## Physics Department Kinematics Questions

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## Equations of motion for uniform acceleration

## Horizontal Motion

1. A car is uniformly decelerated and brought to rest from a speed of $30 \mathrm{~ms}^{-1}$ in 15 s . Find the acceleration.

S
u
v
a
t
2. A car accelerates uniformly from rest at a rate of $2 \mathrm{~ms}^{-2}$ for 6 s . It then maintains a constant speed for half a minute. The brakes are then applied and the vehicle is uniformly retarded to rest in 5 s . Find the maximum speed reached and the total distance covered. (Note acceleration changes during each part of the motion.)
3. An electric train moving at 20 km per hour accelerates to a speed of 30 km per hour in 20 s . Find the acceleration and the distance travelled during the period of the acceleration.

## Vertical Motion

4. A stone is thrown upwards with an initial velocity of $14 \mathrm{~ms}^{-1}$. Neglecting air resistance, find (a) the maximum height reached, (b) the time taken for the whole journey.
5. In Acapulco, divers dive from a rock 36 m above sea level. Assuming that air resistance is negligible, calculate how long the dive lasts, and the speed with which the divers hit the water.
6. A parachute is designed to give a landing speed of $7 \mathrm{~ms}^{-1}$. What height of scaffolding would parachutists in training have to use (without a parachute) to simulate a parachute fall?
7. A Honda Civic is advertised as being able to cover the standing quarter mile ( say 400 m ) in 17.5 s . Calculate the acceleration and the speed at the end of the quarter mile.
8. A sandbag is released from a balloon which is ascending with a steady vertical speed of $8 \mathrm{~ms}^{-1}$. If the sandbag hits the ground 15 s later, if $\mathrm{a}=+9.81$ what is the initial velocity (magnitude and direction) of the sandbag relative to the ground? What was the height of the balloon when the sandbag was released?
9. A cat, wishing to investigate the laws of physics, jumps out of a second floor window and falls through a height of 7 m . Calculate the velocity of the cat just before it lands and the time of fall. State any assumptions made.


## SUVAT equations

3 A steel ball is released from rest above a cylinder of liquid, as shown in Figure 3. The ball descends vertically in the air then in the liquid until it reaches the bottom of the cylinder.

Figure 3


3 (a) The vertical distance from the bottom of the ball at the point where it is released to the liquid surface is 0.16 m .

3 (a) (i) Calculate the time taken, $t_{\mathrm{o}}$, by the ball to fall to the liquid surface from the point where it is released. Give your answer to an appropriate number of significant figures.
$\qquad$ .. s

3 (a) (ii) Calculate the velocity, $v_{o}$, of the ball on reaching the liquid.

## Further Questions (answer on paper)

Equations of motion

1. A body with an initial velocity of $10 \mathrm{~ms}^{4}$ has an acceleration of $8 \mathrm{~ms}^{2}$. What is its velocity after 5 s and how far has it travelled in that time?
2. A train starting from a platform has an acceleration of $1.2 \mathrm{~ms}^{-2}$. What is its velocity after 5 s and how far has it travelled?
3. A body moves from rest with a uniform acceleration of $10 \mathrm{~ms}^{2}$. How far does it move in 8 s and what is its velocity after that time?

4, How far does a body move in 10 s if it starts from rest with a uniform acceleration of $12 \mathrm{~ms}^{-2}$ ? What is its velocity after 10 s ?
5. How far does a body move in the third second if it starts from rest with a uniform acceleration of $10 \mathrm{~ms}^{2}$ ?
6. How far does a body travel in the fourth second if it starts from rest with a uniform acceleration of $0.8 \mathrm{~ms}^{2}$ ?
7. A body with an initial velocity of $24 \mathrm{~km} \mathrm{~h}^{4}$ has a uniform acceleration of $3 \mathrm{~ms}^{-2}$. How far does it move in $3 s$ ? What is its velocity after $6 s$ ?
8. A body starting from rest has an acceleration of $2 \mathrm{~ms}^{2}$. What is its velocity after moving 16 m ? How long does it take to travel 16 m ?
9. An aircraft has a take off velocity of $180 \mathrm{~km} \mathrm{~h}^{-1}$. What length of runway is needed if the aircraft's average acceleration along the ground is $2.5 \mathrm{~ms}^{2}$ ?
10. The brakes of a car can give a maximum retardation of $10 \mathrm{~ms}^{-2}$. Find the least distance in which the car can stop if its velocity is $30 \mathrm{~ms}^{4}$.

## Projectiles (Horizontal and Vertical Motion)

1. A football is kicked from a flat roof with a horizontal velocity of $20 \mathrm{~ms}^{-1}$. If the roof is 14 m above ground level, calculate:
(a) the time taken for the football to hit the ground, (hint think vertically)
b) the horizontal range of the football. (hint think horizontally; the time of flight will be the same as for vertically)
2. A helicopter is hovering in mid-air when it fires its guns horizontally to strike a target on the ground.
The horizontal velocity of the bullets is $200 \mathrm{~ms}^{-1}$. If each bullet takes 4 s to reach the target, find
a) how far the target is horizontally from the helicopter
b) how high the helicopter is at the time of firing
3. An aeroplane flying horizontally with a uniform velocity of $40 \mathrm{~ms}^{-1}$ drops a bomb which hits a factory. When the bomb is released it will continue to travel horizontally at $40 \mathrm{~ms}^{-1}$ (i.e. air resistance is negligible). When the bomb is released the horizontal distance between the factory and the aeroplane is 200 m .
Draw a diagram


Find
a) The time of flight of the bomb
b) how high the aeroplane is flying
c) where the plane is relative to the factory when the bomb explodes (assume negligible air resistance on the plane)
4. A dart player stands 3.0 m from a board and throws a dart with an unknown horizontal velocity, at a distance of 1.8 m above the ground. The dart hits the board at a point 1.5 m above the ground.

Write down your vertical and horizontal information. Calculate the vertical distance the dart will travel and make a note of this on your diagram.


Calculate:
(a) the time of flight of the dart,
b) the initial speed of the dart,

## 5. Harder - a challenge

An electron moving at $2.0 \times 10^{7} \mathrm{~ms}^{-1}$ horizontally enters an electric field which provides a vertical force on the electron of $3.2 \times 10^{-15} \mathrm{~N}$. The electron travels 4 cm horizontally through the field. Calculate:
(a) the vertical acceleration of the electron, (use $F=m$ where $F$ is force in Newtons and $m$ is
 mass of a moving object in kg and a is acceleration $\mathrm{ms}^{-2}$ ).
(b) the time taken to pass through the field, (think horizontally)
c) the vertical displacement of the electron on leaving the field,
6. a) A ball is dropped from a height of 80 m . Calculate the time taken to reach the ground.
b) A ball is thrown horizontally at $20 \mathrm{~ms}^{-1}$ from the top of a cliff of height 80 m . It falls into the sea. For each of the following, sketch graphs (giving appropriate values on the axes)
i) the horizontal component of the velocity against time.
ii) the vertical component of the velocity against time.
iii) the height of the ball above ground level against time
7. A tennis ball is returned from a point close to the ground on the base line and just clears the net, hitting the ground on the base line at the other side of the net. The net is 1.0 m high and the distance from the net to either base line is 12 m .


Assuming no air resistance, find
a) The time it takes the ball to travel from the top of the net to the baseline (Hint consider the second half of the motion only in the vertical direction)
b) The horizontal velocity with which the ball crosses the net. (draw a diagram).


4 Figure 3 shows the path of a ball thrown horizontally from the top of a tower of height 24 m which is surrounded by level ground.

Figure 3


4 (a) Using two labelled arrows, show on Figure 3 the direction of the velocity, $\boldsymbol{v}$, and the acceleration, $a$, of the ball when it is at point $\mathbf{P}$.

4 (b) (i) Calculate the time taken from when the ball is thrown to when it first hits the ground. Assume air resistance is negligible.

Answer $\qquad$ s
(2 marks)
4 (b) (ii) The ball hits the ground 27 m from the base of the tower. Calculate the speed at which the ball is thrown.

Answer $\qquad$ $\mathrm{ms}^{-1}$
(2 marks)

Q1. The diagram below shows two different rifles being fired horizontally from a height of 1.5 m above ground level.
Assume the air resistance experienced by the bullets is negligible.

(a) When rifle $\mathbf{A}$ is fired, the bullet has a horizontal velocity of $430 \mathrm{~m} \mathrm{~s}^{-1}$ as it leaves the rifle. Assume the ground is level.
(i) Calculate the time that the bullet is in the air before it hits the ground
(ii) Calculate the horizontal distance travelled by the bullet before it hits the ground.
m
(b) Rifle $\mathbf{B}$ is fired and the bullet emerges with a smaller horizontal velocity than the bullet from rifle $A$.

Explain why the horizontal distance travelled by bullet $\mathbf{B}$ will be less than bullet $\mathbf{A}$.
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$

## Projectiles

## Resolving vectors and finding magnitude and direction

1. A shot is projected at an angle of $55^{\circ}$ to the horizontal with a velocity of $8 \mathrm{~ms}^{-1}$. Calculate:
(a) the vertical and horizontal components of $v$
(b) the highest point reached, (hint split the motion into two and think about the vertical velocity as the shot crosses the top
 halves of its motion).
(c) the time taken to return to the ground. (hint: think about $1 / 2$ of the motion again, find the time for this, then double to find the full time).
(a) the horizontal range

## Jan 08 - Monkey and Hunter experiment

4 A dart is thrown horizontally at a speed of $8.0 \mathrm{~m} \mathrm{~s}^{-1}$ towards the centre of a dartboard that is 2.0 m away. At the same instant that the dart is released, the support holding the dartboard fails and the dartboard falls freely, vertically downwards. The dart hits the dartboard in the centre before they both reach the ground.
(a) State and explain the motion of the dart and the dartboard, while the dart is in flight.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
(b) Calculate
(i) the time taken for the dart to hit the dartboard,
$\qquad$
$\qquad$
(ii) the vertical component of the dart's velocity just before it strikes the dartboard,
$\qquad$
$\qquad$
(iii) the magnitude and direction of the resultant velocity of the dart as it strikes the dartboard.
$\qquad$
$\qquad$
$\qquad$
$\qquad$

## Further Questions (answer on paper)

## Motion under Gravity and Projectiles

1. A stone is thrown vertically upwards and reaches a height of 90 m . Find a) the velocity with which it was thrown b) the time taken to return to its starting point c) its velocity at a height of 50 m d ) how far the stone will be from its starting point 7 s after it was thrown.
2. A man standing on a tower 32 m high throws a ball vertically downwards with a velocity of $6 \mathrm{~ms}^{-1}$. How long does the ball take to reach the ground?
3. A pebble is dropped from rest at the top of a cliff 125 m high. How long does it take to reach the foot of the cliff and with what speed does it strike the ground? With what speed must a second pebble be thrown vertically downwards if it is to reach the ground in $4 s$ ? (ignore air resistance)
4. A ball is thrown vertically upwards from the surface of the earth with an initial velocity $u$. Neglecting frictional forces sketch graphs to show a) the variation in vertical height with time from the instant of release to the balls return to earth b) the variation of velocity v of the ball with time t as the ball rises and then falls back to earth. What information in this graph enables you to find i) the gravitational acceleration ii) the maximum height reached by the ball?
If frictional forces in the air were not negligible, how in the above situation would the initial acceleration and the maximum height reached be affected?
5. A stone thrown horizontally from the top of a vertical cliff with a velocity of $15 \mathrm{~ms}^{-1}$ is observed to strike the horizontal ground 45 m from the base of the cliff: What is a) the height of the cliff b) the angle the path of the stone makes with the ground at the moment of impact?
6. A gun, on the top of a vertical cliff 90 m high, fires a shell horizontally with a velocity of $350 \mathrm{~ms}^{-1}$. How far is the shell from the bottom of the cliff when it strikes the water?
7. A pistol is fired horizontally at a target 20 m away and it is noted that the bullet hits a point 7.5 cm below the mark aimed at. What was the velocity of the bullet when it left the pistol?
8. A ball is thrown up with a velocity of $20 \mathrm{~ms}^{-1}$ at an angle of $60^{\circ}$ to the horizontal. What height does it reach? What is is the horizontal distance travelled when it strikes level ground again?
9. A gun can project a shell at $70 \mathrm{~ms}^{-1}$. Find its maximum range on a horizontal plane. $\left(45^{\circ}\right)$
10. A shot is fired horizontally at a velocity of $300 \mathrm{~ms}^{-1}$. Find the magnitude and direction of its velocity after 8.0 s .

## Displacement-time and velocity-time graphs

1. The table and graph below describe the motion of three cars, $a, b$ and $c$

| time/s | 0 | 1 | 2 | 3 | 4 | 5 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Displacement car A/m | 0 | 10 | 20 | 30 | 40 | 50 |
| Displacement car B/m | 0 | 20 | 40 | 60 | 80 | 100 |
| Displacement car C/m | 50 | 50 | 50 | 50 | 50 | 50 |


a) Label the two lines on the graph $A$ and $B$ using the table above it.
b) Plot line corresponding to the displacement time for car C on the axis above
c) Describe the motion of each car
d) Calculate the velocity of each car.
2. The following data represents a space probe which is moving in a straight line away from Earth.

| Time/s | 0 | 100 | 200 | 300 | 400 | 500 | 600 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Velocity $/ \mathrm{ms}^{-1}$ | 5374 | 5329 | 5283 | 5238 | 5193 | 5147 | 5102 |


(b) What does the shape of the graph tell you about the motion of the space probe?
(c) Calculate, from the graph, the deceleration of the probe.
(d) Calculate, from the graph, the distance travelled by the probe during the 600 s period. Note if you have a break in your $y$-axis, the area under the graph must go down to the real $x$ axis i.e. where $y=0$.
3. A road test report gives the following data for a standing start acceleration test for a car.

| $\mathrm{t} / \mathrm{s}$ | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathrm{v} / \mathrm{ms}^{-1}$ | 0 | 14 | 24 | 30 | 34 | 37 | 39 | 40 | 40 |



From the velocity/time graph above find:
(a) the displacement of the car when it has reached a speed of $25 \mathrm{~ms}^{-1}$
(b) the acceleration of the car when its speed is $30 \mathrm{~ms}^{-1}$

## Extension

4. Sketch velocity/time graphs (freehand without numbers on the axes) to illustrate the following:
(a) a stone dropped from the roof of a tall building
(b) a tennis ball thrown vertically upwards from the time it leaves your hand until you catch it again
(c) a tennis ball released from 2 m height and allowed to bounce twice before being caught
d) a tennis ball during a rally

## Distance time graphs

1 The distance-time graphs for two runners, A and B , in a 100 m race are shown.

(a) Explain how the graph shows that athlete B accelerates throughout the race.
$\qquad$
$\qquad$
(b) Estimate the maximum distance between the athletes.
$\qquad$
(c) Calculate the speed of athlete A during the race.
$\qquad$

| Join the definitions/facts | The distance in a straight line from the <br> start point to the end point (vector) |
| :--- | :--- |
| Scalar | Magnitude and direction |
| Vector | The total distance travelled in $m$ <br> (scalar) |
| Displacement | Constant acceleration |
| Distance | Displacement/time |
| Average speed | Distance travelled/time |
| Average Velocity | Equals negative acceleration |
| Speed | rate of change of velocity |
| Velocity | magnitude only |
| Acceleration | rate of change of distance |
| Uniform acceleration | rate of change of displacement |
| Deceleration | displacement |
| Gradient of displacement time graph | acceleration |
| For projectiles, the time is the same for | speed |
| both... | velocity |

The magnitude of velocity can be found from the components using..

The direction of the velocity can be found from the components using...

The components of velocity or acceleration can be found from magnitude and direction using ...

If two objects with different masses fall the same distance, the time taken to hit the floor. $\qquad$

When air resistance is added to a projectile...
is the same for both

Trigonometry

Tan $^{-1}$ (opposite/adjacent)

It doesn't travel as far or as high

Pythagoras

Q1.The velocity-time graph for a falling object is shown.


Which of the following shows the corresponding acceleration-time graph?
A



D


A
B $\quad 0$
C 0
D 0
(Total 1 mark)

Q2.A girl jogs at $2.0 \mathrm{~m} \mathrm{~s}^{-1}$ in a straight line for 30 seconds, turns around and returns to her starting point 20 seconds later.

What is her average velocity and average speed?

|  | Average velocity/ $\mathrm{m} \mathrm{s}^{-1}$ | Average speed/m s ${ }^{-1}$ |  |
| :---: | :---: | :---: | :---: |
| A | $0 \mathrm{~m} \mathrm{~s}^{-1}$ | $2.4 \mathrm{~m} \mathrm{~s}^{-1}$ | $\bigcirc$ |
| B | $0 \mathrm{~m} \mathrm{~s}^{-1}$ | $2.5 \mathrm{~m} \mathrm{~s}^{-1}$ | $\bigcirc$ |
| C | $1.0 \mathrm{~m} \mathrm{~s}^{-1}$ | $2.0 \mathrm{~m} \mathrm{~s}^{-1}$ | $\bigcirc$ |
| D | $2.5 \mathrm{~m} \mathrm{~s}^{-1}$ | $2.5 \mathrm{~m} \mathrm{~s}^{-1}$ | $\bigcirc$ |

(Total 1 mark)

Q3.An object is dropped from a cliff. How far does the object fall in the third second? Assume that $\mathrm{g}=10 \mathrm{~m} \mathrm{~s}^{-2}$.

A $\quad 10 \mathrm{~m}$


B $\quad 20 \mathrm{~m}$ $\square$

C $\quad 25 \mathrm{~m}$


D $\quad 45 \mathrm{~m}$ $\square$
(Total 1 mark)

Q4.A ballbearing $\mathbf{X}$ of mass $2 m$ is projected vertically upwards with speed $u$. A ballbearing $\mathbf{Y}$ of mass $m$ is projected at $30^{\circ}$ to the horizontal with speed $2 u$ at the same time. Air resistance is negligible. Which of the following statements is correct?

A The horizontal component of Y's velocity is $u$.
B The maximum height reached by $\mathbf{Y}$ is half that reached by $\square$
X


C $\mathbf{X}$ and $\mathbf{Y}$ reach the ground at the same time.
D $\mathbf{X}$ reaches the ground first.

Q5.The velocity of a vehicle varies with time as shown by the following graph.


Which graph below represents how the resultant force $F$ on the car varies during the same time?


A $\quad \circ$
B $\quad \square$
C $\quad \square$
D $\quad \circ$

Q6.A roller coaster car is raised to a height of 65 m and released from rest.
What is the maximum possible speed of the car?

A $\quad 11 \mathrm{~m} \mathrm{~s}^{-1}$ $\square$
B $\quad 25 \mathrm{~m} \mathrm{~s}^{-1}$


C $\quad 36 \mathrm{~m} \mathrm{~s}^{-1}$


D $\quad 130 \mathrm{~m} \mathrm{~s}^{-1}$

(Total 1 mark)

Q7. The figure below shows a rollercoaster train that is being accelerated when it is pulled horizontally by a cable.

(a) The train accelerates from rest to a speed of $58 \mathrm{~ms}^{-1}$ in 3.5 s . The mass of the fully loaded train is 5800 kg .
(i) Calculate the average acceleration of the train.
answer $=$ $\qquad$ $\mathrm{ms}^{-2}$
(2)
(ii) Calculate the average tension in the cable as the train is accelerated, stating an appropriate unit.
$\qquad$
(iii) Calculate the distance the train moves while accelerating from rest to $58 \mathrm{~ms}^{-1}$.
$\qquad$
answer =
(iv) The efficiency of the rollercoaster acceleration system is $20 \%$. Calculate the average power input to this system during the acceleration.
answer = .................................... W
W
(b) After reaching its top speed the driving force is removed and the rollercoaster train begins to ascend a steep track. By considering energy transfers, calculate the height that the train would reach if there were no energy losses due to friction.
m

Q8. The aeroplane shown in the diagram below is travelling horizontally at $95 \mathrm{~m} \mathrm{~s}^{-1}$. It has to drop a crate of emergency supplies.
The air resistance acting on the crate may be neglected.

(a) (i) The crate is released from the aircraft at point $\mathbf{P}$ and lands at point $\mathbf{Q}$. Sketch the path followed by the crate between $\mathbf{P}$ and $\mathbf{Q}$ as seen from the ground.
(ii) Explain why the horizontal component of the crate's velocity remains constant while it is moving through the air.
$\qquad$
$\qquad$
$\qquad$
(b) (i) To avoid damage to the crate, the maximum vertical component of the crate's velocity on landing should be $32 \mathrm{~m} \mathrm{~s}^{-1}$. Show that the maximum height from which the crate can be dropped is approximately 52 m .
$\qquad$
$\qquad$
$\qquad$
(ii) Calculate the time taken for the crate to reach the ground if the crate is dropped from a height of 52 m .
$\qquad$
$\qquad$
(iii) If $\mathbf{R}$ is a point on the ground directly below $\mathbf{P}$, calculate the horizontal distance QR.
$\qquad$
$\qquad$
(c) In practice air resistance is not negligible. State and explain the effect this has on the maximum height from which the crate can be dropped.
$\qquad$
$\qquad$

Q10. A supertanker of mass $4.0 \times 10^{8} \mathrm{~kg}$, cruising at an initial speed of $4.5 \mathrm{~m} \mathrm{~s}^{-1}$, takes one hour to come to rest.
(a) Assuming that the force slowing the tanker down is constant, calculate
(i) the deceleration of the tanker,
$\qquad$
$\qquad$
(ii) the distance travelled by the tanker while slowing to a stop.
$\qquad$
$\qquad$
(b) Sketch, using the axes below, a distance-time graph representing the motion of the tanker until it stops.

| distance |  |
| :---: | :---: |
| 0 |  |
| 0 |  |
| 0 |  |
| 0 |  |
|  |  |

(c) Explain the shape of the graph you have sketched in part (b).
$\qquad$
$\qquad$

Q9.The graph below shows how the velocity of a toy train moving in a straight line varies over a period of time.

(a) Describe the motion of the train in the following regions of the graph.

AB $\qquad$
BC $\qquad$
CD $\qquad$
DE $\qquad$
EF $\qquad$
(b) What feature of the graph represents the displacement of the train?
$\qquad$
$\qquad$
-
(c) Explain, with reference to the graph, why the distance travelled by the train is different from its displacement.
$\qquad$
$\qquad$
$\qquad$

## Olympiad Questions

## AS-2007 Q3

3. A stone, thrown vertically into the air from ground level, returns to the ground in 4 seconds due to the constant gravitational force acting upon it (ignore air resistance). If the stone is thrown up at twice the initial speed, the time taken to return to the ground will now be

## AS-2008 Q6

6. The graph below represents the kinetic energy, gravitational potential energy, and total energy of a moving block


Which best describes the motion of the block?
A Sliding down an incline with constant friction
B Falling at a constant velocity
C Accelerating on a flat horizontal surface
D Falling freely under gravity

A

fig. 4
A. Via X
B. Via Y
C. You cannot say
D. Same time taken

## AS-2010 Q2

A small object is dropped from the top of a building and falls to the ground. As it falls, accelerating due to gravity, it passes a window. If it has speed $v_{l}$ at the top of the window, and speed $v_{2}$ at the bottom of the window, at what point does it have a speed $\left(v_{1}+v_{2}\right) / 2$ ?
Neglect the effect of air resistance.
A. It depends on the height of the window or its distance from the top of the building
B. Above the centre point of the window
C. Below the centre point of the window
D. At the centre point of the window

## AS-2012 Q1

1. A stone is dropped to the ground from a height $h$ and takes time $t$ to reach the ground. When this experiment is carried out in a lift rising at a constant speed, the time taken for the stone to fall the same height $h$ in the lift is
A. Dependent upon
B. Greater than $t$
C. Equal to $t$
D. Less than $t$ the speed of the lift

## AS-2009 Q3

A 750 kg car is moving at a speed of $20.0 \mathrm{~ms}^{-1}$ when at a height of 5.0 m above the bottom of a hill when it runs out of fuel. The car coasts down the hill and then continues up the other side until it comes to rest. Ignoring frictional forces and air resistance, what is the value of $h$, the highest position the car reaches above the bottom of the hill?
A. 6 m
B. 15 m
C. 25 m
D. 45 m

## AS-2011 Q12

A solid sphere of mass $m$ rolls down a slope. The sphere gains kinetic energy in two forms: rotational kinetic energy and translational kinetic energy in which the centre of mass moves along at speed $v$. For the solid sphere, a fixed fraction, $2 / 7$, of the gravitational potential energy lost as it rolls down the slope appears as rotational kinetic energy. If the sphere now rolls along a flat surface, moving at a speed of $4.0 \mathrm{~ms}^{-1}$ and then encounters a rising slope at $30^{\circ}$ to the horizontal, we can calculate how far up the slope the sphere will rise. We can take the mass of the sphere as 1 kg .
a) Calculate the translational KE of the sphere and hence the total energy of the rolling sphere.
$\qquad$
$\qquad$
$\qquad$
b) Describe the energy changes that take place as the sphere rolls up the slope.
$\qquad$
$\qquad$
$\qquad$
c) What is the vertical height reached by the sphere?
$\qquad$
$\qquad$
d) How far up along the slope does this take the sphere?
$\qquad$
$\qquad$

## AS-2009 Q11

A plane accelerates from rest to take off from a runway. There is a point of no return where the pilot will not be able to stop the plane before the end of the runway if he fails to take off. The runaway is 2 km long and the plane can accelerate at $3 \mathrm{~ms}^{-2}$ and can decelerate at $2 \mathrm{~ms}^{-2}$. We can calculate the length of time available from the start of the take off to the point of no return.
a) Sketch a graph of the speed of the plane against time for the situation where the plane fails to take off but the whole length of the runway is used. (no values are required)
b) If $t_{1}$ is the time taken for the plane to reach its maximum speed $v$, and $t_{2}$ is the time taken for it to decelerate before it goes beyond the end of the runway, express $v$ in terms of $t_{1}$ and $t_{2}$, and the respective accelerations.
$\qquad$
$\qquad$
$\qquad$
c) Calculate the distance $s_{1}$ travelled by the plane whilst accelerating, in terms of $t_{1}$, and the distance $s_{2}$ travelled by the plane whilst decelerating, in terms of $t_{2}$.
$\qquad$
$\qquad$
$\qquad$

## AS-2009 Q11 (continued)

d) From your answers to (b) and (c), calculate the value of $t_{1}$, the time taken to reach the point of no return, given that the runaway is 2 km long.
$\qquad$
$\qquad$
$\qquad$
$\qquad$

## Answers

## Equations of motion for uniform acceleration

1. $2 \mathrm{~ms}^{-2}$
2. A) 10 m ,
B) $2.86 \mathrm{~s}(=1.43 \mathrm{~s}$ for $1 / 2$ of the motion)
3. A) $12 \mathrm{~ms}^{-1}$,
B) 426 m
4. A) $0.14 \mathrm{~ms}^{-2}$,
B) 139 m
5. A) 2.7 s ,
B) $26.5 \mathrm{~ms}^{-1}$
6. 2.5 m
7. A) $2.6 \mathrm{~ms}^{-2}$,
B) $46 \mathrm{~ms}^{-1}$
8. A) $-8 \mathrm{~ms}^{-1}$,
B) 983.6 m
9. A) $11.7 \mathrm{~ms}^{-1}$,
B) 1.2 s , assuming negligible air resistance.

| Question 3 |  |  |
| :--- | :--- | :--- |
| (a) (i) | $\left(u=0, s=0.16 \mathrm{~m}, a=9.8(1) \mathrm{ms}^{-2}\right)$ <br> (rearranging $s=u t+1 / 2 a^{2}$ with $u=0$ gives) <br> $t^{2}=\frac{2 s}{a}$ or $v^{2}=u^{2}+2 g s$ or $0.16=1 / 2 \times 9.81 t^{2}$ <br> or $t_{0}=\sqrt{\frac{(2 \times 0.16)}{9.8(1)}} \checkmark=0.1804$ or 0.1806 or 0.181 etc $\checkmark$ (s) 2 sf only $\checkmark$ <br> (ii) <br> $\left(v_{0}=u+a t_{0}=\right) 0+9.81 \times 0.18$ ecf 3 (a) (i) or $v^{2}=2 \times 9.81 \times 0.16 \checkmark$ <br> $=1.8$ or $1.77\left(\mathrm{~ms}^{-1}\right) \checkmark$ | 5 |

## Horizontal and Vertical motion

1. A) 1.4 s ,
B) 34 m
2. A) 800 m
B) 78.4 m
3. A) 5 s
B) 122.5 m
C) Over the factory
4. A) 0.25 s ,
B) $12 \mathrm{~ms}^{-1}$
C) $12.2 \mathrm{~ms}^{-1}$
5. A) $3.5 \times 10^{15} \mathrm{~ms}^{-2}$
B) $2 \times 10^{-9} \mathrm{~s}$
C) $7 \times 10^{6} \mathrm{~ms}^{-1}$
6. A) 4.04 s
B) i) horizontal straight line with zero gradient.

ii) diagonal straight line with constant gradient of $9.81 \mathrm{~ms}^{-1}$

iii) at $t=0 \mathrm{~s}=80 \mathrm{~m}$ and at $\mathrm{t}=4 \mathrm{~s} \mathrm{~s}=0$. As the ball accelerates downwards the velocity will increase as time increases hence, the gradient (representing velocity) will increase (line will go steeper) as $t$ increases.

7. A) 0.45 s
B) $26.7 \mathrm{~ms}^{-1}$

## Jan 09

| Question 4 |  |  |
| :---: | :---: | :---: |
| (a) | velocity vector tangential to path and drawn from the ball, arrow in correct direction <br> acceleration vector vertically downwards, arrow drawn and in line with ball | 2 |
| (b) <br> (i) <br> (ii) | $\begin{aligned} & s=1 / 2 g t^{2} \text { gives } t=\sqrt{\frac{2 y}{g}}=\sqrt{\frac{2 \times 24}{9.8(1)}} \checkmark=2.2(1) \mathrm{s} \checkmark \\ & v(=s / t)=27 / 2.2(1) \checkmark=12\left(.2 \mathrm{~ms}^{-1}\right) \text { or } 12(.3) \checkmark(\text { ecf from (b) (i)) } \end{aligned}$ <br> (answer only gets both marks) | 4 |
|  | Total | 6 |

M1.
(a) (i) $\left(s=\frac{1}{2} g t^{2}\right)$

Allow $g=10$ ( 0.5477 )
$1.5=\frac{1}{2} 9.81 t^{2} \quad$ OR $\quad t=\sqrt{\frac{2 s}{g}} \quad$ OR $t=\sqrt{\frac{2 \times 1.5}{9.81}} \quad$
$(=0.553)=0.55(\mathrm{~s})$
$(=0.553)=0.55(\mathrm{~s}) \checkmark$
0.6 gets 2 marks only if working shown. 0.6 on its own gets 1 mark.
(ii) $\quad(s=v t=430 \times 0.553=237.8=) 240(\mathrm{~m}) \checkmark$ ecf a(i)
(b) their vertical motion is independent of their horizontal motion

OR downward / vertical acceleration is the same for both
OR acceleration due to gravity is the same for both
OR vertical speed/velocity is the same for both $\checkmark$
Allow 'time is constant'
Dont allow 'similar'
(bullets $A$ and $B$ will be in the air) for the same time
(Horizontal acceleration is zero and thus horizontal) distance is proportional to horizontal speed OR $s=u t$ where $u$ is the horizontal velocity $\checkmark$
'velocity smaller so distance smaller' is not sufficient

## Projectiles - Horizontal and Vertical motion

## Questions resolving vectors and finding magnitude and direction

1. A) $6.55 \mathrm{~ms}^{-1}, 4.59 \mathrm{~ms}^{-1}$
B) 1.08 m ,
C) 0.94 s
D) 6.15 m

## Jan 08 - monkey and hunter

| Question 4 |  |  |
| :---: | :---: | :---: |
| (a) | dart moves at a constant speed horizontally <br> as no horizontal force/air resistance <br> but accelerates vertically downwards <br> this results in a parabolic path $\checkmark$ <br> dartboard accelerates vertically downwards <br> at same rate as dart $\checkmark$ <br> gravity acting on dart and/or dartboard at same rate as dart $\checkmark$ <br> at a particular instant vertical (component of) velocity is the same for dart and dartboard at same rate as dart $\checkmark$ | $\max 4$ |
| (b) <br> (i) <br> (ii) <br> (iii) | $\begin{aligned} & \text { (use of speed }=\text { distance } / \text { time }) \\ & \text { time }=2 / 8.0=0.25 \mathrm{~s} \\ & (\text { use of } v=u+a t) \\ & v=9.81 \times 0.25=2.45 \mathrm{~m} \mathrm{~s}^{-1} \checkmark\left(\text { accept } \mathrm{g}=10 \mathrm{~m} / \mathrm{s}^{2}\right) \\ & \left(\text { use of } v^{2}=v_{h}^{2}+v_{v}^{2}\right) \\ & v^{2}=2.45^{2}+8.0^{2} \checkmark \\ & \mathrm{v}=8.37 \mathrm{~m} \mathrm{~s}^{-1} \checkmark \\ & \text { angle below horizontal } \left.=\tan ^{-1}(2.45 / 8)=17^{\circ} \checkmark \text { (or } 17.3^{\circ}\right) \end{aligned}$ | 5 |
|  | Total | 6 |

## Displacement time and velocity time graphs

1. a) $10 \mathrm{~ms}^{-1}$
b) $20 \mathrm{~ms}^{-1}$
c) $50 \mathrm{~ms}^{-1}$
2. a) $-0.45 \mathrm{~ms}^{-2}$
b) $3.1 \times 10^{6} \mathrm{~m}$
3. a) 135 m
b) $1.2 \mathrm{~ms}^{-2}$
4. a) stone dropped from the roof of a tall building

b) a tennis ball thrown vertically upwards from the time it leaves your hand until you catch it again

c) a tennis ball released from $2 m$ height and allowed to bounce twice before being caught

d) a tennis ball during a rally


## M1.B

## M2.A

## M3.C

M4.C

## M5.C

M6.C

M7.
(a) (i) $\left(\alpha=\frac{v-u}{t}\right)=\frac{58}{3.5}, ~, ~=17\left(\mathrm{~m} \mathrm{~s}^{-2}\right) \vee$
(ii) $\quad(F=m a)=5800 \times 16.57$ ecf (a)(i) $\downarrow$
$=96000 \checkmark$
allow 98600 or 99000 for use of 17
$N$
(iii)
$\left(s=\frac{1}{2}(u+\nu) t\right)=\frac{1}{2} \times 58 \times 3.5$
$=100(101.50,102$, accept 101 m$)$
or use of $\nu^{2}=u^{2}+2$ as ( $=101 \mathrm{~m} .98 .9$ for use of 17) 2
or $\mathrm{s}=u t+\frac{1}{2} a t^{2}\left(=101.7\right.$, use of 17 gives 104) (ecf from (a)(i)) ${ }_{2}$
(iv) $(W=F s)(\mathrm{a})($ (ii $) \times(\mathrm{a})$ (iii) or use of $\frac{1}{2} \operatorname{mv}^{\prime}(=13.6$ to 14.7)
$\left(P=\frac{F s}{t}\right)=\frac{96106 \times 101.5}{3.5} \quad v^{\prime}=2.8 \mathrm{M}(\mathrm{W}) \operatorname{ecf}(\mathrm{a})(\mathrm{ii})$, (a)(iii)
or use of $P=\frac{F V}{2}$ their answer $\times 5 \mathbf{V}^{\prime}=14,000,000=14 \mathrm{M}(\mathrm{W})_{3}$
(b) $\frac{1}{2}(m) v^{2}=(m) g(\Delta) h$ or (loss of) $K E=$ (gain in) PE $v^{\prime}$
allow their work done from (iv) used as KE

$$
\begin{aligned}
& h=\frac{1}{2} \frac{v^{2}}{g} \text { or } h=\frac{1}{2} \times \frac{58^{2}}{9.81} \\
& \text { accept use of } \text { kinematics equation } \\
& =170 \checkmark
\end{aligned}
$$

M8. (a) (i)

(ii) no horizontal force acting (1)
(hence) no (horizontal) acceleration (1)
[or correct application of Newton's First law]
(b) (i) (use of $v^{2}=u^{2}+2$ as gives) $32^{2}=(0)+2 \times 9.81 \times s(1)$
$s=\frac{1024}{19.62}$
(1) $\quad(=52.2 \mathrm{~m})$
(ii) (use of $s=1 / 2$ at gives) $\quad 52=1 / 29.81 \times t^{2}(1)$
$t=\sqrt{\left(\frac{104}{9.81}\right)}=3.3 \mathrm{~s}(1) \quad(3.26 \mathrm{~s})$
[or use of $v=u+$ at gives $32=(0)+9.81 \times t(1)$
$\left.t=\frac{32}{9.81}=3.3 \mathrm{~s}(1) \quad(3.26 \mathrm{~s})\right]$
(iii) (use of $x=v t$ gives) $\times(=\mathrm{QR})=95 \times 3.26$ (1)
$=310 \mathrm{~m}$ (1)
(use of $t=3.3$ gives $x=313.5 \mathrm{~m}$ )
(allow C.E. for value of $t$ from (ii)
(c) maximum height is greater (1) because vertical acceleration is less (1) [or longer to accelerate]

M9.(a) AB: (uniform) acceleration (1)
BC: constant velocity / speed or zero acceleration (1)
CD: negative acceleration or deceleration or decreasing speed / velocity (1)
DE: stationary or zero velocity (1)
EF ; (uniform) acceleration in opposite direction (1)
(c) distance is a scalar and thus is the total area under the graph [or the idea that the train travels in the opposite direction] (1) displacement is a vector and therefore the areas cancel (1)

M10. (a) (i) (use of $a=\frac{\Delta v}{\Delta t}$ gives) $a=\frac{4.5}{3600}$

$$
\begin{equation*}
=1.25 \times 10^{-3} \mathrm{~ms}^{-2}(1) \tag{1}
\end{equation*}
$$

(ii) (use of $v^{2}=u^{2}+2$ as gives) $0=4.5^{2}-2 \times 1.25 \times 10^{-3} \times s(1)$

$$
\begin{equation*}
s\left(=\frac{20.25}{2.5 \times 10^{-3}}\right)=8.1 \times 10^{3} \mathrm{~m} \tag{1}
\end{equation*}
$$

(b) increasing curve (1) correct curve (1)

(c) gradient (slope) of graph represents speed (1) hence graph has decreasing gradient (1)

## Challenge Questions

2007 3. B
2007 6. A
2008 6. D
6. Friction will produce heat energy and so the total energy will not be $\mathrm{PE}+\mathrm{KE}$ (or all of the PE will not turn into KE). At a constant velocity there is no gain of KE. On a horizontal surface there is no change of PE. Falling freely, the PE turns solely into KE.

## 2010 2. B

2. Constant acceleration so the speed increases linearly with time. But the distance fallen increases as $t^{2}\left(s=1 / 2 g t^{2}\right)$. So the average speed occurs at half the time taken to pass the window, which is before it has covered half the height of the window.

2009 3. C
3. Initial energy is $\mathrm{KE}+$ grav PE and this is converted to grav PE is it goes up the slope and stops.

$$
\begin{aligned}
1 / 2 \times 750 \times 20^{2}+750 \times 9.8 \times 5 & =750 \times 9.8 \times h \\
\mathrm{~h} & =25 \mathrm{~m}
\end{aligned}
$$

## 2012 1. C

Qu. 1 The laws of physics are the same in different inertial (constant velocity) reference frames. Alternatively, viewed from outside the lift, when the stone is released it is observed to be rising at speed $v$, i.e. that of the lift, whilst the floor is rising at this speed. So the time taken for it to reach the floor is the same.

2012 6. D
Qu. 6 Jack throws his penny up and it decelerated by $g$, whilst on the way down it falls back to the window level with the same acceleration of $g$ and taking the same time. So it passes the window on the way down with the same $4 \mathrm{~m} / \mathrm{s}$ that it started with on the way up. So it is indistinguishable from Jill's penny.

## 200911.

## Question 11.

A plane accelerates from rest to take off from a runway. There is a point of no return where the pilot will not be able to stop the plane before the end of the runway if he fails to take off. The runaway is 2 km long and the plane can accelerate at $3 \mathrm{~ms}^{-2}$ and can decelerate at $2 \mathrm{~ms}^{-2}$. We can calculate the length of time available from the start of the take off to the point of no return.
a) Sketch a graph of the speed of the plane against time for the situation where the plane fails to take off but the whole length of the runway is used. (no values are required)

b) If $t_{l}$ is the time taken for the plane to reach its maximum speed $v$, and $t_{2}$ is the time taken for it to decelerate before it goes beyond the end of the runway, express $v$ in terms of $t_{l}$ and $t_{2}$.
$\qquad$
c) Calculate the distance $s_{l}$ travelled by the plane whilst accelerating, in terms of $t_{l}$, and the distance $s_{2}$ travelled by the plane whilst decelerating, in terms of $t_{2}$.

(having substituted for a)

OR area under graph: $s_{l}=1 / 2 v t_{l} \quad \checkmark$ and $s_{l}=1 / 2 v t_{l} \quad \checkmark \quad$ [2]
d) From your answers to (b) and (c), calculate the value of $t_{l}$, the time taken to reach the point of no return, given that the runaway is 2 km long.
$2000=s_{L}+s_{2} \quad$ so, $2000=3 / 2 t_{L}{ }^{2}+t_{2}{ }^{2}$
But $t_{2}=3 / 2 t_{l} \quad$ so, $2000=3 / 2 t_{l}{ }^{2}+9 / 4 t_{l}{ }^{2}$ (solvable equ) ${ }^{\checkmark} t_{l}=23 \mathrm{~s}{ }^{\checkmark}$ OR $2000=s_{l}+s_{2} \quad$ so, $2000=1 / 2 v_{l}+1 / 2 v_{2}=1 / 2 v\left(t_{l}+t_{2}\right)=1 / 2 v^{2} 5 / 6 \quad{ }^{\checkmark} \quad$ (solvable
$\qquad$ [2]

## Question 12.

A solid sphere of mass $m$ rolls down a slope. The sphere gains kinetic energy in two forms: rotational kinetic energy and translational kinetic energy in which the centre of mass moves along at speed $v$. For the solid sphere, a fixed fraction, $2 / 7$, of the gravitational potential energy lost as it rolls down the slope appears as rotational kinetic energy. If the sphere now rolls along a flat surface at a speed of $4.0 \mathrm{~ms}^{-1}$ and then encounters a rising slope at $30^{\circ}$ to the horizontal, we can calculate how far up the slope the sphere will rise. We can take the mass of the sphere as 1 kg .
a) Calculate the translational KE of the sphere and hence the total energy of the rolling sphere.
$1 / 2 m v^{2}=8 \mathrm{~J}$
this is $5 / 7$ of the total energy
total energy $=7 / 5 \times 8=11.2 \mathrm{~J}$
b) Describe the energy changes that take place as the sphere rolls up the slope.
$\qquad$
Translational \& rotational $\checkmark$
gravitational PE gained $\qquad$
c) What is the vertical height reached up the slope?

| $m g h=11.2 \mathrm{~J}$ |
| :---: |
| $h=11.2 / 9.8=1.14 \mathrm{~m}$ |

$\qquad$ [2]
d) How far up along the slope does this take the sphere?
$\qquad$
$\qquad$
slope length $=$ height $/ 0.5=2.3 \mathrm{~m}$ $\checkmark$

