

Kinematics and projectile motion: practice worksheet

IB Physics HL · A.1 · 52 minutes · 44 marks

Question 1

A ball is thrown vertically upwards from the ground with an initial speed of 20 m s^{-1} . Air resistance is negligible. Take $g = 10 \text{ m s}^{-2}$ for this question.

- (a) Find the time taken for the ball to reach its maximum height. [1]
- (b) Find the maximum height reached by the ball. [1]
- (c) State the acceleration of the ball at the instant it is at its maximum height. [1]
- (d) Write down the velocity of the ball when it returns to the point from which it was thrown. [1]

Question 2

A tram moves along a straight track. Its velocity–time graph consists of three straight-line segments: from $t = 0$ to $t = 4 \text{ s}$ the velocity increases uniformly from 0 to 6 m s^{-1} ; from $t = 4 \text{ s}$ to $t = 10 \text{ s}$ the velocity is constant at 6 m s^{-1} ; from $t = 10 \text{ s}$ to $t = 12 \text{ s}$ the velocity decreases uniformly to 0 .

- (a) Find the acceleration of the tram during the first 4 s . [1]
- (b) Determine the total displacement of the tram between $t = 0$ and $t = 12 \text{ s}$. [2]
- (c) Hence find the average velocity of the tram over the 12 s journey. [1]

Question 3

A stone is thrown horizontally from the top of a vertical sea cliff with a speed of 12.0 m s^{-1} . The top of the cliff is 45.0 m above the sea. Air resistance is negligible. Take $g = 9.8 \text{ m s}^{-2}$.

- (a) State the horizontal component of the acceleration of the stone while it is in flight. [1]
- (b) Show that the time taken for the stone to reach the sea is about 3 s . [1]
- (c) Calculate the horizontal distance from the base of the cliff to the point where the stone enters the sea. [1]
- (d) Determine the speed of the stone and the angle its velocity makes with the horizontal at the instant it enters the sea. [3]

Question 4

A ball is kicked from the flat roof of a building. The ball leaves the roof at a height of 15.0 m above horizontal ground with a speed of 18.0 m s^{-1} at an angle of 30° above the horizontal. Air resistance is negligible. Take $g = 9.8 \text{ m s}^{-2}$.

- (a) Show that the maximum height of the ball above the ground is about 19 m . [2]
- (b) Determine the time taken for the ball to reach the ground. [3]
- (c) Calculate the horizontal distance travelled by the ball before it reaches the ground. [1]
- (d) In reality, air resistance acts on the ball. Explain how air resistance affects the horizontal distance travelled by the ball. [2]

Question 5

A skydiver of mass 75 kg steps from a stationary balloon and falls vertically. The table gives the downward velocity v of the skydiver at time t after leaving the balloon.

t / s	$v / \text{m s}^{-1}$
0	0
1.0	9.7
2.0	18.5
3.0	25.8
4.0	31.6
5.0	35.8
6.0	38.9
8.0	42.3
10.0	43.9
12.0	44.5
15.0	44.9
20.0	45.0

- (a) State the terminal speed of the skydiver. [1]
- (b) Estimate the instantaneous acceleration of the skydiver at $t = 4.0 \text{ s}$. [2]
- (c) Estimate the distance fallen by the skydiver during the first 6.0 s. [3]
- (d) Explain, with reference to the forces acting on the skydiver, why the acceleration decreases with time and why the velocity eventually becomes constant. [3]

Question 6

A ball of mass 0.150 kg is thrown from a balcony that is 8.00 m above horizontal ground. The ball leaves the hand with a speed of 14.0 m s^{-1} at an angle of 25° below the horizontal. Air resistance is negligible unless stated otherwise. Take $g = 9.8 \text{ m s}^{-2}$.

- (a) Determine the time taken for the ball to reach the ground. [3]
- (b) Show that the speed of the ball just before it hits the ground is about 19 m s^{-1} . [2]
- (c) A second identical ball is thrown from the same balcony with the same speed of 14.0 m s^{-1} , but at 25° above the horizontal. Without further calculation, state and explain how the impact speed and the time of flight of the second ball compare with those of the first ball. [3]
- (d) On hitting the ground the first ball sinks into soft mud and comes to rest in 25 ms. Determine the magnitude of the average net force acting on the ball while it is being brought to rest. [3]
- (e) In reality air resistance acts on the first ball during its flight. Explain how air resistance affects the time of flight and the impact speed of the ball. [2]

Markscheme

Question 1

(a)

$$v = u + at \Rightarrow 0 = 20 - 10t \text{ so } t = 2 \text{ s } \checkmark \quad 1$$

(b)

$$v^2 = u^2 + 2as \Rightarrow 0 = 400 - 20s \text{ so } s = 20 \text{ m } \checkmark \quad 1$$

Accept $s = \frac{(u+v)t}{2} = \frac{20 \times 2}{2} = 20 \text{ m}$ or any other correct equation of motion.

(c)

$$10 \text{ m s}^{-2} \text{ directed downwards / towards the ground } \checkmark \quad 1$$

Both magnitude and direction required. Do not accept zero.

(d)

$$20 \text{ m s}^{-1} \text{ downwards } \checkmark \quad 1$$

Accept -20 m s^{-1} with upwards taken as positive. Direction must be given.

Question 2

(a)

$$\text{gradient} = \frac{6-0}{4} = 1.5 \text{ m s}^{-2} \checkmark \quad 1$$

(b)

$$\text{recognises displacement as area under the graph, e.g. } \frac{1}{2}(4)(6) + (6)(6) + \frac{1}{2}(2)(6) \checkmark \quad 1$$

$$12 + 36 + 6 = 54 \text{ m } \checkmark \quad 1$$

Accept a single trapezium: $\frac{1}{2}(12 + 6)(6) = 54 \text{ m}$.

(c)

$$\bar{v} = \frac{54}{12} = 4.5 \text{ m s}^{-1} \checkmark \quad 1$$

ECF from (b). Do not accept $\frac{0+6}{2} = 3 \text{ m s}^{-1}$.

Question 3

(a)

$$\text{zero } \checkmark \quad 1$$

(b)

$$45.0 = \frac{1}{2}(9.8)t^2 \Rightarrow t = \sqrt{\frac{2 \times 45.0}{9.8}} = 3.03 \text{ s } \checkmark \quad 1$$

Award the mark for the substituted expression with an unrounded result of 3.03 s.

(c)

$$x = 12.0 \times 3.03 = 36.4 \text{ m } \checkmark \quad 1$$

Accept 36 m if $t = 3.0 \text{ s}$ is used.

(d)

$$\text{vertical component } v_y = 9.8 \times 3.03 = 29.7 \text{ m s}^{-1} \text{ (or } v_y = \sqrt{2 \times 9.8 \times 45.0} = 29.7 \text{ m s}^{-1}) \checkmark \quad 1$$

$$v = \sqrt{12.0^2 + 29.7^2} = 32.0 \text{ m s}^{-1} \checkmark \quad 1$$

$$\theta = \tan^{-1}\left(\frac{29.7}{12.0}\right) = 68.0^\circ \text{ below the horizontal } \checkmark \quad 1$$

Accept $v^2 = 12.0^2 + 2(9.8)(45.0)$ giving 32.0 m s^{-1} directly. Accept 22° to the vertical. ECF from (b).

Question 4

(a)

$$u_y = 18.0 \sin 30^\circ = 9.0 \text{ m s}^{-1} \quad \checkmark \quad 1$$

$$\text{rise above roof} = \frac{9.0^2}{2 \times 9.8} = 4.13 \text{ m, so height above ground} = 15.0 + 4.13 = 19.1 \text{ m} \quad \checkmark \quad 1$$

Award the second mark only if the 15.0 m is added and an unrounded value is shown.

(b)

$$\text{uses } s = ut + \frac{1}{2}at^2 \text{ with a consistent sign convention, e.g. } -15.0 = 9.0t - 4.9t^2 \quad \checkmark \quad 1$$

$$\text{solves the quadratic: } t = \frac{9.0 + \sqrt{9.0^2 + 4(4.9)(15.0)}}{2 \times 4.9} \quad \checkmark \quad 1$$

$$t = 2.89 \text{ s} \quad \checkmark \quad 1$$

ALTERNATIVE: time to top 0.918 s $\checkmark$, fall of 19.1 m from rest takes $\sqrt{\frac{2 \times 19.1}{9.8}} = 1.98 \text{ s} \quad \checkmark$, total 2.89 s $\checkmark$. ECF from (a).

(c)

$$x = 18.0 \cos 30^\circ \times 2.89 = 45.1 \text{ m} \quad \checkmark \quad 1$$

ECF from (b).

(d)

air resistance acts opposite to the velocity so there is a horizontal component of force / horizontal deceleration $\checkmark \quad 1$

horizontal component of velocity decreases during flight (is no longer constant) $\checkmark \quad 1$

so the horizontal distance is smaller / the trajectory is asymmetric and steeper on the way down $\checkmark \quad 1$

Award [max 2]. OWTTE.

Question 5

(a)

$$45 \text{ m s}^{-1} \quad \checkmark \quad 1$$

(b)

acceleration identified as gradient of the velocity–time graph at $t = 4.0 \text{ s}$, e.g. uses $1 \quad 1$

$$\frac{35.8 - 25.8}{5.0 - 3.0} \quad \checkmark$$

$$a \approx 5.0 \text{ m s}^{-2} \quad \checkmark \quad 1$$

Accept values in the range 4.5 to 5.5 m s^{-2} from a tangent or symmetric chord about $t = 4.0 \text{ s}$.

(c)

distance identified as area under the velocity–time graph $\checkmark \quad 1$

area found by trapezia (or counting strips), e.g. $1.0 \times 1 \quad 1$

$$\left(\frac{0}{2} + 9.7 + 18.5 + 25.8 + 31.6 + 35.8 + \frac{38.9}{2}\right) \quad \checkmark$$

$$s \approx 141 \text{ m} \quad \checkmark \quad 1$$

Accept values in the range 135 to 147 m. Do not award the final mark for $\frac{1}{2}(9.8)(6.0)^2 = 176 \text{ m}$, which ignores fluid resistance.

(d)

at $t = 0$ the only force is the weight so the acceleration is $g / 9.8 \text{ m s}^{-2} \quad \checkmark \quad 1$

air resistance (fluid resistance / drag) increases as the speed increases $\checkmark \quad 1$

net force = weight – air resistance decreases, so the acceleration decreases $\checkmark \quad 1$

when air resistance equals the weight the net force is zero, so acceleration is zero 1

and the velocity is constant (terminal speed) $\checkmark$

Award [max 3]. OWTTE.

Question 6

(a)

vertical component $u_y = 14.0 \sin 25^\circ = 5.92 \text{ m s}^{-1}$ downwards ✓ 1

taking downwards as positive: $8.00 = 5.92t + 4.9t^2$ ✓ 1

$t = \frac{-5.92 + \sqrt{5.92^2 + 4(4.9)(8.00)}}{2 \times 4.9} = 0.809 \text{ s}$ ✓ 1

ALTERNATIVE: find v_y from $v_y^2 = u_y^2 + 2gs$ giving 13.8 m s^{-1} ✓, then $t = \frac{v_y - u_y}{g}$ ✓, $t = 0.809 \text{ s}$ ✓. Accept 0.81 s.

(b)

$v^2 = u^2 + 2gh = 14.0^2 + 2(9.8)(8.00)$ (or $v_x = 12.7 \text{ m s}^{-1}$ and $v_y = 13.8 \text{ m s}^{-1}$ 1

combined in quadrature) ✓

$v = \sqrt{352.8} = 18.8 \text{ m s}^{-1}$ ✓ 1

An unrounded value must be shown for the second mark. Accept an energy argument $\frac{1}{2}mv^2 = \frac{1}{2}mu^2 + mgh$.

(c)

impact speed is the same ✓ 1

because $v^2 = u^2 + 2gh$ (or the energy transferred, mgh) depends only on the initial 1
speed and the height fallen, not on the launch direction ✓

time of flight is longer because the second ball first rises and returns to the balcony 1

height (with the same downward vertical velocity component 5.92 m s^{-1}) before
repeating the motion of the first ball ✓

OWTTE. Do not award the third mark for 'it travels further' without reference to the vertical motion.

(d)

change in momentum $\Delta p = 0.150 \times 18.8 = 2.82 \text{ kg m s}^{-1}$ ✓ 1

converts time to seconds: $\Delta t = 0.025 \text{ s}$ and uses $F = \frac{\Delta p}{\Delta t}$ ✓ 1

$F = \frac{2.82}{0.025} = 113 \text{ N}$ ✓ 1

Accept 110 to 115 N depending on rounding of v . ECF from (b). Accept an equivalent approach using $a = \frac{\Delta v}{\Delta t}$ and $F = ma$.

(e)

air resistance acts opposite to the velocity so the (vertical) acceleration is less than 1

g and the ball gains speed more slowly / kinetic energy is transferred to the air ✓

so the impact speed is lower than 18.8 m s^{-1} ✓ 1

the vertical component of velocity is smaller at every instant, so the ball takes longer 1

to fall 8.00 m / time of flight increases ✓

Award [max 2]. OWTTE.