AQA AS Kinematics, Projectile Motion and Terminal Speed solutions

Matching solutions and teaching prompts for the class review

Specification points covered

• 3.4.1.3(a–c) Displacement, speed, velocity and acceleration. • 3.4.1.3(d–f) Motion graphs, gradients and areas. • 3.4.1.3(g–h) Uniform acceleration and straight-line motion.	• 3.4.1.4(a–d) Independent horizontal and vertical projectile motion. • 3.4.1.4(e–h) Drag, non-uniform acceleration and terminal speed. • 8.2.RP3 Determination of g by a free-fall method.

Teaching focus

Correct phrases such as ‘the velocity is accelerating’ to a quantity that increases, decreases or remains constant.
Use graph gradients and areas as physical quantities with units.

1. Survey-line motion

1. Define displacement, velocity and acceleration. Each definition must identify whether the quantity is a vector and what changes with time. [3 marks]

Answer / mark points: Displacement is distance in a stated direction from a reference point. Velocity is rate of change of displacement and is a vector. Acceleration is rate of change of velocity and is a vector.

Teacher prompt / common error: Velocity is not simply speed with a direction unless it is tied to displacement change.

2. A monitoring drone flies 600 m east in 50 s and then 200 m west in 20 s. Calculate its total distance, displacement, average speed and average velocity. [4 marks]

Answer / mark points: Distance = 600 + 200 = 800 m. Displacement = 400 m east. Average speed = 800/70 = 11.4 m s^{-1}. Average velocity = 400/70 = 5.71 m s^{-1} east.

Teacher prompt / common error: Distance and speed are scalars; displacement and velocity need the east direction.

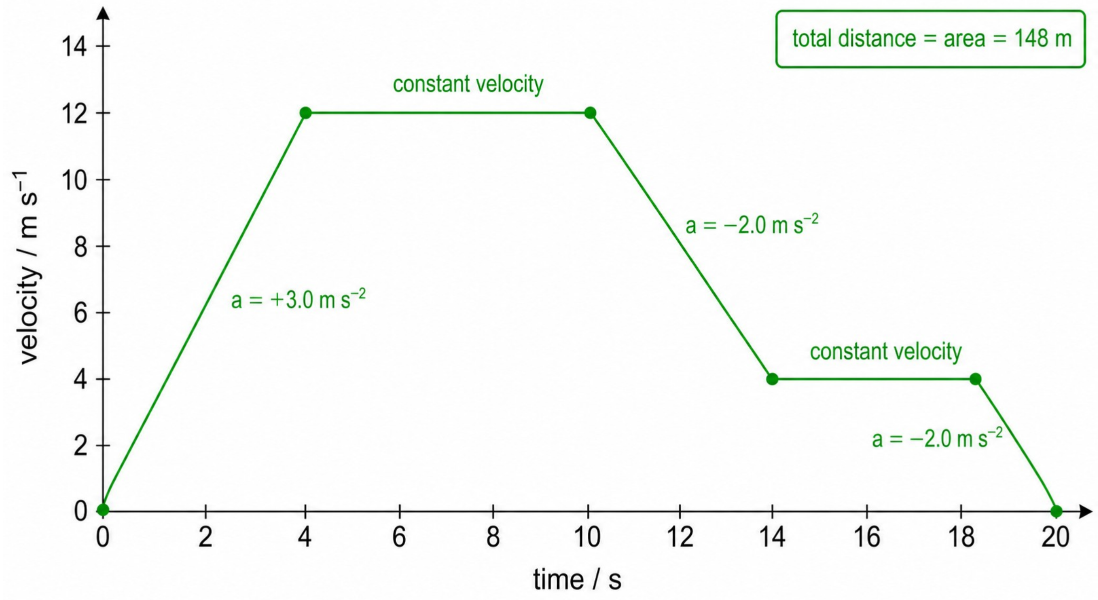
3. The drone increases its velocity uniformly from 0 to 18.0 m s^{-1} in 6.00 s. Calculate its acceleration and displacement during this interval. [3 marks]

Answer / mark points: $a = \Delta v/\Delta t = 18.0/6.00 = 3.00$ m s^{-2}. Displacement is the area under the velocity–time graph, ½ × 6.00 × 18.0 = 54.0 m.

Teacher prompt / common error: For a straight v–t segment, gradient gives acceleration and area gives displacement.

2. Reading the flight graph

4. The velocity–time graph shows the drone's motion along a straight survey line. Describe the motion during each of the five straight-line sections. Use the words velocity and acceleration precisely. [3 marks]



Answer / mark points: 0–4 s: velocity increases linearly, so acceleration is constant and positive. 4–10 s: velocity remains constant at 12 m s^{-1}, so acceleration is zero. 10–14 s: velocity decreases linearly from 12 to 4 m s^{-1}, so acceleration is constant and negative. 14–18 s: velocity remains constant at 4 m s^{-1}. 18–20 s: velocity decreases linearly to zero, so the drone has constant negative acceleration and stops.
Teacher prompt / common error: A velocity cannot ‘accelerate’; it increases, decreases or remains constant.

5. Use the graph to calculate the total distance travelled from 0 to 20 s. [3 marks]

Answer / mark points: Distance = area under the graph = ½(4)(12) + (6)(12) + ½(12 + 4)(4) + (4)(4) + ½(2)(4) = 148 m.
Teacher prompt / common error: Add geometrical areas without counting the same interval twice.

6. Use the graph to calculate the displacement between 8.0 s and 16.0 s. [2 marks]

Answer / mark points: From 8–10 s: 24 m. From 10–14 s: 32 m. From 14–16 s: 8 m. Total displacement = 64 m.
Teacher prompt / common error: Use only the portion from 8 s to 16 s.

3. Releasing the sensor

7. The drone releases a sensor horizontally at 18.0 m s^{-1} from a height of 45.0 m. Ignore air resistance. Calculate the time to reach the ground and the horizontal distance travelled. [4 marks]

Answer / mark points: Vertical motion: $45.0 = \frac{1}{2}gt^2$, so $t = \sqrt{(90.0/9.81)} = 3.03$ s. Horizontal distance = $18.0 \times 3.03 = 54.5$ m.
Teacher prompt / common error: Horizontal velocity does not determine the fall time when drag is ignored.

8. For the release in Question 7, calculate the vertical component and the magnitude and direction of the sensor's velocity immediately before impact. [3 marks]

Answer / mark points: Vertical component just before impact = $gt = 9.81 \times 3.03 = 29.7$ m s^{-1} downward. Resultant speed = $\sqrt{(18.0^2 + 29.7^2)} = 34.7$ m s^{-1}. Direction = $\tan^{-1}(29.7/18.0) = 58.8°$ below the horizontal.
Teacher prompt / common error: Combine perpendicular velocity components and state ‘below the horizontal’.

9. Air resistance is now significant. Explain how it changes the horizontal velocity, the vertical acceleration while the sensor is falling, and the shape or range of the trajectory. Do not assume the acceleration remains equal to g. [3 marks]

Answer / mark points: Drag opposes the velocity. The horizontal velocity decreases, so horizontal acceleration is not zero. During the downward part, upward drag makes the magnitude of vertical acceleration less than g. The trajectory is not a symmetric parabola and its horizontal range is generally reduced.
Teacher prompt / common error: With drag, neither horizontal velocity nor vertical acceleration must remain constant.

4. Falling through volcanic gas

10. A sampling capsule falls through dense volcanic gas and reaches terminal speed. Describe how its velocity, acceleration, weight and drag change from release until terminal speed is reached. Use increase, decrease or remain constant for each quantity. [4 marks]

Answer / mark points: Weight remains constant. Initially drag is small, so the downward resultant force and acceleration are large. As downward velocity increases, drag increases; the resultant force and acceleration decrease. At terminal speed drag equals weight, the resultant force is zero, acceleration remains zero and velocity remains constant.	
Teacher prompt / common error: At terminal speed the velocity is constant, not zero; the forces are balanced.	

11. The capsule has mass 2.40 kg. Calculate the upward drag force when it moves at terminal speed. [1 mark]

Answer / mark points: At terminal speed drag = weight = 2.40 × 9.81 = 23.5 N upward.

Teacher prompt / common error: Use force equilibrium at terminal speed.

12. Capsules X, Y and Z have the same shape and move through the same gas. X has mass 2.40 kg and area 0.050 m². Y has mass 4.80 kg and area 0.050 m². Z has mass 2.40 kg and area 0.100 m². Predict the order of their terminal speeds from greatest to smallest and explain your reasoning. [3 marks]

Answer / mark points: Y has the greatest terminal speed because the larger weight requires a larger drag, reached at a higher speed for the same area. Z has the lowest because its larger area produces more drag at a given speed. Order: Y, X, Z.

Teacher prompt / common error: Terminal speed is the speed at which drag has increased to match weight.

5. Measuring gravitational acceleration

13. Design a high-speed-camera experiment to determine g from the free fall of a small target. Include a scale, frame rate or timing method, measurements, a graph or calculation, repeats, uncertainty reduction and safety. Explain how the analysis identifies a constant acceleration rather than merely a high speed. [6 marks]

Answer / mark points: Award one mark for each valid point, to six: place a vertical scale in the same plane as the motion; record with a known high frame rate or reliable time stamps; release without a push; obtain position at successive known times; plot displacement against t^2 so a straight line supports constant acceleration and g is twice the gradient, or obtain velocities and use the gradient of a v–t graph; use many frames, a long safe fall, repeats and an average; reduce parallax and calibrate pixels against the scale; use a safe catch zone and secure the camera. Speed alone does not establish acceleration; the change of velocity or the t^2 relationship does.
Teacher prompt / common error: A method must show how measured positions and times produce g and must control scale and parallax.

Language and method check

Award independent, creditworthy physics steps; do not award extra marks for repeated statements.
Accept equivalent methods when the physical reasoning, units and final precision remain consistent.