A-Level Physics

Projectile Motion

Question Paper

Time available: 81 minutes
Marks available: 60 marks

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1. **Figure 1** shows the H-shaped posts used in a game of rugby.

Figure 1

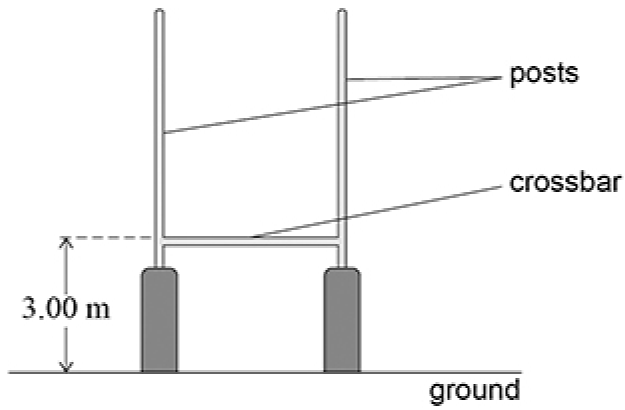
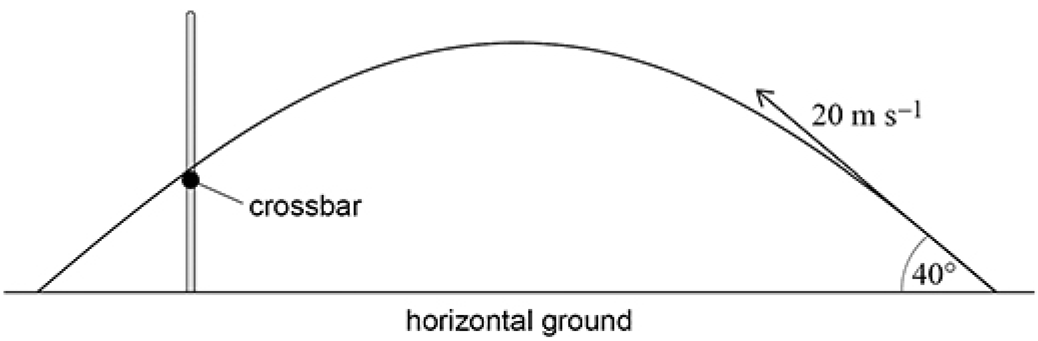


Figure 2 shows the path of a ball that is kicked and just passes over the crossbar. The initial velocity of the ball is 20.0 m s^{-1} at an angle of 40.0° to the ground.

You should consider air resistance to be negligible and treat the ball as a simple projectile.

Figure 2



The top of the crossbar is 3.00 m above the horizontal ground.

(a) Show that the minimum speed of the ball in flight is about 15 m s^{-1}.

Explain your answer.

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(2)

(b) The ball just passes over the crossbar at a time t after it is kicked.

Show that t must satisfy the following equation:

$$4.91t^2 - 12.9t + 3.00 = 0$$

(2)

(c) There are two solutions to the equation

$$4.91t^2 - 12.9t + 3.00 = 0$$

Discuss which of the two solutions is the time taken for the ball to pass over the crossbar from when it is kicked.

In your answer you should

- state the value for t given by each solution
- explain the physical significance of the other solution.

solution 1 = _______________ s

solution 2 = _______________ s

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(4)

(d) Another attempt is made to kick the ball over the crossbar. The initial velocity of the ball is the same as in the first attempt.
This kick is made from a horizontal distance of 38 m from the posts.

Deduce whether the ball can pass over the crossbar.

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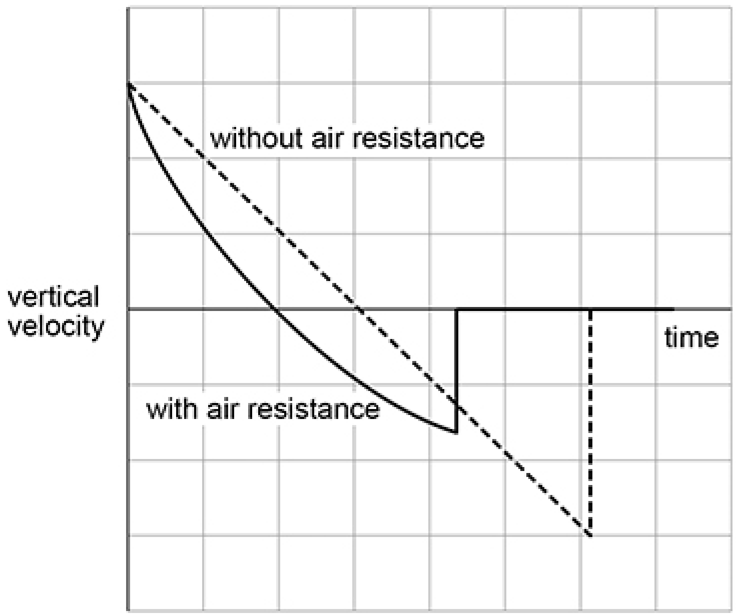
(1)

(e) **Figure 3** shows the variations with time of the vertical velocity of a ball with and without air resistance.

Figure 3



Discuss the features of the motion of the ball shown by the two graphs.

In your answer you should refer to

- the gradients of the graphs
- the area between each line and the time axis.

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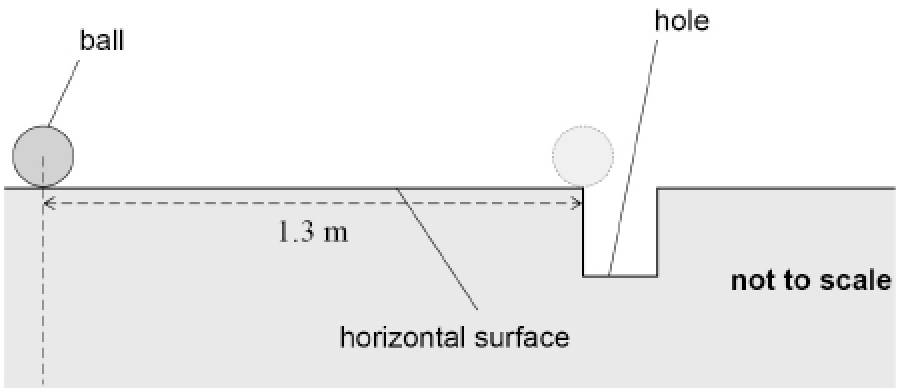
(5)

(Total 14 marks)

2. (a) **Figure 1** shows a golf ball at rest on a horizontal surface 1.3 m from a hole.

Figure 1



A golfer hits the ball so that it moves horizontally with an initial velocity of 1.8 m s^{-1}. The ball experiences a constant deceleration of 1.2 m s^{-2} as it travels to the hole.

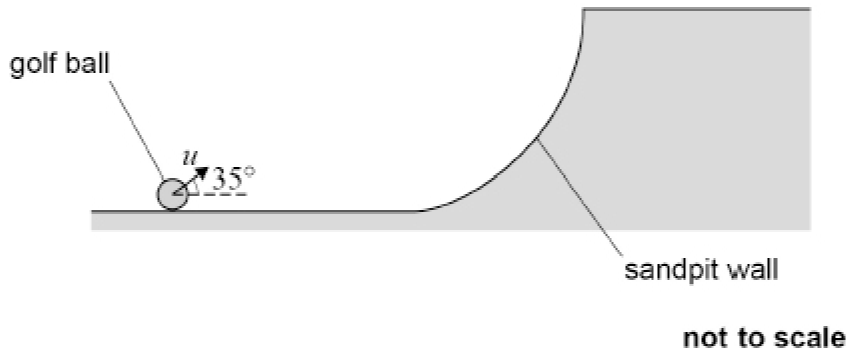
Calculate the velocity of the ball when it reaches the edge of the hole.

velocity = ________________ m s^{-1}

(2)

(b) Later, the golf ball lands in a sandpit. The golfer hits the ball, giving it an initial velocity u at 35° to the horizontal, as shown in **Figure 2**. The horizontal component of u is 8.8 m s^{-1}.

Figure 2

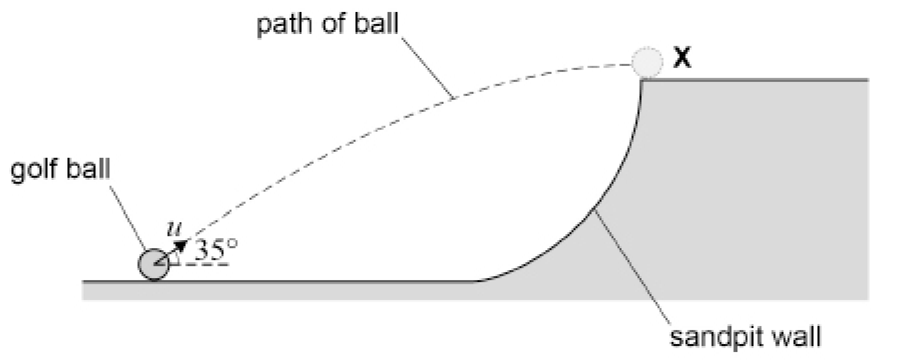


Show that the vertical component of u is approximately 6 m s^{-1}.

(1)

(c) The ball is travelling horizontally as it reaches **X**, as shown in **Figure 3**.

Figure 3



Assume that weight is the only force acting on the ball when it is in the air.

Calculate the time for the ball to travel to **X**.

time = _______________ s

(2)

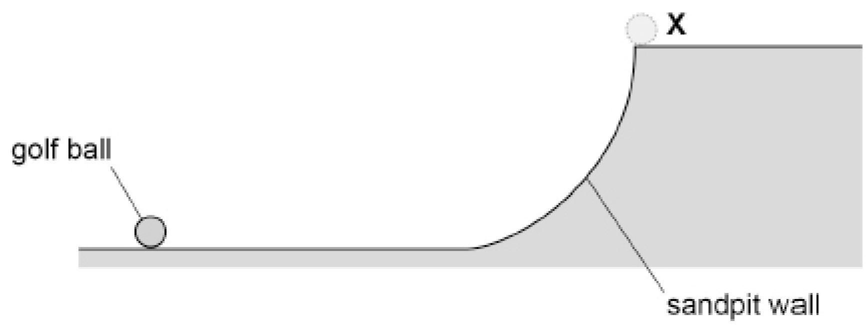
(d) Calculate the vertical distance of **X** above the initial position of the ball.

vertical distance = _______________ m

(2)

The golfer returns the ball to its original position in the sandpit. He wants the ball to land at **X** but this time with a **smaller** horizontal velocity than in **Figure 3**.

Figure 4



(e) Sketch on **Figure 4** a possible trajectory for the ball.

(1)

(f) Explain your reason for selecting this trajectory.

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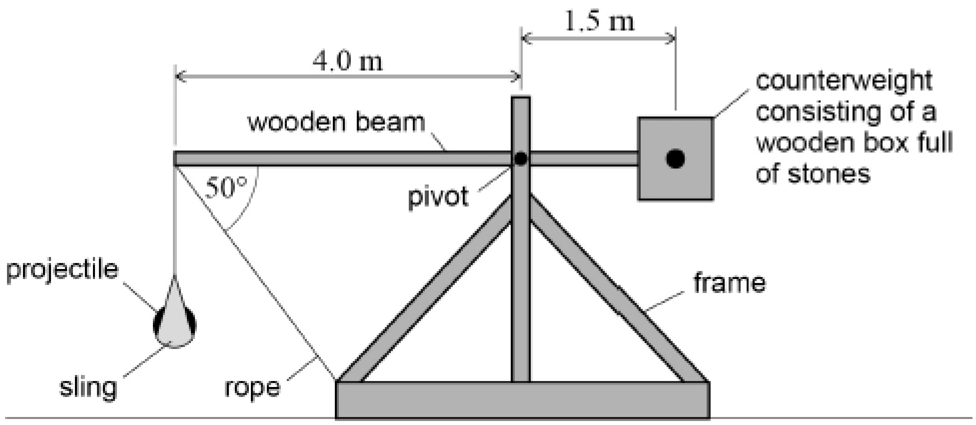
(2)
(Total 10 marks)

3. **Figure 1** shows a simplified catapult used to hurl projectiles a long way.

Figure 1



The counterweight is a wooden box full of stones attached to one end of the beam. The projectile, usually a large rock, is in a sling hanging vertically from the other end of the beam. The weight of the sling is negligible.
The beam is held horizontal by a rope attached to the frame.

(a) The catapult is designed so that the weight of the beam and the weight of the **empty** wooden box have no effect on the tension in the rope.

Suggest how the pivot position achieves this.

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(2)

(b) The stones in the counterweight have a total mass of 610 kg and the projectile weighs 250 N.

Calculate the tension in the rope.

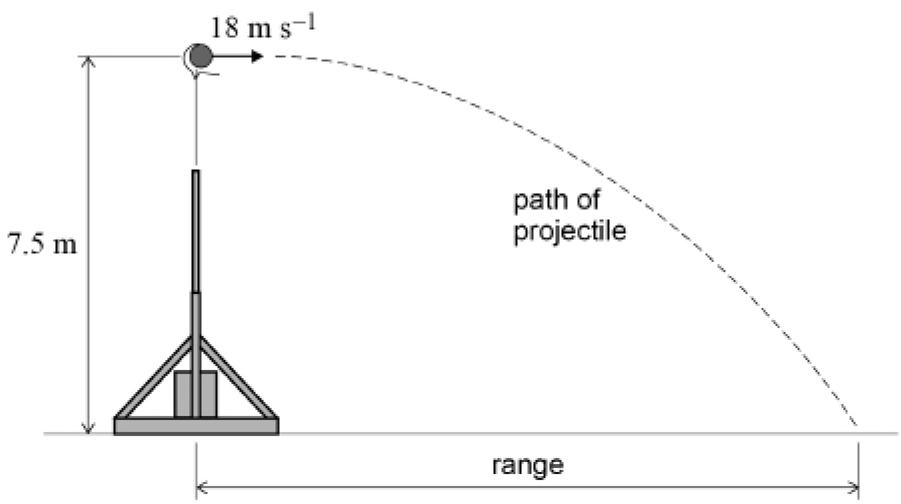
tension = ____________________ N

(5)

(c) When the rope is cut, the counterweight rotates clockwise. When the beam is vertical it is prevented from rotating further. The projectile is then released horizontally with a velocity of 18 m s^{-1}, as shown in **Figure 2**.

The projectile is released at a height of 7.5 m above ground level.

Figure 2



The range of the catapult is the horizontal distance between the point where the projectile is released to the point where it lands.

Calculate the range.
Ignore air resistance.

range = ____________________ m

(2)

(d) In another release, the sling is adjusted so that a projectile of the same mass is released just before the wooden beam is vertical. The projectile is not released horizontally.

Discuss the effect this change has on the range of the catapult.

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(3)
(Total 12 marks)

4. A car is designed to break the land speed record. The thrust exerted on the car is 230 kN at one instant of its motion. The mass of the car at this instant is 11 000 kg.

(a) The acceleration of the car at this instant is 2.9 m s^{-2}.

Calculate the air resistance acting on the car.

air resistance =__________________ N

(3)

(b) The thrust on the car remains constant as the speed increases.

Explain why the acceleration decreases and eventually reaches zero.

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(2)

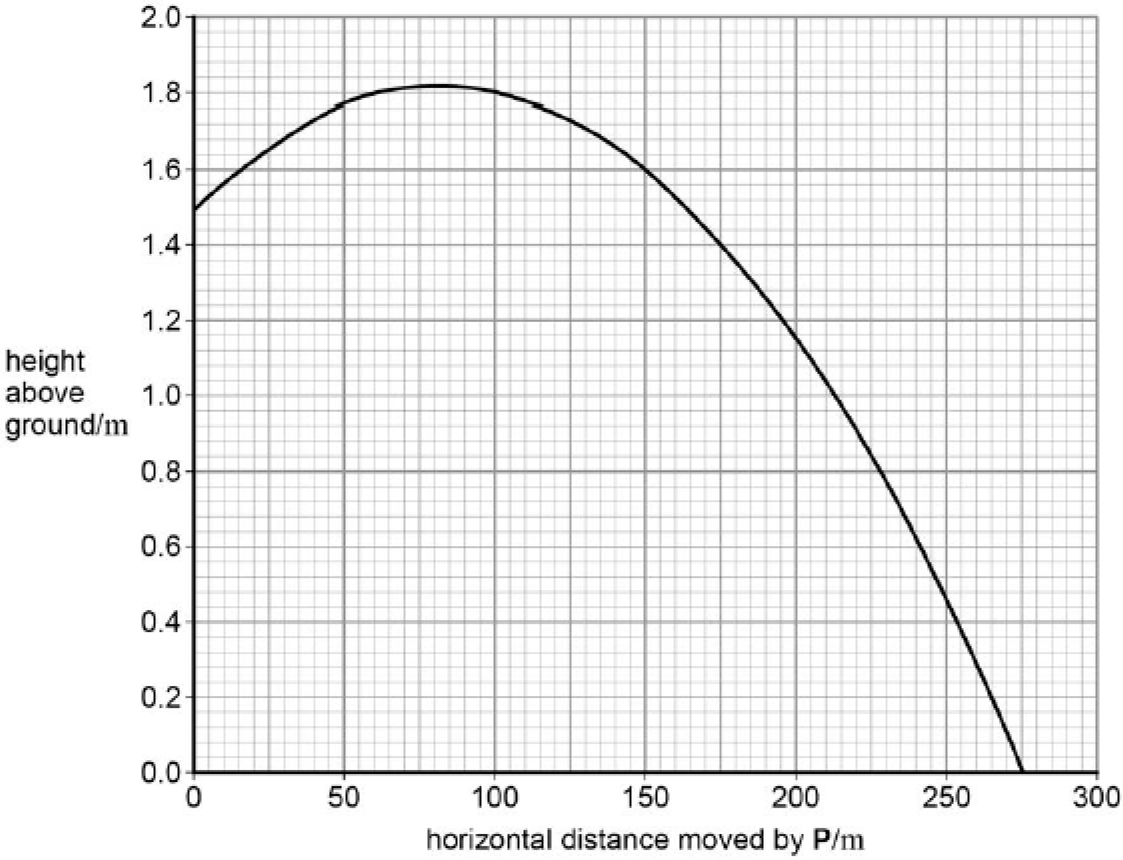
(c) A supersonic car is attempting to break the land speed record on a horizontal track. When it is travelling at 320 m s^{-1}, a small part **P** that is 1.5 m above the ground becomes detached from the car. The initial vertical velocity of **P** is 2.5 m s^{-1} in the upwards direction.

Calculate the time taken for the small part **P** to reach the ground.
Assume that air resistance has a negligible effect on the vertical motion.

time =______________________s

(3)

(d) The graph below shows the path that **P** would follow from the instant that it became detached if there were no air resistance in the horizontal direction.



In practice, air resistance is not negligible in the horizontal direction.

Draw, on the graph, a line to show the path that **P** would follow assuming that air resistance only affects motion in the horizontal direction.

(2)

(e) Explain your answer to part **(d)**, including the reason why air resistance is negligible in the vertical direction.

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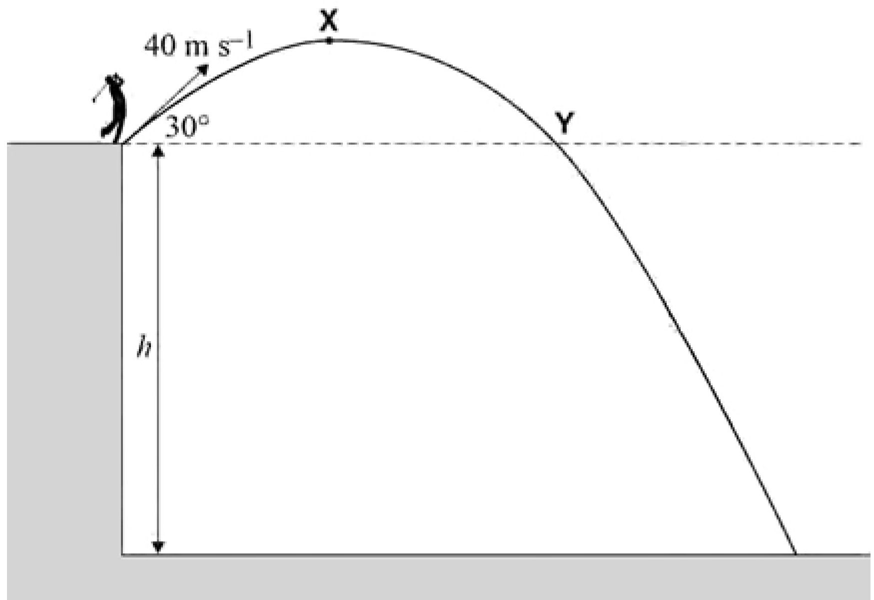
(2)
(Total 12 marks)

5. **Figure 1** shows a golfer hitting a ball from the top of a cliff. The ball follows the path shown. The ball is hit with an initial velocity of 40 m s^{-1} at an angle of 30° above the horizontal, as shown. Assume that there is no air resistance.

Figure 1



(a) Calculate the initial vertical component of velocity of the ball.

initial vertical component of velocity = ______________________________ m s^{-1}

(1)

(b) Draw on the diagram an arrow to show the direction of the force acting on the ball when it is at point **X**, the highest point of the flight. Label this arrow **F**.

(1)

(c) At point **Y** the ball is level with its initial position.

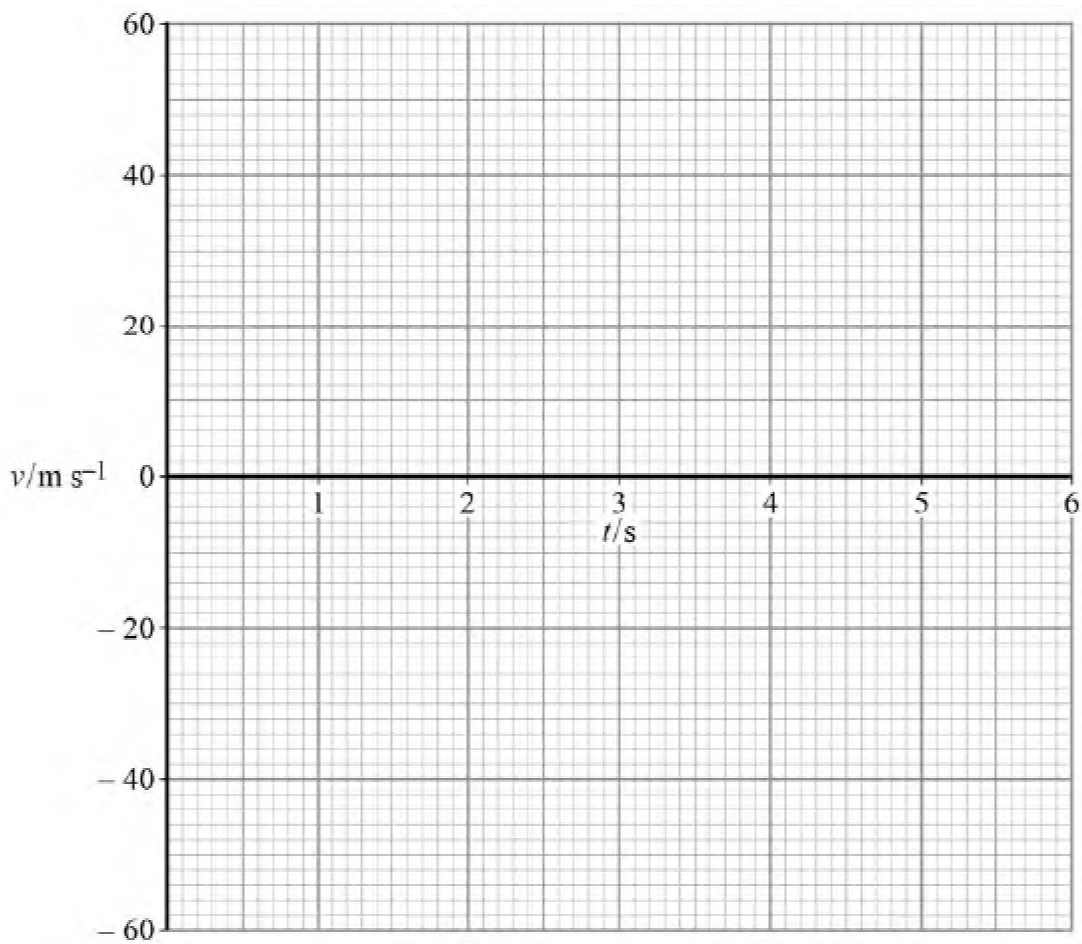
Show that the time taken to reach **Y** is about 4 s.

(2)

(d) The total time of flight of the ball is 6.0 s.

Show on **Figure 2** how v, the vertical component of the velocity, changes throughout the whole 6.0 s.

Figure 2



(3)

(e) Calculate the height h of the cliff.

height ___________________ m

(3)

(f) In practice, the air resistance affects the path of the ball.

Draw on **Figure 1** the path the ball takes when air resistance is taken into account.

(2)

(Total 12 marks)