagram**
  - Use key information in the question to include all relevant values
  - Make sure you clearly show which direction you are choosing to be **positive**
    - Choose the positive direction wisely, try to choose the direction which will result in fewer negative values needed
    - You could choose the initial direction of motion to be positive or you could choose the direction of acceleration to be positive.
- **Step 2**: Write down what you **know** and what you are trying to **find**
  - You should know 3 of the variables and need to find a 4th
  - It's a good idea to go through each of the letters in the word **suvat** and make a note of the ones you know and which one you are trying to find
- **Step 3**: Select the **appropriate equation(s)**
- **Step 4**: **Solve** the equation(s) and problem
  - Include **units** in your answer and give your answer in **context** if appropriate

Can I use the suvat equations for vertical motion?

- The suvat equations also apply to vertical motion (provided the **acceleration** is **constant**)
  - The positive direction is particularly important
- Acceleration will often be related to **gravity**

How can suvat questions be made harder?

- Some problems involve splitting the motion into more than one part
  - For example if acceleration has changed (but is constant for each part)
  - A key feature of these problems is that **v** (**final velocity**) for the **first part** of the motion will be **u** (**initial velocity**) for the **second part** of the motion
- Some problems do not appear to give you enough information

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- You may have to form **two equations** using the suvat formulae and solve them **simultaneously**
- There may be more than one particle or multiple stages to the motion

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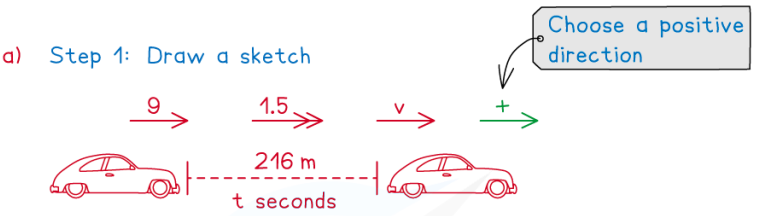
Worked Example

A car is driving along a straight horizontal road with speed 9 m s^{-1} when it begins to accelerate uniformly. The car accelerates at 1.5 m s^{-2} for 216 m. The driver then applies the brakes which causes it to decelerate at a constant rate. The car comes to rest after decelerating for 4 seconds.

(a) Find the speed at the instant that the brakes are applied.

Answer:

a) Step 1: Draw a sketch



Step 2: Write down the values we know/want

$s = 216$ $u = 9$ $v = v$ $a = 1.5$

Step 3: Select the equation

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

Step 4: Solve

$v^2 = 9^2 + 2(1.5)(216)$

$v^2 = 729$

$v = \pm 27$

$v = 27$ ms^{-1} v is positive as it is accelerating so $v > u$

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(b) Find the deceleration of the car after the brakes have been applied.

Answer:

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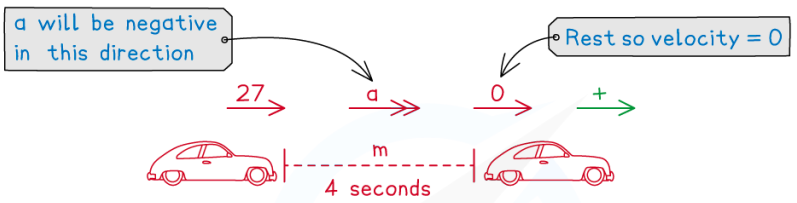
b) Step 1: Draw a sketch



Step 2: Write down the values we know/want

$u = 27 \quad v = 0 \quad a = a \quad t = 4$

Step 3: Select the equation

$v = u + at$

Step 4: Solve

$0 = 27 + 4a$

$4a = -27$

$a = -6.75$

Deceleration = $6.75\ ms^{-2}$

We don't need to write the negative sign as this is implied by "deceleration"

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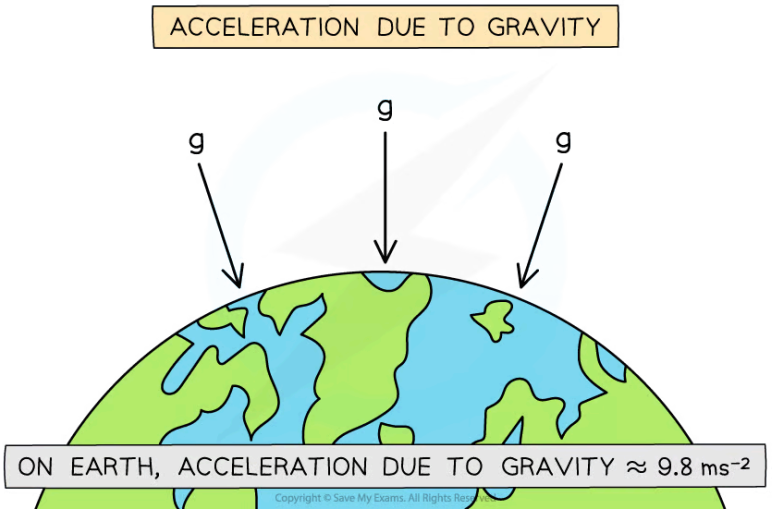
Examiner Tips and Tricks

- If an object is decelerating then its acceleration in that direction is negative. If you are asked to find the deceleration then you do not need to include the negative sign as this is implied by the word deceleration.
- If you need to use the answer from one part of a question in subsequent parts then use the full answer rather than the rounded answer, this avoids loss of accuracy.

Your notes

Acceleration due to gravity

What is acceleration due to gravity?



- If motion is vertical and no other forces are acting on a particle, the acceleration of the particle will be due to gravity
  - Acceleration due to gravity is denoted by the letter **g**
  - The value for gravity on Earth **varies** depending on location (the average value is 9.80665)
  - Take **g = 9.8** m s^{-2} unless told otherwise
  - It is often easier to leave working in terms of **g** as it sometimes cancels out or it can be calculated at the end
  - Some questions may ask for the answer to be left in terms of **g**
- Gravity will always act in the **downwards direction** towards the earth
  - If you decide **upwards** is the positive direction, then **a = -g**
  - If you decide **downwards** is the positive direction then **a = g**
  - It is important to be clear about which direction you have decided is positive

What is vertical displacement and vertical distance?

- There is a difference between **displacement** and **distance**
- It is more pronounced in **vertical** motion problems
  - Particles typically travel in both directions (up and down)

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- What goes up must come down!

- Displacement, **s**, is a vector
  - It is the **position** of a particle (at time **t**) relative to its **starting position**
  - It only takes into account where the particle started and ended
  - If a particle has returned to its starting position then its displacement will be zero
- Distance could be ...
  - ... the distance from the **start**
    - in which case distance is the **magnitude** of displacement
  - ... the distance **travelled**
  - ... the distance from the **origin**
    - the origin is not necessarily the starting position
  - ... the distance from another particle
- Read the question carefully to be clear about which of these you are finding

Your notes

How do I solve freefall questions using suvat equations?

- Virtually the same as suvat in 1D for **horizontal** motion
  - Follow the same steps and be careful with negatives
- You might have to spot that gravity is the acceleration by seeing the phrases:
  - "falling freely"
  - "projected"
  - "thrown/dropped"
- A **diagram** is important to help make clear ...
  - ... the **positive direction** of motion
  - ... the way in which acceleration relates to the positive direction
  - ... differences between displacement and distance
- Particles moving upwards will reach a **maximum height**
  - At the maximum height, velocity is instantaneously zero, **v = 0**
- If you use the value 9.8 for g then your **final answer** must be written as a **decimal** to **2 or 3 significant figures**
  - You may **lose marks** if you leave your answer as **more than 3** significant figures

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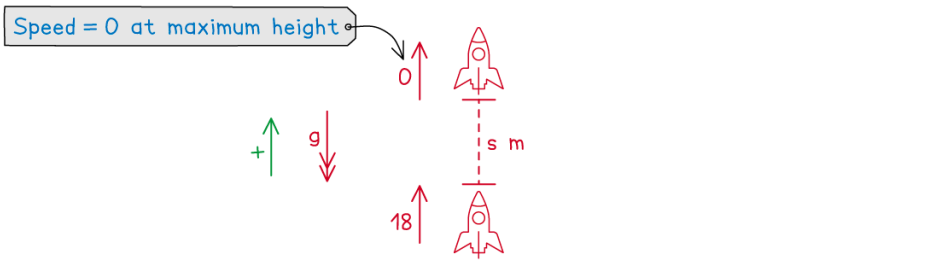
Worked Example

A toy rocket is projected vertically upwards from ground level with initial speed 18 m s^{-1}

(a) Find the maximum height the toy rocket reaches.

Answer:

a) Step 1: Draw a sketch



Step 2: Write down the values we know/want

$s = s \quad u = 18 \quad v = 0 \quad a = -g$

Negative as it is opposite direction to positive direction

Step 3: Select the equation

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

Step 4: Solve

$0 = 324 - 2gs$

$s = \frac{324}{2g}$

$s = \frac{324}{2(9.8)}$ Use $g = 9.8$

$s = \frac{810}{49}$ If your calculator gives you an exact answer then change to a decimal as a non-exact value for g has been used

$s = 16.530...$

Max height = 17 m (2 sf) or 16.5 m (3 sf)

As 9.8 was used, answer should be 2 sf or 3 sf

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(b) Find the time taken from the instant the toy rocket is projected to the instant it returns to the ground.

Answer:

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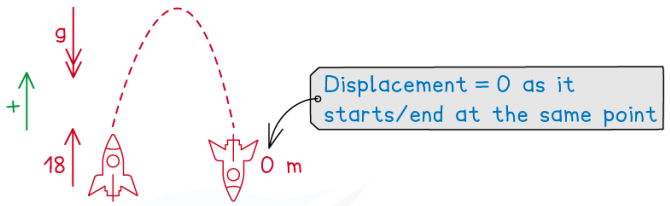
b) Step 1: Draw a sketch



Step 2: Write down the values we know/want

$s = 0 \quad u = 18 \quad a = -g \quad t = t$

Step 3: Select the equation

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

Step 4: Solve

$$0 = 18t - \frac{1}{2}gt^2$$

Multiply by 2

$$0 = 36t - gt^2$$

Factorise

$$0 = t(36 - gt)$$

This is the starting point

$$t = 0 \quad \text{or} \quad t = \frac{36}{g}$$

$$t = \frac{36}{9.8} = 3.6734...$$

Time = 3.7 s (2 sf) or 3.67 s (3 sf)

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Examiner Tips and Tricks

- If you are asked to find how long it takes before a particle returns to the ground, you can simply use suvat with
  - $s = 0$ if the particle started from the ground
  - $s = -h$ if the particle started a height of h m above the ground
- A common mistake is thinking that the speed of the object when it hits the ground is zero. This is incorrect! The object will be travelling with a speed at the instant it hits the ground. It is the impact that causes the speed to go to zero. For an object travelling vertically under gravity, the only time the speed is zero is when it is at its maximum height.