

2.1.4 Free fall and measuring g

Name: _____ Class: _____ Date: _____

Total: 38 marks

KEY WORDS air resistance

• acceleration

• free fall

• acceleration of free fall

• uniform gravitational field

Objective

Answer exam questions on **free fall** : vertical motion when the only force on the object is its weight. Syllabus 2.1, learning outcomes 7 (vertical motion) and 8.

You must be able to:

- state the facts about the **acceleration of free fall** g , and define acceleration
- solve vertical motion in a **uniform gravitational field** with one sign convention, when **air resistance** is negligible
- sketch and read the velocity–time graph of a falling, thrown or bouncing object
- explain the effect of air resistance, and **describe** how to measure g , including a **systematic error**

1 Key knowledge and worked examples

■ Key knowledge: free fall

Fact	What it means
free fall	the only force is the weight: “air resistance is negligible”
$g = 9.81 \text{ m s}^{-2}$	vertically downwards, and the same for every mass
g acts all the time	going up, at the top ($v = 0$, but a is not zero), coming down
g is constant	the four equations apply, with $a = g$
back at the launch level	time up = time down, and the same speed

Definitions, one mark each: **acceleration** is the rate of change of velocity; **velocity** is the rate of change of displacement.

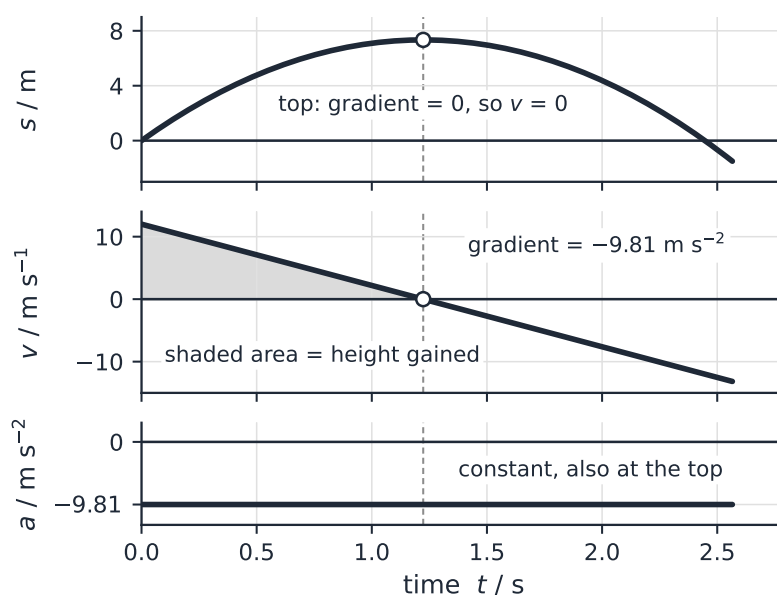
■ **Key knowledge: one sign convention**

Choose **up** as positive and keep it. Then $a = -9.81 \text{ m s}^{-2}$ for the whole flight.

In the question	Write
thrown upwards at $12 \frac{\text{m}}{\text{s}}$	$u = +12 \frac{\text{m}}{\text{s}}$
dropped, or released from rest	$u = 0$
released from a balloon rising at $4.0 \frac{\text{m}}{\text{s}}$	$u = +4.0 \frac{\text{m}}{\text{s}}$, not zero
at the greatest height	$v = 0$
back at the level of the throw	$s = 0$
lands 1.5 m below the throw	$s = -1.5 \text{ m}$
moving downwards	v is negative

Equations: $v = u + at$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$. List s , u , v , a , t , then use the equation with your three knowns and your unknown.

■ **Key knowledge: the graphs, and air resistance**



A ball thrown upwards at 12 m s^{-1} from a hand 1.5 m above the ground, up positive

- velocity–time: **one straight line**, never a V shape; its **gradient** is the acceleration, -9.81 m s^{-2} , and it crosses the axis at the top
- area above the axis = height gained; area below = height lost
- with air resistance: it grows with speed, so the **resultant force** is less than the weight, so the acceleration is less than g : the object lands later and slower

than the equations predict

■ Worked example: up and down

The ball in the graphs: $u = +12 \frac{\text{m}}{\text{s}}$, $a = -9.81 \text{ m s}^{-2}$, and the ground is 1.5 m below the hand. In every step: what you know, **the equation**, then the numbers.

- greatest height: at the top $v = 0$, and t is not known, so use $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - (12 \frac{\text{m}}{\text{s}})^2}{2(-9.81 \text{ m s}^{-2})} = 7.3 \text{ m}$$

- time to the top: use $v = u + at$

$$t = \frac{v - u}{a} = \frac{0 - 12 \frac{\text{m}}{\text{s}}}{-9.81 \text{ m s}^{-2}} = 1.2 \text{ s}$$

- time to reach the ground: $s = -1.5 \text{ m}$, and v is not known, so use $s = ut + \frac{1}{2}at^2$ (values in m and s); the negative root is rejected

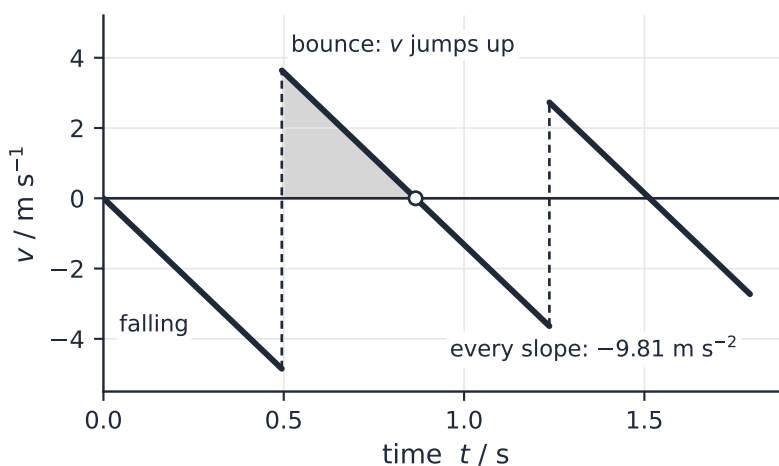
$$-1.5 = 12t - 4.905t^2 \Rightarrow 4.905t^2 - 12t - 1.5 = 0 \Rightarrow t = 2.6 \text{ s}$$

- velocity on landing: use $v^2 = u^2 + 2as$; the minus sign means moving downwards

$$v^2 = u^2 + 2as = (12 \frac{\text{m}}{\text{s}})^2 + 2(-9.81 \text{ m s}^{-2})(-1.5 \text{ m}) \Rightarrow v = -13 \frac{\text{m}}{\text{s}}$$

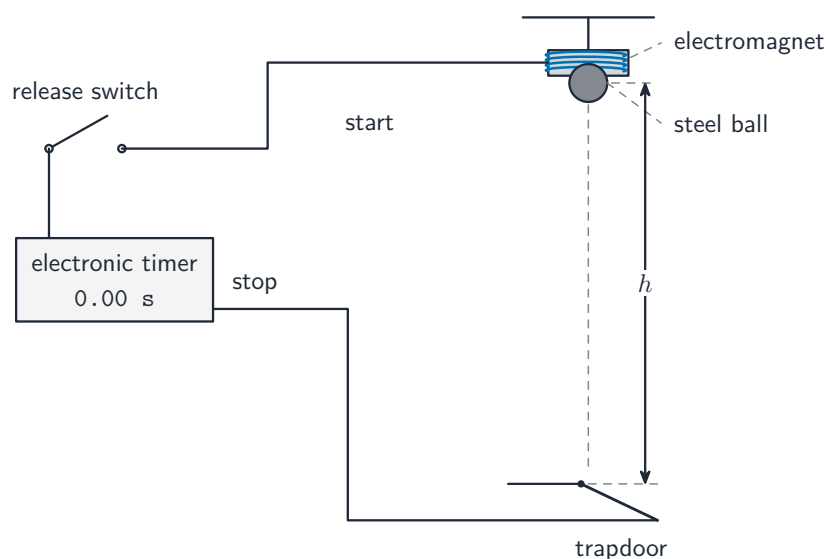
■ Worked example: a bouncing ball

A ball is dropped from rest from 1.2 m and bounces. Up is positive.



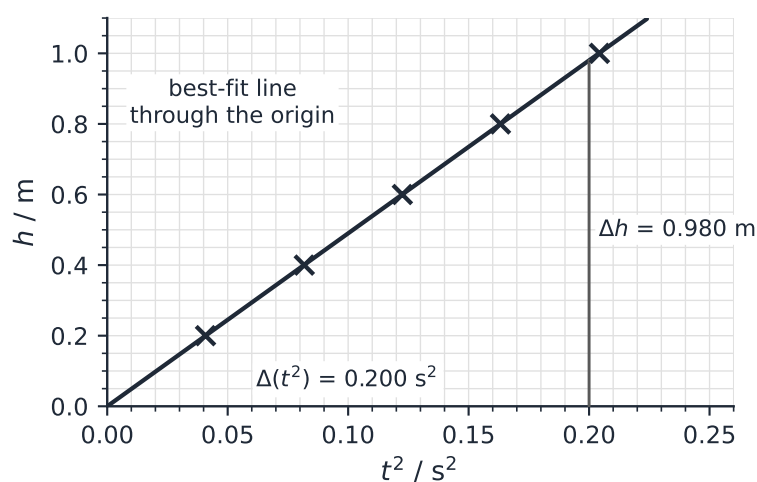
- every sloping line has gradient -9.81 m s^{-2} ; at a bounce v jumps from negative to positive, and it is smaller after the bounce
- top of a bounce: the line crosses the axis; bounce height = area of the triangle, $h = \frac{1}{2}tv = \frac{1}{2} \times 0.37 \text{ s} \times 3.6 \frac{\text{m}}{\text{s}} = 0.67 \text{ m}$

■ Worked example: measuring g



You must be able to **describe** this experiment:

1. Measure the height h from the bottom of the ball to the trapdoor with a metre rule.
2. Switching off the **electromagnet** releases the ball and starts the timer; the ball opens the trapdoor, which stops it: the fall time t .
3. Repeat, take the mean, and use five heights. Plot h against t^2 : from $h = \frac{1}{2}gt^2$ the gradient is $\frac{1}{2}g$.

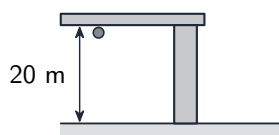


- gradient = $0.980 \text{ m} \div 0.200 \text{ s}^2 = 4.90 \text{ m s}^{-2}$, so $g = 2 \times \text{gradient} = 9.80 \text{ m s}^{-2}$
- uncertainty: $g = 2h/t^2$, so add the percentages and count the time twice: $0.25\% + 2 \times 0.99\% = 2.2\%$
- systematic error: a late release makes every t too long, so g is too small and the line misses the origin

2 Practice

2.1 A stone is dropped from rest from a bridge 20 m above a river. Air resistance is negligible.

- (a) Calculate the time taken for the stone to reach the water. [2]

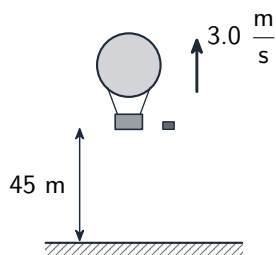


- (b) Calculate the speed of the stone as it reaches the water. [2]

2.2 A camera falls out of a hot-air balloon that is rising at $3.0 \frac{\text{m}}{\text{s}}$. At that moment the camera is 45 m above the ground.

- (a) State the velocity of the camera at the moment it leaves the balloon. [1]
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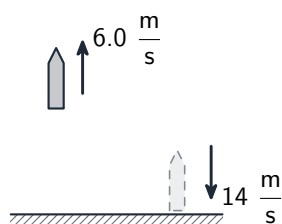
- (b) Calculate the time taken for the camera to reach the ground. (*Hint: with up as positive, $s = -45 \text{ m}$.*) [3]



2.3 The engine of a toy rocket stops when the rocket is moving vertically upwards at $6.0 \frac{\text{m}}{\text{s}}$. The rocket then moves freely, and it hits the ground at a speed of $14 \frac{\text{m}}{\text{s}}$. Air resistance is negligible. Take up as positive.

(a) State the velocity of the rocket as it hits the ground. [1]

(b) Calculate the height of the rocket above the ground when its engine stops. [2]



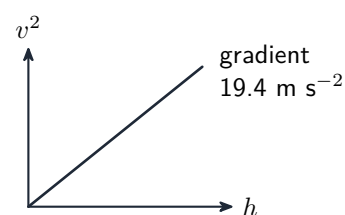
(c) Calculate the time from the engine stopping until the rocket hits the ground. [2]

3 Exam-style questions

3.1 A ball is dropped from rest through different heights h , and its speed v at a light gate is measured each time. A graph of v^2 against h is a straight line through the origin with gradient 19.4 m s^{-2} . What is g ? [1]

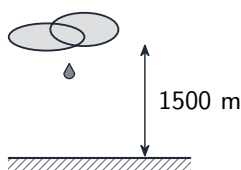
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- A 4.9 m s^{-2}
- B 9.7 m s^{-2}
- C 19 m s^{-2}
- D 39 m s^{-2}



3.2 A raindrop falls from rest from a cloud 1500 m above the ground.

- (a) Calculate the speed at which the raindrop would reach the ground if air resistance were negligible. [2]



- (b) Raindrops really reach the ground at about $9 \frac{\text{m}}{\text{s}}$. Explain why this is so much less than your answer to (a). [3]

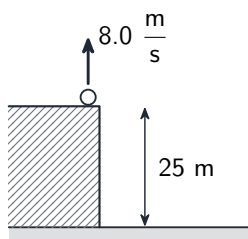
3.3 A ball is thrown vertically upwards at $8.0 \frac{\text{m}}{\text{s}}$ from the top of a cliff. It then falls past the cliff top into the sea 25 m below. Air resistance is negligible. Take up as positive.

- (a) Define *acceleration*. [1]

- (b) Calculate the greatest height of the ball above the cliff top. [2]

- (c) Calculate the time from the throw until the ball reaches the sea. [3]

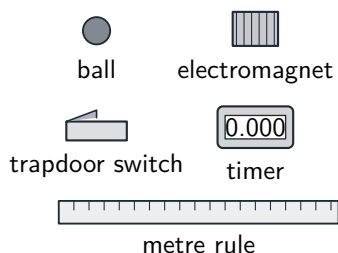
- (d) **Sketch** the velocity–time graph of the ball from the throw until it reaches the sea. Mark the values of the velocity at the start and at the end. [3]



- (e) A heavier ball is thrown in the same way. State and explain how, if at all, this changes the time taken to reach the sea. [2]

3.4 A student has a steel ball, an electromagnet, a trapdoor switch, an electronic timer and a metre rule. She uses them to determine the acceleration of free fall g .

- (a) **Describe** how she carries out the experiment. Include the measurements she takes and how she finds g from a graph. [4]



- (b) For one height, $h = 0.750 \pm 0.002$ m and $t = 0.393 \pm 0.005$ s. Calculate g . [2]

- (c) The electromagnet takes a short time to release the ball after the timer starts. State and explain the effect of this on the value of g calculated from one measurement. [2]
