

Acceleration and velocity–time graphs

4.5.6.1.5 · Forces · revision notes

Acceleration is the rate of change of velocity. You need to use $a = \Delta v \div t$ and $v^2 - u^2 = 2 a s$, and find acceleration from the gradient of a velocity–time graph. You also need free fall and terminal velocity. This subtopic produces many calculation questions.

Key facts

- $a = \Delta v \div t$ (acceleration = change in velocity $\div$ time taken)
- Unit of acceleration: m/s^2
- Free-fall acceleration near the Earth's surface $\approx 9.8 \text{ m/s}^2$
- Terminal velocity: drag = weight, resultant force = 0
- $v^2 - u^2 = 2 a s$ (on the equations sheet)
- Deceleration = negative acceleration
- v–t graph: gradient = acceleration

Notes

Acceleration

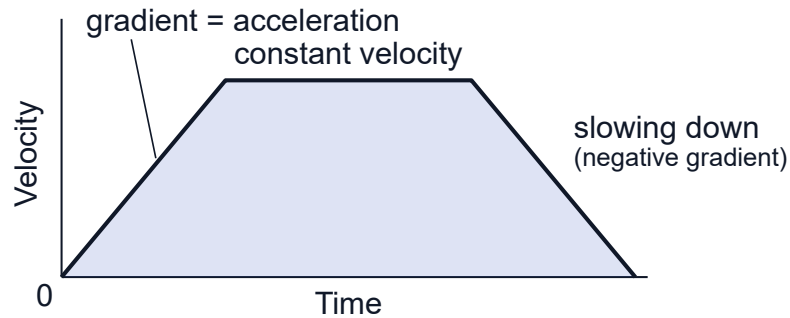
- Acceleration is the rate of change of velocity: $a = \Delta v \div t$
- a in m/s^2 , Δv (change in velocity = final velocity – initial velocity) in m/s , t in s .
- An object that slows down is **decelerating**. Its acceleration is negative.
- Near the Earth's surface, any object falling freely under gravity has an acceleration of about 9.8 m/s^2 .
- Everyday example: a car going from 0 to 30 m/s in about 10 s has an acceleration of about 3 m/s^2 .

Uniform acceleration: $v^2 - u^2 = 2 a s$

- $(\text{final velocity})^2 - (\text{initial velocity})^2 = 2 \times \text{acceleration} \times \text{distance}$. This equation is on the equations sheet.
- Use it when the acceleration is uniform and the question gives no time. u = initial velocity, v = final velocity, s = distance.
- Example: a ball dropped from rest falls 5.0 m . $v^2 = 0 + 2 \times 9.8 \times 5.0 = 98$, so $v = 9.9 \text{ m/s}$.

Velocity–time graphs

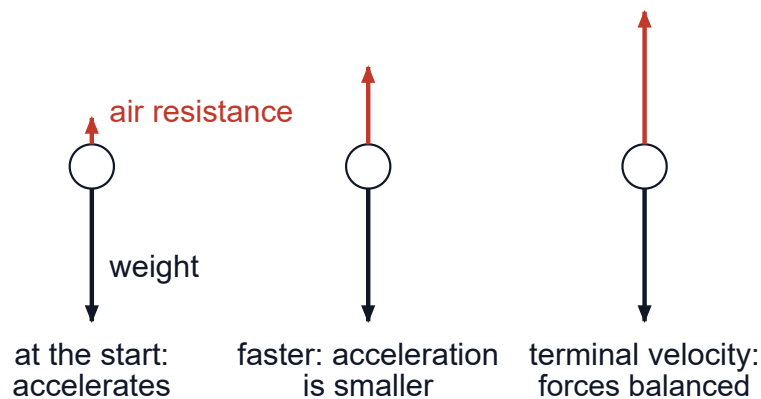
- Velocity is on the y-axis and time is on the x-axis.
- Horizontal line: constant velocity. Straight line sloping up: constant acceleration. Straight line sloping down: constant deceleration.
- **Gradient = acceleration.** A steeper line means a greater acceleration; a curved line means the acceleration is changing.



On a velocity–time graph the gradient is the acceleration.

Falling and terminal velocity

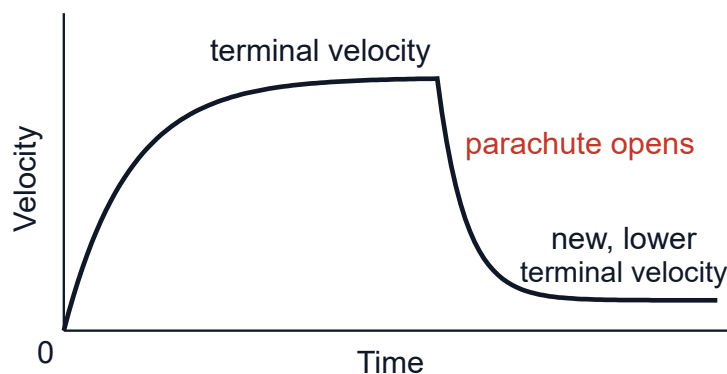
- An object falling through a fluid (air or a liquid) initially accelerates due to the force of gravity.
- As its speed increases, the drag (air resistance) on it increases, so the resultant force decreases.
- Eventually the resultant force is zero and the object moves at a steady speed: its **terminal velocity**.



As the skydiver speeds up, air resistance grows until it balances the weight.

Terminal velocity on a velocity–time graph

- At the start the line is steep: the acceleration is about 9.8 m/s^2 because drag is almost zero.
- The gradient decreases as drag increases, because the resultant force (weight – drag) gets smaller.
- The line becomes horizontal at terminal velocity, when drag = weight.
- When a skydiver opens a parachute, drag suddenly becomes greater than weight, so the skydiver decelerates until the drag has fallen to equal the weight again, at a new, lower terminal velocity.



A skydiver's velocity–time graph, before and after the parachute opens.

How to answer each type of question

Calculate acceleration

2 to 3 marks

Grade 4

1. Find the change in velocity: final – initial.
2. Divide by the time taken.
3. Give the unit m/s^2 .

Example. A train speeds up from 8.0 m/s to 20.0 m/s in 40 s .
Calculate its acceleration.

Model answer. $\Delta v = 20.0 - 8.0 = 12.0 \text{ m/s}$ (1)

$a = 12.0 \div 40$ (1)

$a = 0.30 \text{ m/s}^2$ (1)

Don't lose marks

- ✗ Using the final velocity instead of the change in velocity in $a = \Delta v \div t$.
- ✗ Forgetting to square u and v , or forgetting to take the square root at the end, in $v^2 - u^2 = 2 a s$.
- ✗ Reading a velocity–time graph as if it were a distance–time graph: a horizontal line on a v – t graph means constant velocity, not stationary.
- ✗ Saying there are no forces on an object at terminal velocity. The forces are balanced: drag = weight.
- ✗ Giving acceleration in m/s instead of m/s^2 .

More tips

Memory tricks

- Velocity–time graph: slope = acceleration.
- No time in the question? Use $v^2 - u^2 = 2 a s$.
Time given? Use $a = \Delta v \div t$.
- 'Starts from rest' means $u = 0$; 'comes to rest' means $v = 0$.
- Sense check: road vehicles accelerate at a few m/s^2 , not hundreds.
- Terminal velocity: forces balanced, speed steady.

Exam technique

- $a = \Delta v \div t$ must be recalled; $v^2 - u^2 = 2 a s$ is on the equations sheet.
- For graph questions, draw on the graph and write down the values you read.
- In terminal velocity explanations, describe what happens to the air resistance, then the resultant force, then the acceleration, in that order.
- For deceleration in $v^2 - u^2 = 2 a s$, use a negative value of a , or work with sizes and say 'deceleration'.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4

Calculate acceleration using $a = \Delta v \div t$

From 4 m/s to 16 m/s in 3 s: $a = 12 \div 3 = 4 \text{ m/s}^2$.

Grade 4

Describe motion from a velocity–time graph

Horizontal line: constant velocity; sloping up: accelerating; sloping down: decelerating.

Grade 5

Find acceleration from a velocity–time graph

Acceleration = gradient = change in velocity $\div$ time taken.

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