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 $v^2 - u^2 = 2 a s$, find acceleration from the gradient of a velocity–time graph and, on the Higher tier, find the distance travelled from the area under it. 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 ÷ time taken)
- Unit of acceleration: m/s^2
- Free-fall acceleration near the Earth's surface ≈ 9.8 m/s^2
- Grade 7+ only v–t graph: area under the line = distance travelled
- $v^2 - u^2 = 2 a s$ (on the equations sheet)
- Deceleration = negative acceleration
- v–t graph: gradient = acceleration
- Terminal velocity: drag = weight, resultant force = 0

Notes

Acceleration

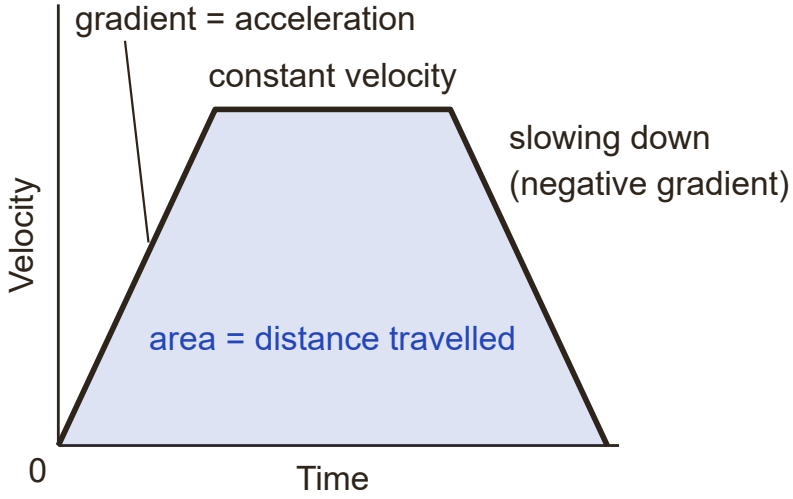
- Acceleration is the rate of change of velocity: **$a = \Delta v \div t$**
- a in m/s^2, Δv (change in velocity = final velocity − initial velocity) in m/s, t in s.
- An object that slows down is **decelerating**. Its acceleration is negative.
- Near the Earth's surface, any object falling freely under 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 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.

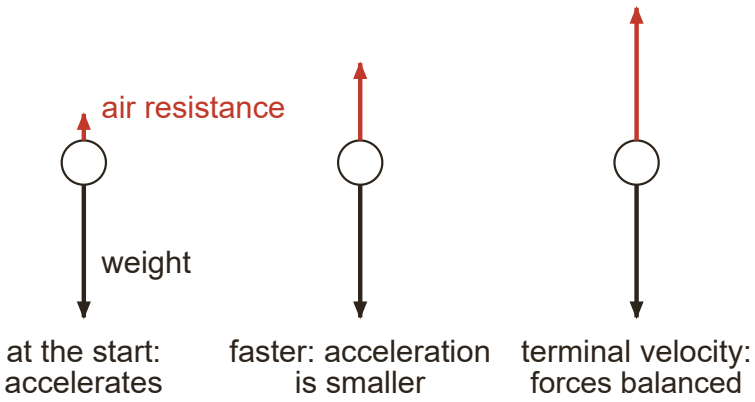


On a velocity–time graph the gradient is the acceleration and the area underneath is the distance travelled.

- **Area under the graph = distance travelled** (or displacement). Split the area into rectangles (base × height) and triangles (½ × base × height). Grade 7+ only
- For a curved line, count the squares under it (count a square if at least half of it is under the line), then multiply by the distance one square represents. Grade 8+ only

Falling and terminal velocity

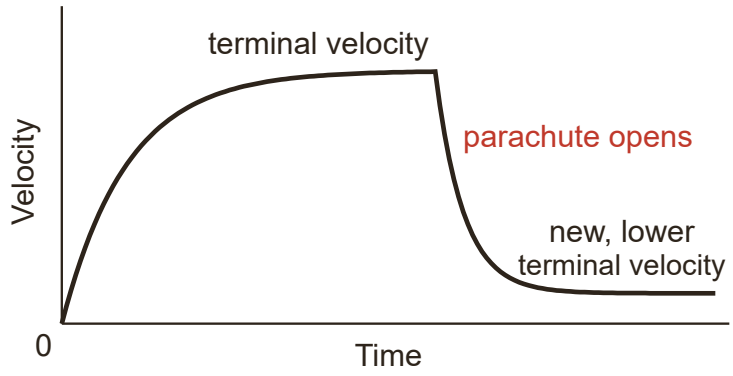
- An object falling through a fluid (air or a liquid) initially accelerates due to the force of gravity.
- As its speed increases, the drag (air resistance) on it increases, so the resultant force decreases.
- Eventually the resultant force is zero and the object moves at a steady speed: its **terminal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

$\Delta v = 20.0 - 8.0 = 12.0$ m/s (1)

$a = 12.0 \div 40$ (1)

$a = 0.30$ m/s^2 (1)

Use $v^2 - u^2 = 2as$

3 marks **Grade 6**

1. Write down u, v, a and s, including any that are zero.
2. Substitute into $v^2 - u^2 = 2\,a\,s$. Use a negative acceleration for slowing down.
3. Rearrange and calculate. Remember the square root if you are finding a velocity.

Example. A car travelling at 25 m/s decelerates uniformly at 5.0 m/s^2 until it stops. Calculate the distance it travels while decelerating.

Model answer.

$0^2 - 25^2 = 2 \times (-5.0) \times s$ (1)

$-625 = -10 \times s$ (1)

$s = 62.5$ m (1)

Gradient and area of a velocity–time graph

4 marks **Grade 7**

1. Acceleration: gradient = change in velocity ÷ time.
2. Distance: split the area under the line into rectangles and triangles.
3. Add the areas, with the unit m.

Example. A velocity–time graph for a cyclist is a straight line from 0 m/s at 0 s to 8.0 m/s at 10 s, then a horizontal line at 8.0 m/s until 30 s.
(a) Calculate the acceleration in the first 10 s.
(b) Calculate the total distance travelled in the 30 s.

Model answer.

(a) $a = 8.0 \div 10$ (1) = 0.80 m/s^2 (1)

(b) triangle = ½ × 10 × 8.0 = 40 m; rectangle = 20 × 8.0 = 160 m (1)

total distance = 200 m (1)

Explain the motion of a falling object in terms of forces 4 marks **Grade 7**

1. At the start: weight is the only significant force, so the object accelerates.
2. As the speed increases, air resistance increases.
3. So the resultant force and the acceleration decrease.
4. Finally air resistance = weight, so the resultant force is zero: terminal velocity.

Example. A skydiver jumps from a plane.
Explain, in terms of the forces acting, why the skydiver's velocity increases at first and then becomes constant.

Model answer.

At first, weight is much bigger than air resistance, so there is a resultant force downwards and the skydiver accelerates (1).
As the velocity increases, the air resistance increases (1).
So the resultant force decreases and the acceleration decreases (1).
Eventually the air resistance equals the weight, the resultant force is zero and the skydiver falls at terminal velocity (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.
- Leaving out the ½ for a triangle area, or using ½ for a rectangle.
- 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, area = distance.
- 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

- $a = \Delta v \div t$ and $v^2 - u^2 = 2\,a\,s$ are both on the Physics Equations Sheet: pick the one that fits the data.
- 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: $a = 12 \div 3 = 4\ m/s^2$.

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 ÷ time taken.

Grade 6 — **Use the equation $v^2 - u^2 = 2as$**
It is on the equations sheet and applies to uniform acceleration; rearrange it for a, s, u or v.

Grade 6 — **Explain terminal velocity for a falling object**
It accelerates at first; drag increases with speed until the resultant force is zero.

Grade 7 — **Estimate the size of everyday accelerations**
For example, a car reaching 30 m/s in about 10 s accelerates at about $3\ m/s^2$.

Grade 7 — **Find distance from area under v–t graph**
Split the area into rectangles and triangles and add them.

Grade 8 — **Count squares to find area under curves**
Count the squares under a curved line and multiply by the distance one square represents.

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