

Exercise walk-through

2.1.4

Free fall and measuring g

A-Level Physics

Sheet 2.1.4 – what you need to know

You must be able to:

- state the facts about g : the same for every mass, also at the top
- use **one sign convention** for a whole flight
- sketch the v - t graph of a thrown or a bouncing object
- explain the effect of air resistance; **describe** how to measure g

What the exam asks

“Show that the maximum height is ...” [2]

“Sketch the variation of v with t from 0 to T .” [3]

“State what the gradient represents.” [1]

Practise on exercise sheet 2.1.4, then try the real exam questions on past-paper sheet 2.1.4.

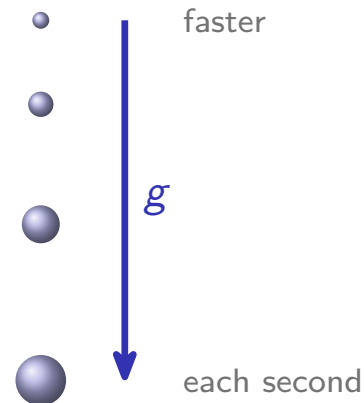
Free fall under gravity

Ignore **air resistance** : **free fall** in
a **uniform gravitational field** has
constant $g \approx 9.81 \text{ m s}^{-2}$ downward.

Dropped from rest, falling a height h :

$$h = \frac{1}{2}gt^2, \quad v = gt, \quad v^2 = 2gh.$$

Same for every mass – a feather and a hammer fall together in a vacuum and land at the **same speed**.



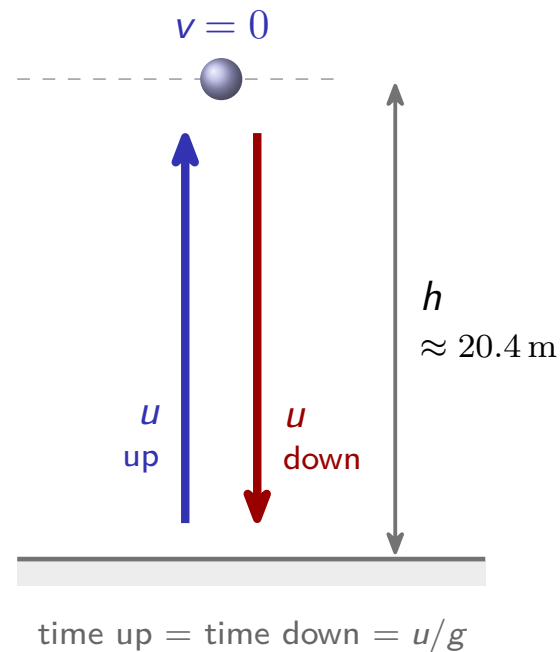
Worked example – greatest height

Thrown straight up at $u = 20 \text{ m s}^{-1}$

At the top $v = 0$, so $h = \frac{u^2}{2g}$:

$$h = \frac{20^2}{2 \times 9.81} = \frac{400}{19.62} \approx 20.4 \text{ m.}$$

Up and back is **symmetric** : total time
 $= 2u/g$.



One sign convention for the whole flight

Choose one direction as positive, usually **up**, and keep it. Then $a = -9.81 \text{ m s}^{-2}$ **all the time**.

In the question

Write

thrown upwards at 12 m s^{-1}

$$u = +12 \text{ m s}^{-1}$$

dropped, or released from rest

$$u = 0$$

released from something moving at velocity w

$$u = w, \text{ not zero}$$

at the greatest height

$$v = 0$$

back at the level of the throw

$$s = 0$$

lands 1.5 m below the throw

$$s = -1.5 \text{ m}$$

At the top the velocity is zero, but the acceleration is **not**: it is still 9.81 m s^{-2} downwards.

Worked example – thrown up, lands below

12 m s^{-1} upwards from a hand 1.5 m above the ground

up positive: $u = +12$, $a = -9.81$, $s = -1.5$

$s = ut + \frac{1}{2}at^2$: $-1.5 = 12t - 4.905t^2$, so
 $t = 2.6 \text{ s}$

$v^2 = u^2 + 2as$: $v^2 = 12^2 + 2(-9.81)(-1.5)$, so
 $v = -13 \text{ m s}^{-1}$

The other root is negative, a time before the throw: reject it. The minus sign on v means **moving down**.

Released from something moving

A sandbag leaves a balloon rising at 4.0 m s^{-1} , 30 m up.

$u = +4.0 \text{ m s}^{-1}$, not zero

$s = ut + \frac{1}{2}at^2$:
 $-30 = 4.0t - 4.905t^2$

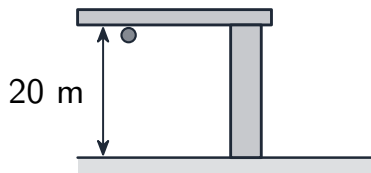
so $t = 2.9 \text{ s}$ (with $u = 0$: 2.5 s, wrong)

Exercise 2.1 (a)

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]

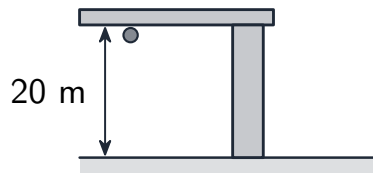


Exercise 2.1 (a)

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]



(a) $u = 0$, $s = 20 \text{ m}$, $a = 9.81 \text{ m s}^{-2}$ (down positive); use $s = \frac{1}{2}at^2$

$$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 20 \text{ m}}{9.81 \text{ m s}^{-2}}} = \mathbf{2.0 \text{ s}}$$

Exercise 2.1 (b)

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

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

Exercise 2.1 (b)

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

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

(b) use $v^2 = u^2 + 2as$

$$v = \sqrt{u^2 + 2as} = \sqrt{0 + 2 \times 9.81 \text{ m s}^{-2} \times 20 \text{ m}} = \mathbf{20} \frac{\text{m}}{\text{s}}$$

Exercise 2.2 (a)

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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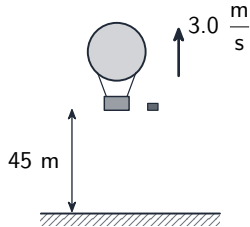
(a) State the velocity of the camera at the moment it leaves the balloon. [1]

(a) **$3.0 \frac{\text{m}}{\text{s}}$ upwards**, the velocity of the balloon

Exercise 2.2 (b)

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.

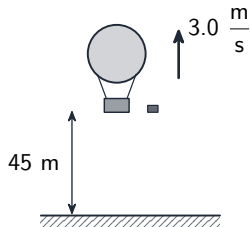
(b) Calculate the time taken for the camera to reach the ground. (*Hint: with up as positive, $s = -45 \text{ m}$.*) [3]



Exercise 2.2 (b)

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.

(b) Calculate the time taken for the camera to reach the ground. (*Hint: with up as positive, $s = -45 \text{ m}$.*) [3]



(b) $u = +3.0 \frac{\text{m}}{\text{s}}$, $a = -9.81 \text{ m s}^{-2}$, $s = -45 \text{ m}$ in $s = ut + \frac{1}{2}at^2$

$$-45 = 3.0t - 4.905t^2 \quad \Rightarrow \quad 4.905t^2 - 3.0t - 45 = 0$$

- quadratic formula (values in m and s)

$$t = \frac{3.0 + \sqrt{9.0 + 883}}{9.81} = \mathbf{3.4 \text{ s}}$$

Exercise 2.3 (a)

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]

Exercise 2.3 (a)

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.

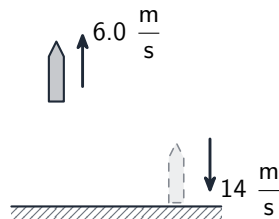
(a) State the velocity of the rocket as it hits the ground. [1]

(a) $-14 \frac{\text{m}}{\text{s}}$: it is moving downwards, and up is positive

Exercise 2.3 (b)

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.

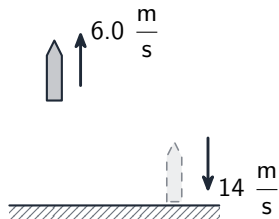
(b) Calculate the height of the rocket above the ground when its engine stops. [2]



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



(b) $u = +6.0 \frac{\text{m}}{\text{s}}, v = -14 \frac{\text{m}}{\text{s}}, a = -9.81 \text{ m s}^{-2}$ in $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a} = \frac{(14 \frac{\text{m}}{\text{s}})^2 - (6.0 \frac{\text{m}}{\text{s}})^2}{2(-9.81 \text{ m s}^{-2})} = -8.2 \text{ m}$$

- the ground is 8.2 m below the point where the engine stops, so the height is **8.2 m**

Exercise 2.3 (c)

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.

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

Exercise 2.3 (c)

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

(c) use $v = u + at$ with the signs

$$t = \frac{v - u}{a} = \frac{-14 \frac{\text{m}}{\text{s}} - 6.0 \frac{\text{m}}{\text{s}}}{-9.81 \text{ m s}^{-2}} = \mathbf{2.0 \text{ s}}$$

Exercise 3.1

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]

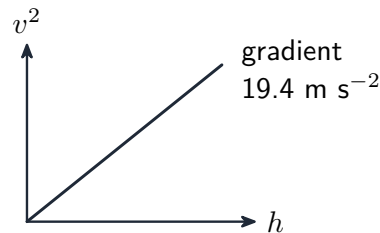
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A 4.9 m s^{-2}

B 9.7 m s^{-2}

C 19 m s^{-2}

D 39 m s^{-2}



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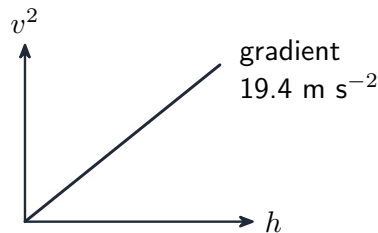
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A 4.9 m s^{-2}

B 9.7 m s^{-2}

C 19 m s^{-2}

D 39 m s^{-2}



3.1 B

- from $v^2 = u^2 + 2as$ with $u = 0$: $v^2 = 2gh$, so the gradient is $2g$

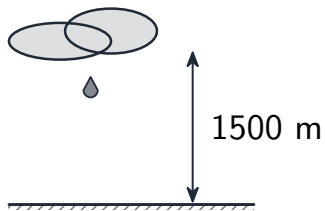
$$g = \frac{19.4 \text{ m s}^{-2}}{2} = \mathbf{9.7 \text{ m s}^{-2}}$$

- C** takes the gradient as g ; **A** and **D** use the wrong factor of 2

Exercise 3.2 (a)

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

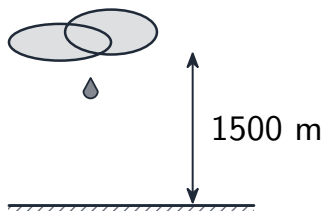
(a) Calculate the speed at which the raindrop would reach the ground if air resistance were negligible. [2]



Exercise 3.2 (a)

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]



(a) from rest, $v^2 = u^2 + 2as$ with $u = 0$

$$v = \sqrt{u^2 + 2as} = \sqrt{0 + 2 \times 9.81 \text{ m s}^{-2} \times 1500 \text{ m}} = \mathbf{170} \frac{\text{m}}{\text{s}}$$

Exercise 3.2 (b)

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

(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]

Exercise 3.2 (b)

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

(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]

(b)

- air resistance acts on the raindrop, and it increases as the speed increases
- the resultant force on the drop is then less than its weight
- so its acceleration is less than 9.81 m s^{-2} , and it gains much less speed over the same distance

Exercise 3.3 (a)

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]

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(a) Define *acceleration*. [1]

(a) rate of change of velocity

Exercise 3.3 (b)

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.

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

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

(b) at the top $v = 0$; use $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - (8.0 \frac{\text{m}}{\text{s}})^2}{2(-9.81 \text{ m s}^{-2})} = \mathbf{3.3 \text{ m}}$$

Exercise 3.3 (c)

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.

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

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

(c) $s = -25 \text{ m}$, $u = +8.0 \frac{\text{m}}{\text{s}}$, $a = -9.81 \text{ m s}^{-2}$ in $s = ut + \frac{1}{2}at^2$

$$-25 = 8.0t - 4.905t^2 \quad \Rightarrow \quad 4.905t^2 - 8.0t - 25 = 0$$

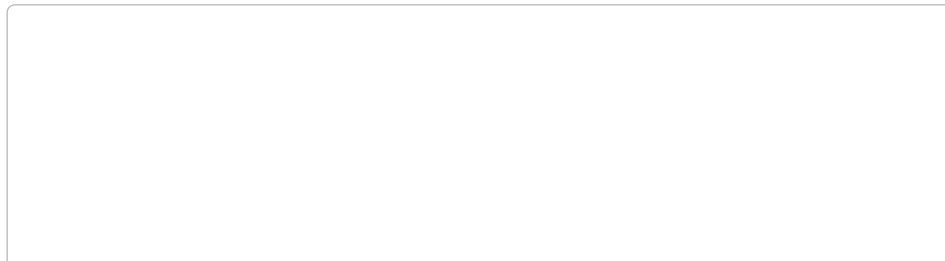
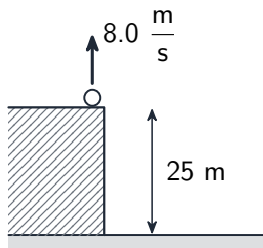
- quadratic formula, keeping the positive root

$$t = \frac{8.0 + \sqrt{64 + 490.5}}{9.81} = \mathbf{3.2 \text{ s}}$$

Exercise 3.3 (d)

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.

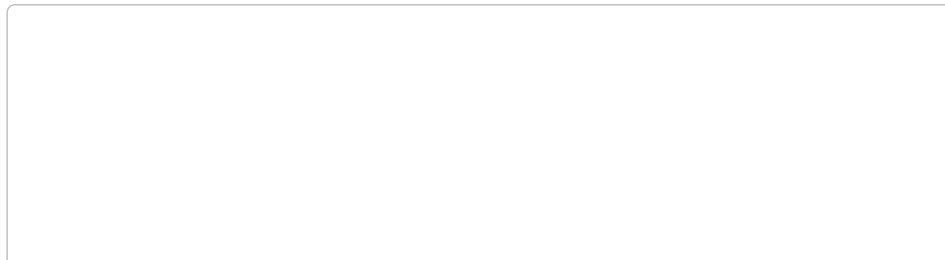
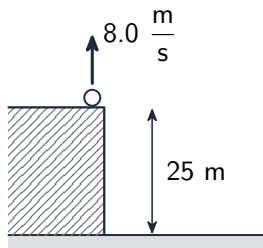
(d) **Sketch** the velocity–time graph of the ball from the throw until it reaches the sea. Mark the values of the velocity at the start and at the end. [3]



Exercise 3.3 (d)

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.

(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]



(d)

- a single straight line with a negative gradient
- starting at $+8.0 \frac{\text{m}}{\text{s}}$ and crossing $v = 0$ at about 0.8 s
- ending at about $-24 \frac{\text{m}}{\text{s}}$ at 3.2 s

Exercise 3.3 (e)

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.

(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]

Exercise 3.3 (e)

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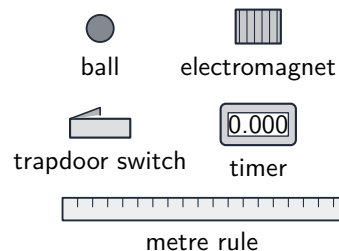
(e)

- the time does not change
- the acceleration of free fall is the same for every mass, and the ball has the same initial velocity and the same displacement

Exercise 3.4 (a)

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 .

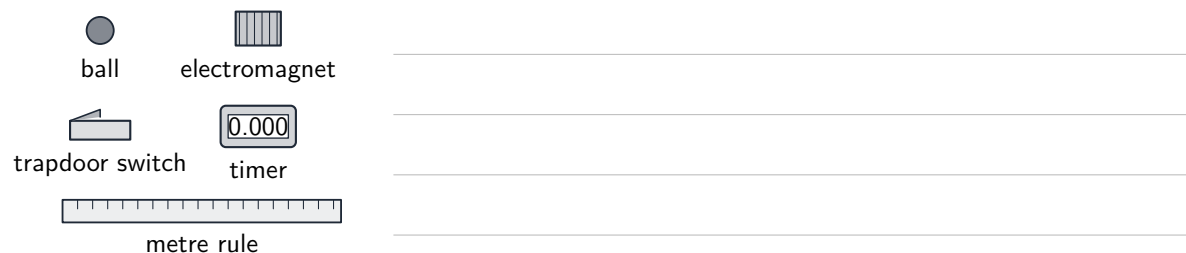
(a) **Describe** how she carries out the experiment. Include the measurements she takes and how she finds g from a graph. [4]



Exercise 3.4 (a)

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]



(a)

- measure h from the bottom of the ball to the trapdoor with the metre rule
- switching off the electromagnet releases the ball and starts the timer; the ball hitting the trapdoor stops it, giving t
- repeat for several different heights, repeating each timing and taking the mean
- plot h against t^2 and find the gradient; $g = 2 \times \text{gradient}$

Exercise 3.4 (b)

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 .

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

Exercise 3.4 (b)

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

(b) the ball starts from rest, so $h = \frac{1}{2}gt^2$

$$g = \frac{2h}{t^2} = \frac{2 \times 0.750 \text{ m}}{(0.393 \text{ s})^2} = \mathbf{9.71 \text{ m s}^{-2}}$$

Exercise 3.4 (c)

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 .

(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]

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(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]

(c)

- the measured time is longer than the real time of fall
- $g = 2h/t^2$, so the calculated value of g is too small