VCE PHYSICS UNIT 3 & 4
Australian Curriculum

WORKBOOK

Physics

TOPICS

UNIT 3: HOW DO FIELDS EXPLAIN MOTION AND ELECTRICITY?

Area of Study 1: How do physicists explain motion in two dimensions?

Area of Study 2: How do things move without contact?

Area of Study 3: How are fields used in electricity generation?

UNIT 4: HOW HAVE CREATIVE IDEAS AND INVESTIGATIONS REVOLUTIONISED THINKING IN PHYSICS?

Area of Study 1: How has understanding about the physical world changed?

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Supporting Teachers of Science
Advancing Science Education

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Area of Study 1:
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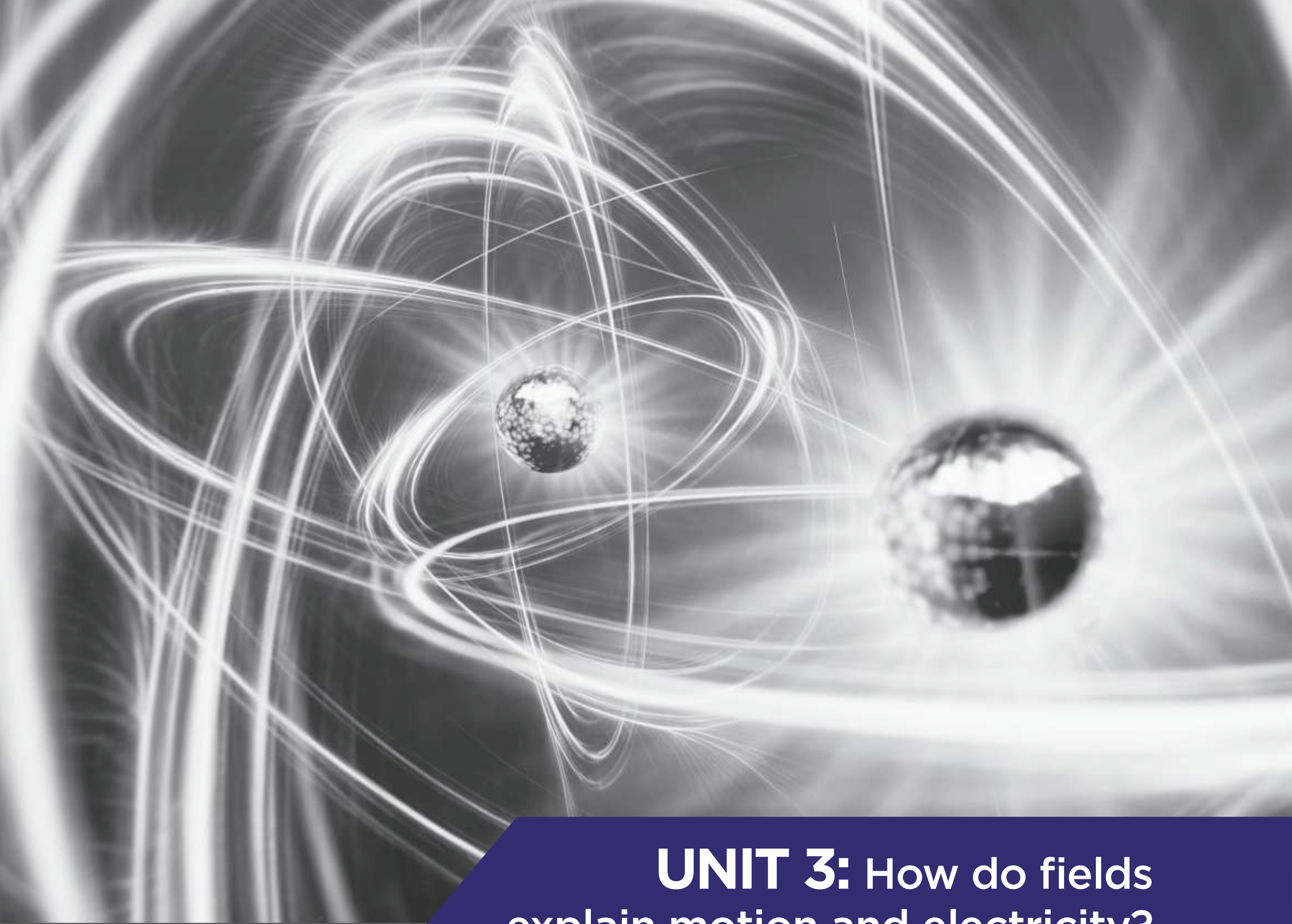


UNIT 3: How do fields explain motion and electricity?

Area of Study 1: How do physicists explain motion in two dimensions?

3.1.3 Projectile Motion

Investigate and analyse theoretically and practically the motion of projectiles near Earth's surface, including a qualitative description of the effects of air resistance.

A **projectile** is any object launched into the air whose motion is influenced only by gravity and, in some cases, air resistance. It moves in two dimensions—horizontal and vertical—which are treated independently. Together, these create a curved, parabolic trajectory determined by the object's initial velocity, launch angle, and gravity. Understanding projectile motion enables accurate predictions of an object's position and velocity throughout its flight—essential in fields such as sports science, aerospace, and engineering. This chapter explores projectile motion close to Earth's surface.

Motion in Two Dimensions

When an object is launched near Earth's surface—such as the ball in **Figure 3.18**—it follows a curved, parabolic path. At any instant, the object's velocity is tangent to the parabolic path and is represented with the symbol v, with the exception of the moment of launch when the velocity is represented by u, the initial velocity. The velocity at any instant has two perpendicular components called its horizontal and vertical velocity components. **The horizontal component of velocity (v_x)** remains constant in magnitude, assuming air resistance is negligible, as no net force acts in the horizontal direction. In contrast, the **vertical component of velocity (v_y)** changes over time due to the constant downward force of gravity. Gravity causes a uniform acceleration, slowing the vertical motion as the object rises and increasing it as the object falls.

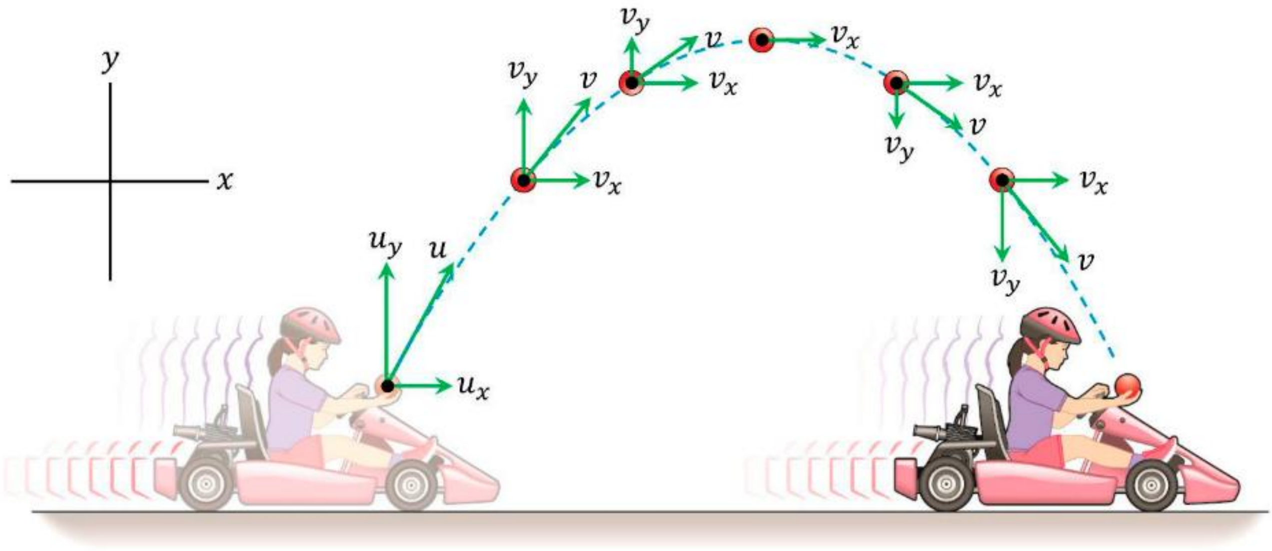


Figure 3.18: Motion of a projectile

Figure 3.18 illustrates how velocity changes throughout a projectile's flight. First, the horizontal velocity vectors remain constant in both length and direction, indicating that the horizontal component of velocity stays unchanged. In contrast, the vertical velocity vectors decrease in length as the projectile rises, reaching zero at the peak, then increase again during descent—demonstrating the effect of gravity. These vectors also change direction during flight, pointing upward during ascent and downward during descent. At the highest point, the vertical component is absent, confirming that it is zero at this position and that the velocity is purely horizontal.

Calculating Velocity

The horizontal and vertical components of a projectile's velocity at any instant are calculated using the velocity (v) and the angle (θ) between the velocity vector and its horizontal component. The velocity is broken down into two perpendicular components using trigonometry.

The horizontal component of velocity is calculated using the cosine function:

$$v_x = vcos\theta$$

The vertical component of velocity is calculated using the sine function:

$$v_y = vsin\theta$$

Conversely, in situations where the horizontal and vertical components of velocity are known, the magnitude and direction of the velocity can be calculated.

The magnitude of the velocity (speed) is calculated using Pythagoras theorem:

$$v^2 = {v_x}^2 + {v_y}^2$$

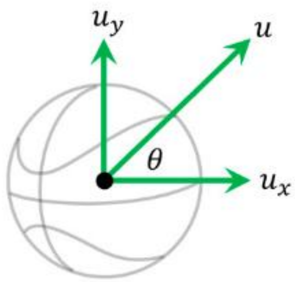
The direction of the velocity is determined by calculating the angle between the velocity vector and its horizontal component using the tangent function:

$$tan\theta = \frac{v_y}{v_x}$$

The direction is then stated as an angle above or below the horizontal component of velocity vector. When the projectile is ascending away from the surface, the angle is **above the horizontal**, and when descending, the angle is **below the horizontal**.

Example 3.15

A basketball is launched into the air with an initial velocity of 7.0 m s^{-1} at 52° above the horizontal.



The horizontal and vertical components of the initial velocity are calculated as follows:

$$u_x = ucos\theta = 7.0 \text{ x } cos52 = 4.3 \text{ m s}^{-1}$$

$$u_y = usin\theta = 7.0 \text{ x } sin52 = 5.5 \text{ m s}^{-1}$$

Example 3.16

A short time after launch, the basketball ascends with a vertical component of velocity of 2.6 m s^{-1} and a horizontal component of velocity of 4.3 m s^{-1}.

The magnitude of the velocity at this instant is calculated as follows:

$$v = \sqrt{{v_x}^2 + {v_y}^2} = \sqrt{(4.3)^2 + (2.6)^2} = 5.0\ m\ s^{-1}$$

The direction is calculated as follows:

$$\theta = tan^{-1}\left(\frac{v_y}{v_x}\right) = tan^{-1}\left(\frac{2.6}{4.3}\right) = 31° \text{ above the horizontal}$$

The Independence of Velocity Components

The horizontal and vertical components of velocity are **independent** because different factors influence them. The vertical motion is affected by gravity, which acts solely in the vertical direction. In contrast, the horizontal motion experiences no net force (in the absence of air resistance) and thus remains unchanged. According to Newton's Second Law, forces in perpendicular directions do not interfere with one another. This separation allows physicists to analyse projectile motion by resolving it into two simpler one-dimensional motions. By treating each component independently, it becomes possible to accurately predict the projectile's position, velocity, and trajectory at any point in time.

A simple experiment can help demonstrate the independence of horizontal and vertical components in projectile motion. First, while standing still, drop a rubber ball and catch it as it rebounds. You'll observe that the ball falls straight down, lands near your feet, and returns to about the same height in roughly one second. Now repeat the experiment while walking or skating forward at a constant speed, like the person in **Figure 3.19**. Drop the ball again and observe closely. From your perspective, the ball behaves just as it did before: it falls straight down, bounces back up, and returns to your hand after about a second. However, to an outside observer, the ball follows a curved, parabolic path. This illustrates that the ball's vertical motion—its fall and bounce—is unaffected by your horizontal movement. The two motions occur simultaneously but do not influence each other, proving they are independent.

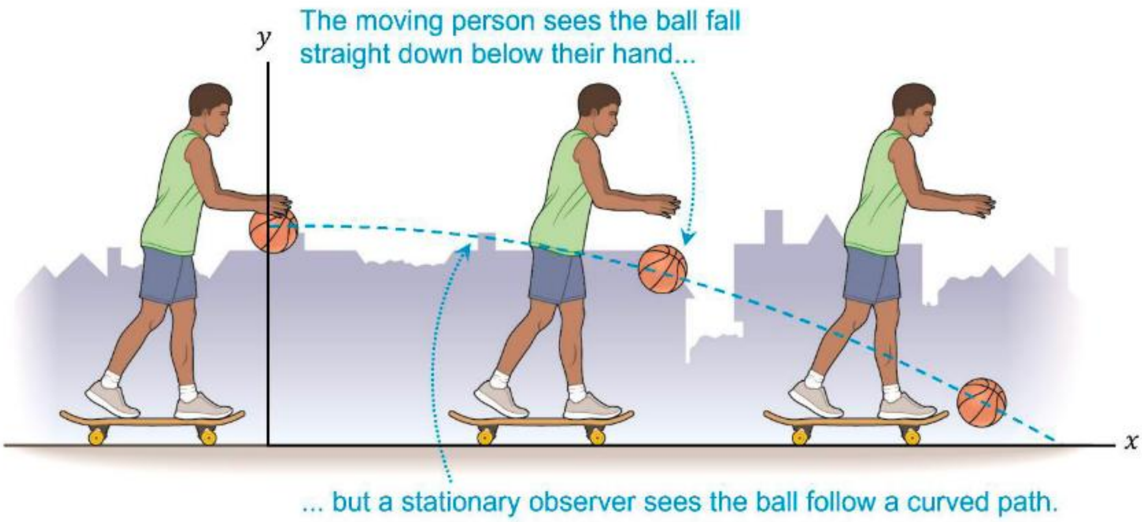


Figure 3.19: Independence of Velocity Components

The independence of horizontal and vertical velocity components leads to an important observation: if two projectiles are launched from the same height—one horizontally and the other dropped vertically—they will hit the ground at the same time. This is because both projectiles share the same vertical motion; they start with the same vertical velocity (zero, in this case) and are affected equally by gravity. As a result, their vertical displacement changes at the same rate. The horizontal motion of one of the projectiles does not influence how quickly it falls, highlighting the complete independence of vertical and horizontal motion in projectile motion. This feature of projectile motion is evident in **Figure 3.20,** which shows yellow and green balls descending toward the surface after being launched from rest. Notice that each is launched from the same height and lands at the same time.

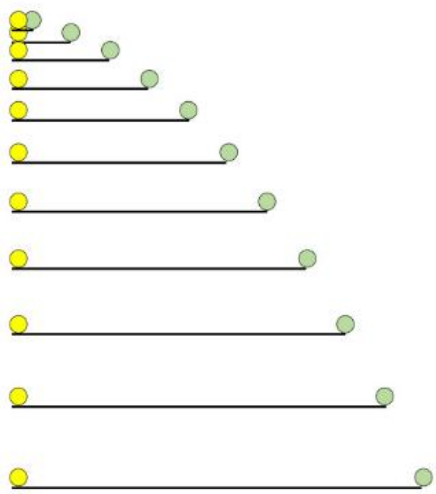


Figure 3.20: Simultaneous motion

Projectile Motion

Two types of projectile motion are explored in this text, one in which the object has **a zero launch angle to the horizontal** and the other where the projectile has a **non-zero launch angle above the horizontal**. These two types of projectile motion are illustrated in **Figure 3.21**. The diver at the left is launching themselves with a non-zero launch angle above the horizontal, and the diver at the right is launching themselves horizontally with a zero launch angle to the horizontal.

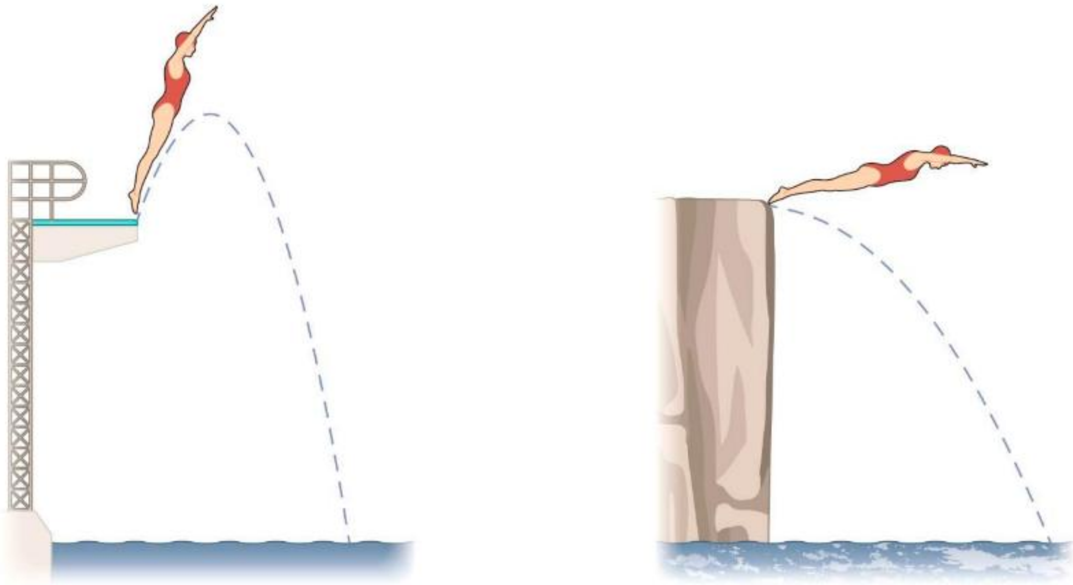


Figure 3.21: Projectile motion with a zero launch angle (right) and non-zero launch angle (left).

Each diver has motion in the horizontal and vertical direction after launch. Each of these motions is treated independently, such that horizontal aspects of their motion, such as their horizontal displacement (s_x), called range (R), is calculated using the horizontal component of velocity and vertical aspects of motion, such as the vertical displacement (s_y) are calculated using the vertical component of velocity.

Furthermore, since the horizontal component of velocity is constant, there is zero horizontal acceleration. This means we use the **equations for constant velocity** to calculate horizontal aspects of motion. For example, the range is calculated using:

$$s_x = v_x t$$

In situations where the range and time of flight (t) are known, the horizontal component of velocity is calculated using:

$$v_x = \frac{s_x}{t}$$

Conversely, since the vertical component of velocity is affected by the constant vertical force of gravity, the vertical acceleration (g) is constant and equal to 9.8 m s^{-2}. This means we use the **equations of motion for constant acceleration** to calculate vertical aspects of motion. For example, the vertical displacement may be calculated using:

$$s_y = u_y t + \frac{1}{2} g t^2$$

The vertical component of velocity at any instant (t) after launch is calculated using:

$$v_y = u_y + g t$$

Projectile Motion with Zero Launch Angle

When a projectile is launched with zero launch angle to the horizontal, its initial velocity (u) is entirely horizontal, such that it is equal to the horizontal component of velocity (v_x):

$$u = v_x$$

Hence, the vertical component of the initial velocity is zero:

$$u_y = usin\theta = usin0 = 0$$

Substituting these specific values into our fundamental equations of motion gives the following simplified results for zero launch angle (θ = 0):

For the horizontal displacement (s_x), or range (R):

$$s_x = v_x t$$

For the vertical displacement (s_y):

$$s_y = u_y t + \frac{1}{2}gt^2 = 0 + \frac{1}{2}gt^2$$

$$s_y = \frac{1}{2}gt^2$$

When the range is not known, the time of flight (t), representing the number of seconds the projectile moves through the air after launch and before it lands, is calculated by rearranging the equation for the vertical displacement.

$$s_y = \frac{1}{2}gt^2$$

$$t = \sqrt{\frac{2s_y}{g}}$$

For the vertical component of velocity (v_y) at any time (t) after launch:

$$v_y = u_y + gt$$

$$v_y = gt$$

Example 3.17

A mountain climber launches themselves horizontally at 2.8 m s^{-1} and falls 2.4 m before landing.

Their **time of flight** is:

$$t = \sqrt{\frac{2s_y}{g}} = \sqrt{\frac{2(2.4)}{9.8}} = 0.70 \text{ s}$$

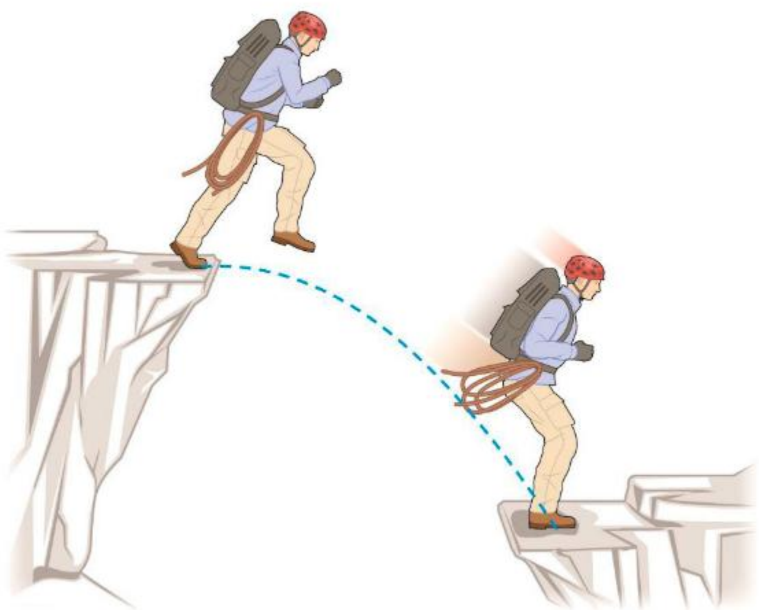
Their **range** is:

$$s_x = v_x t = 2.8 \text{ x } 0.70 = 2.0 \text{ m}$$

Their **vertical component of velocity** 0.35 s after launch is:

$$v_y = u_y + gt = 0 + (9.8 \text{ x } 0.35)$$

$$v_y = 3.4 \text{ m s}^{-1}$$



Projectile Motion with a Non-Zero Launch Angle

When a projectile is launched with a non-zero launch angle above the horizontal, its initial velocity (u) is through two dimensions, so it has a non-zero horizontal and vertical component of velocity.

The horizontal component of the initial velocity is:

$$u_x = ucos\theta$$

The horizontal component of velocity is constant throughout flight, so:

$$u_x = v_x$$

The vertical component of the initial velocity is:

$$u_y = usin\theta$$

Substituting these specific values into our fundamental equations of motion gives the following simplified results for a non-zero launch angle ($\theta > 0$):

The time taken for the projectile to reach its maximum height after launch (t) is calculated by rearranging the formula for the average acceleration:

$$a = \frac{v - u}{t}$$

Substituting the vertical components of the initial (u_y) and final velocity (v_y) and the vertical acceleration (g) gives:

$$\mathrm{g} = \frac{v_y - u_y}{t}$$

The vertical component of the initial velocity is directed upwards, and the vertical acceleration is downwards, so **we make g a negative value**. This ensures the equation gives a positive value for the time. Since the vertical component of velocity at maximum height is zero, the time taken to reach the maximum height is:

$$t = \frac{v_y - u_y}{\mathrm{g}} = \frac{0 - u_y}{-\mathrm{g}} = \frac{-u_y}{-\mathrm{g}}$$

The maximum height above the launch point is calculated using the time taken to reach maximum height. Once again, the value of g is made negative as the vertical component of the initial velocity (u_y) and vertical acceleration (g) have opposite directions.

$$s_y = u_y t + \frac{1}{2}\mathrm{g}t^2$$

The maximum height may also be calculated using:

$$s_y = \frac{{v_y}^2 - {u_y}^2}{2\mathrm{g}}$$

When the launch and landing heights are the same, the time of flight is twice the time taken to reach maximum height. In such cases, the horizontal displacement (s_x), or range (R) is calculated as:

$$s_x = v_x t$$

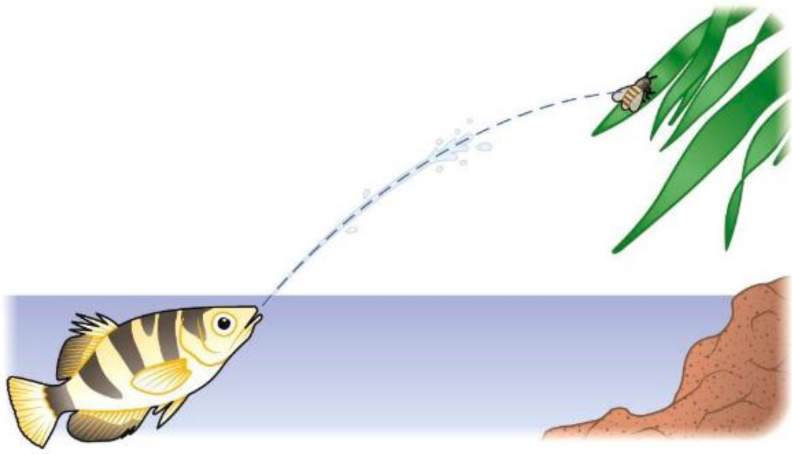
For the vertical component of velocity (v_y) at any time (t) after launch:

$$v_y = u_y + \mathrm{g}t$$

However, in this case, the value of u_y is non-zero, and the value of g is negative.

Example 3.18

An archerfish shoots a stream of water at an insect positioned on a leaf, as shown below.



The stream of water is launched with an initial velocity of 2.30 m s^{-1} at 45.0° above the horizontal.

The **horizontal component** of the initial velocity is:

$$u_x = ucos\theta = 2.30 \text{ x } cos45.0 = 1.63 \text{ m s}^{-1}$$

The **vertical component** of the initial velocity is:

$$u_y = usin\theta = 2.30 \text{ x } sin45.0 = 1.63 \text{ m s}^{-1}$$

The **time taken** for the stream of water to reach its maximum height is:

$$t = \frac{v_y - u_y}{\text{g}} = \frac{0 - 1.63}{-9.8} = 0.166 \text{ s}$$

The **horizontal displacement (range)** of the stream when it reaches maximum height is:

$$s_x = v_x t = 1.63 \text{ x } 0.166 = 0.270 \text{ m}$$

The **maximum height** of the stream above the launch position is:

$$s_y = u_y t + \frac{1}{2}\text{g}t^2 = (1.63 \text{ x } 0.166) + \frac{1}{2}(-9.8)(0.166)^2 = 0.135 \text{ m}$$

Alternatively, the **maximum height** of the stream is:

$$s_y = \frac{{v_y}^2 - {u_y}^2}{2\text{g}} = \frac{0^2 - (1.63)^2}{2(-9.8)} = 0.135 \text{ m}$$

The **vertical component of velocity** of the stream 0.0855 s after launch is:

$$v_y = u_y + \text{g}t = 1.63 + (-9.8) \text{ x } 0.0855 = 0.788 \text{ m s}^{-1}$$

The **magnitude of the velocity** of the stream 0.0855 s after launch is:

$$v = \sqrt{{v_x}^2 + {v_y}^2} = \sqrt{(1.63)^2 + (0.788)^2} = 1.81\ m\ s^{-1}$$

The **direction of the velocity** 0.0855 s after launch is:

$$\theta = tan^{-1}\left(\frac{v_y}{v_x}\right) = tan^{-1}\left(\frac{0.788}{1.63}\right) = 25.9°$$

Hence, the velocity of the stream 0.0855 s after launch is 1.81 m s^{-1}, at 25.9° above the horizontal.

Air Resistance

When a projectile is launched near Earth's surface, its motion is influenced by **air resistance**—a force that acts in the opposite direction to its motion. Air resistance opposes both the horizontal and vertical components of velocity as the projectile moves through the air. This resistance causes horizontal acceleration in the opposite direction, reducing the horizontal velocity and, consequently, the range of the projectile. Vertically, air resistance slows the upward motion during ascent, lowering the maximum height reached. Overall, air resistance decreases both the maximum height and horizontal distance the projectile travels compared to motion in a vacuum. **Figure 3.22** illustrates the trajectory of a baseball with and without air resistance over a 10-second flight.

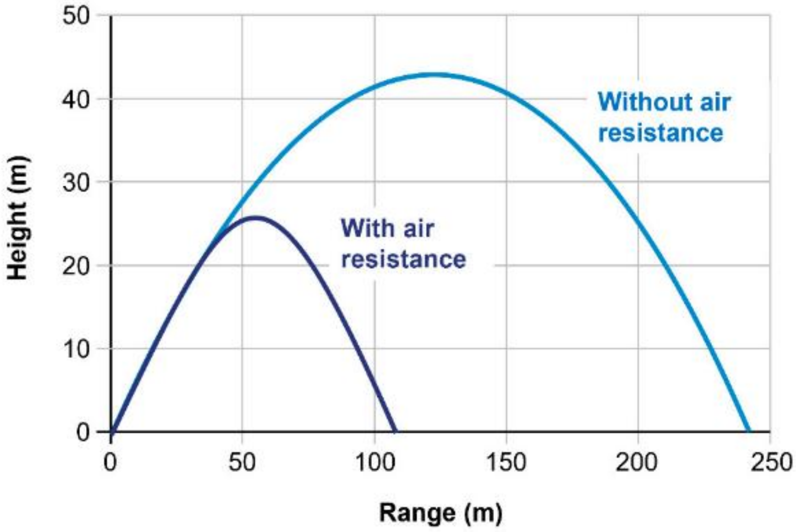


Figure 3.22: Motion of a baseball with and without air resistance

Air resistance also influences a projectile's time of flight. During ascent, air resistance opposes the upward vertical velocity, reducing both the maximum height and the time taken to reach it. During descent, air resistance opposes the downward motion, slowing the fall and slightly increasing the time to reach the ground. However, because the projectile descends from a lower maximum height, the reduced ascent time outweighs the increased descent time. As a result, the overall time of flight is shorter compared to motion without air resistance.

The magnitude of air resistance, also called **aerodynamic drag (F_D)**, depends on several key factors. First, **air density** (ρ)—denser air contains more molecules, increasing the opposing force on the projectile. Second, the **cross-sectional area (A)**—a larger area presents a bigger surface for air to push against. Third, the **drag coefficient (C_D)**—a dimensionless value that reflects how easily an object moves through the air, influenced by its shape, surface texture, and flow conditions. Lastly, air resistance increases with the **square of the projectile's velocity (v^2)**; faster motion displaces air molecules with greater force, and by Newton's Third Law, the air pushes back with an equal and opposite force. These relationships are captured in the formula:

$$F_D = \frac{1}{2}\rho A C_D v^2$$

Although this formula is not required in the course, it clearly shows how air resistance depends on air density, cross-sectional area, drag coefficient, and the square of the projectile's velocity. In most cases, air resistance is **ignored** or **considered negligible**. This is because its magnitude depends on velocity, which itself changes throughout the projectile's motion. As a result, air resistance is constantly changing, making it extremely complex to include in the standard equations of projectile motion.

Question 46

When serving, a volleyball player strikes a ball horizontally at 26.5 m s^{-1} from a height of 2.85 m.

The range of the volleyball is

- A 7.63 m
- B 18.0 m
- C 20.2 m
- D 10.6 m

(1 mark)

Question 47

An aircraft travelling horizontally releases a food and medical supplies crate. The crate is damaged if the vertical component of velocity upon landing exceeds 44 m s^{-1}.

The maximum height at which the crate can be launched without being damaged is

- A 99 m
- B 88 m
- C 430 m
- D 440 m

(1 mark)

Question 48

A soccer ball is kicked with an initial velocity of 18 m s^{-1}, 22° above ground level.

The maximum height of the soccer ball above the launch point is

- A 2.4 m
- B 14 m
- C 22 m
- D 2.3 m

(1 mark)

Question 49

A cricket ball is hit from ground level at 25.0 m s^{-1} and 35.0° to the horizontal.

The time of flight of the cricket ball is

- A 3.02 s
- B 2.93 s
- C 1.51 s
- D 1.46 s

(1 mark)

Question 50

A skier travels 13 m above their launch point when their initial velocity is

- A 22 m s^{-1} at 56° above the horizontal
- B 20 m s^{-1} at 48° above the horizontal
- C 18 m s^{-1} at 63° above the horizontal
- D 16 m s^{-1} at 72° above the horizontal

(1 mark)

Question 51

A tree frog launches itself from a branch with a velocity of 2.90 m s^{-1}, 20.0° above the horizontal.

The vertical component of the frog's velocity 0.145 s after launch is

- A 0.409 m s^{-1}, downwards
- B 0.429 m s^{-1}, downwards
- C 2.41 m s^{-1}, upwards
- D 2.43 m s^{-1}, upwards

(1 mark)

Question 52

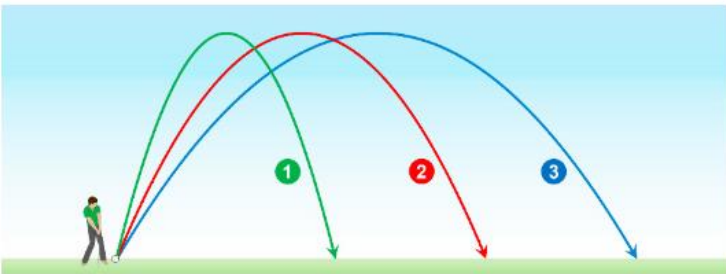
A tennis ball is launched horizontally at 52.0 m s^{-1}. The velocity of the ball 0.620 s after launch is

- A 6.08 m s^{-1}, 83.3° below the horizontal
- B 6.08 m s^{-1}, 6.66° below the horizontal
- C 52.4 m s^{-1}, 6.66° below the horizontal
- D 52.4 m s^{-1}, 83.3° below the horizontal

(1 mark)

Question 53

The diagram below shows the path of three golf balls launched into the air.



Which of the golf balls has the greatest time of flight?

- A Ball 1
- B Ball 2
- C Ball 3
- D They have the same time of flight.

(1 mark)

Question 54

Consider the following statements about air resistance.

I. Air resistance increases with the projectile's velocity.
II. Air resistance opposes the vertical component of velocity but not the horizontal component.
III. Air resistance increases a projectile's time of flight when the launch angle is zero.

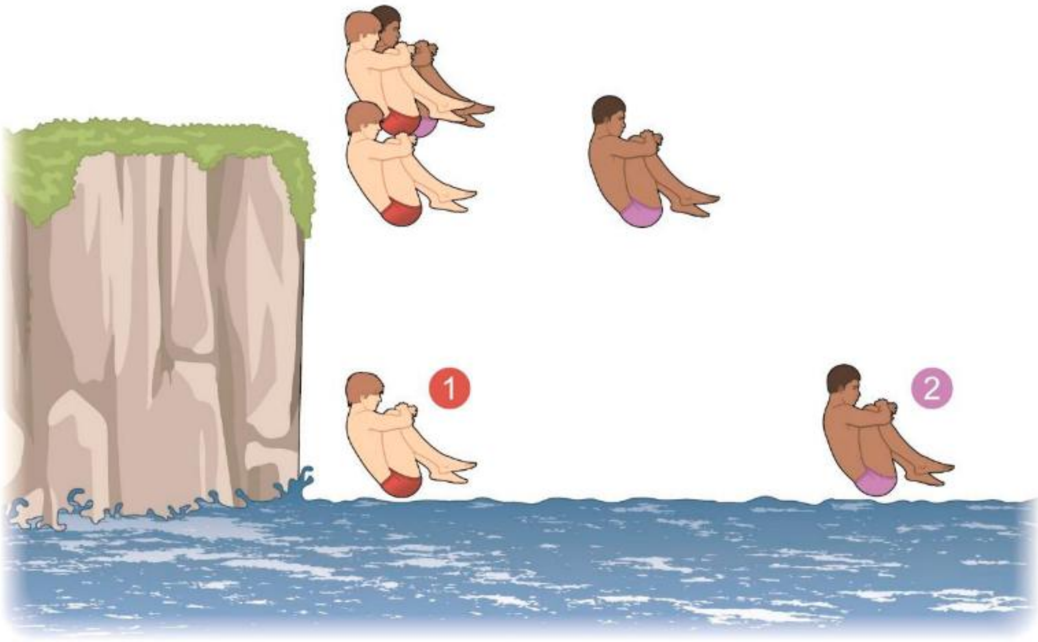
Which of the statements above are correct?

- A I and III only
- B II and III only
- C I and II only
- D I only

(1 mark)

Question 55

The diagram below shows two children launching themselves simultaneously from the same height.



(a) Describe and explain how the vertical component of velocity of Child 1 changes with time.

(2 marks)

(b) Describe and explain how the horizontal component of velocity of Child 2 changes with time.

(2 marks)

(c) Explain why the children contact the water simultaneously.

(2 marks)

(d) The two children jump from the same height at the same time again, but this time, Child 2 pushes off with a greater horizontal velocity.

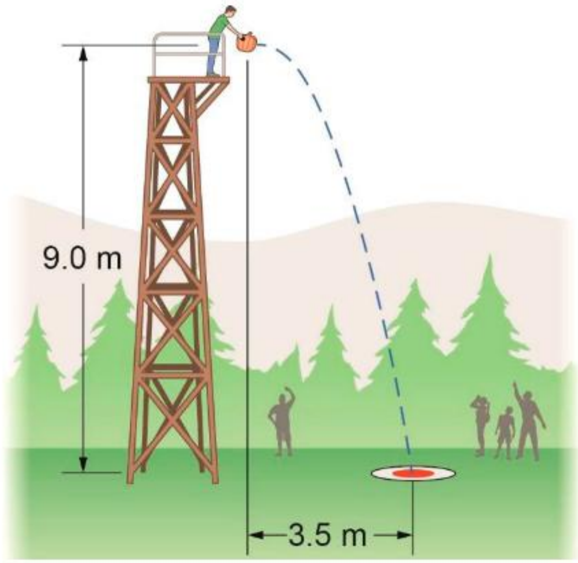
Describe and explain how Child 2's motion changes.

(2 marks)

Question 56

The pumpkin toss is a competitive event where teams launch pumpkins at a target.

The diagram below shows one contestant launching their pumpkin from the edge of a tower positioned 9.0 m above the target.



(a) Calculate the time of flight of the pumpkin.

(2 marks)

(b) Calculate the horizontal velocity necessary to reach the target positioned 3.5 m from the edge of the tower.

(2 marks)

Question 57

A paintball is fired horizontally at 85.0 m s^{-1} towards a target 40.0 m away.

(a) Calculate the time of flight of the paintball.

(2 marks)

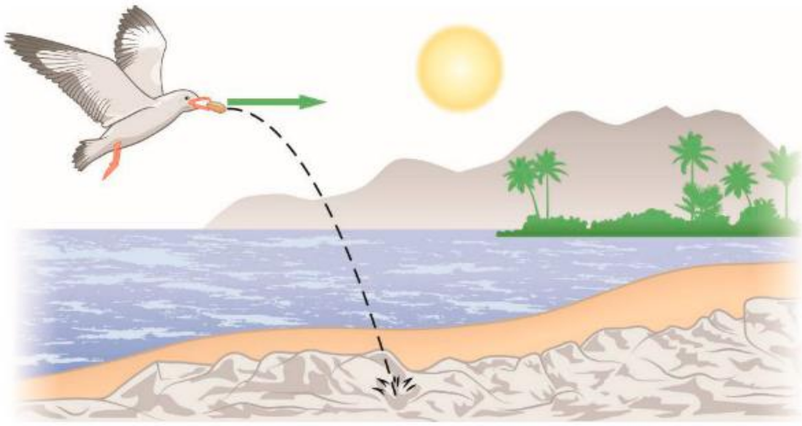
(b) Calculate the vertical displacement of the paintball as it moves towards the target.

(2 marks)

Question 58

Seagulls often drop seeds from heights onto rocks or hard surfaces to break them open and access the edible contents.

The diagram shows a seagull flying horizontally with a constant speed of 2.70 m s^{-1} when it releases a seed from its beak.



The seed lands on the rocky beach 2.10 s later.

(a) Calculate the height of the seagull above the rocky beach.

(2 marks)

(b) Calculate the vertical component of the velocity of the seed 1.50 s after it is released.

(2 marks)

(c) Calculate the horizontal displacement (range) of the seed while in the air.

(2 marks)

(d) The motion of the seed is affected by air resistance.

Describe and explain the effect of air resistance on:

1. the range of the seed.

(2 marks)

2. the time of flight.

(2 marks)

Question 59

Before 1980, firefighters used a life net to catch civilians trapped in burning buildings.

In 1930, a civilian survived leaping 26.4 m from a burning building into the life net below.

(a) Calculate the time taken for the civilian to reach the life net after launch.

(2 marks)

(b) The civilian's horizontal displacement was 3.80 m.

Calculate the horizontal component of their velocity.

(2 marks)

(c) Calculate the vertical component of the civilian's velocity when they contact the net.

(2 marks)

(d) Calculate the magnitude and direction of the civilian's velocity when they contact the net.

(3 marks)

Question 60

In the sport of dock jumping, dogs run at full speed and launch themselves horizontally off the end of a dock positioned 0.60 m above a pool of water.

(a) Calculate the launch velocity of a dog that travels 11 m from the end of the dock.

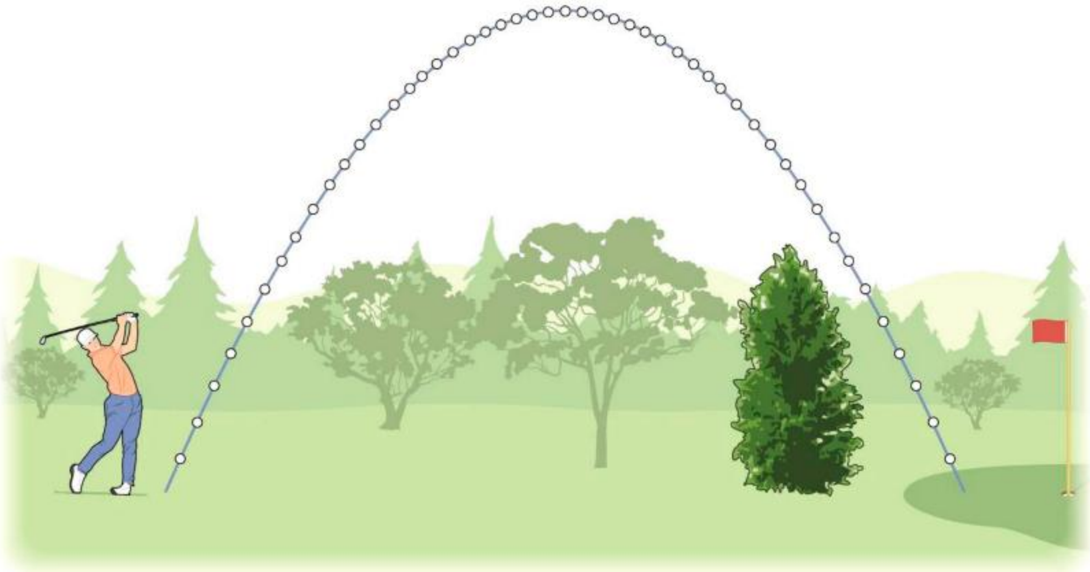
(3 marks)

(b) Calculate the speed at which the dog contacts the water.

(3 marks)

Question 61

The diagram below shows the motion of a golf ball in the air.



The golfer hit the ball at 20.0 m s^{-1} and 65.0° above the horizontal

(a) Calculate the horizontal and vertical components of the initial velocity.

(2 marks)

(b) Calculate the time to reach maximum height.

(2 marks)

(c) Calculate the maximum height of the golf ball above the launch point.

(2 marks)

(d) Calculate the range.

(2 marks)

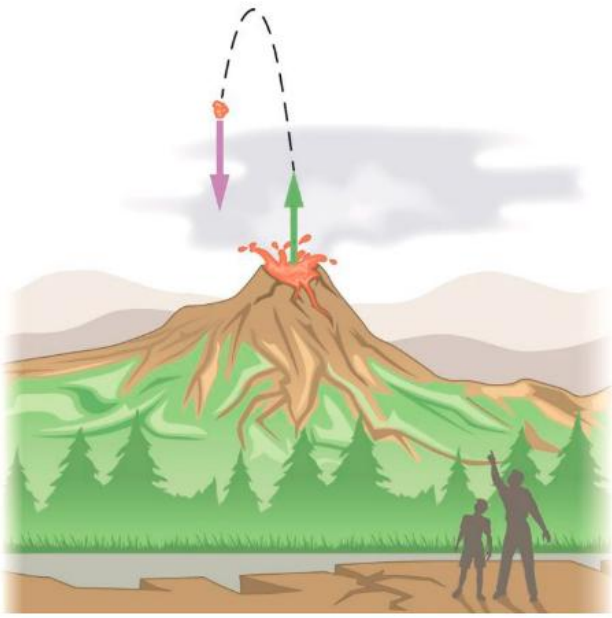
(e) Calculate the vertical component of velocity 3.00 s after launch.

(2 marks)

Question 62

Volcanoes eject large rocks during an eruption.

The diagram shows the path of a large rock ejected from a volcano at 125 m s^{-1}, at an angle of 75.0° above the horizontal.



(a) Calculate the vertical component of the rock's initial velocity.

(1 mark)

(b) Calculate the time for the rock to reach its maximum height above the launch point.

(2 marks)

(c) Determine the maximum height that the rock reached above the launch point.

(2 marks)

(d) A second rock of the same size and mass was launched with the same initial velocity but at an angle closer to 45.0°.

State and explain which of the two rocks travelled the greatest horizontal distance from the volcano while in the air.

(3 marks)

Question 63

The diagram below shows a firefighter spraying a stream of water onto the side of a building.

The water is launched at 14.9 m s^{-1} from a hose positioned 1.50 m above the surface.

The stream of water reaches the second-floor window located 10.0 m above the surface.

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

(2 marks)

(b) Determine the launch angle.

(2 marks)

(c) Calculate the time taken for the stream to contact the building after launch.

(2 marks)

(d) Calculate the horizontal distance between the firefighter and the building.

(3 marks)

(e) The firefighter is overheated and moves 5.00 m away from the building.

State the appropriate change to ensure the stream contacts the same position on the building.

(1 mark)

Review Test 1

Questions 1 to 10

Questions 1 to 10 are **multiple-choice questions.** For each multiple-choice question, indicate the best answer to the question by clicking the bubble [O] beside it.

1. A car moving around a circular path at a constant speed

- ○ **A** has constant acceleration.
- ○ **B** has balanced forces acting on it.
- ○ **C** has centripetal acceleration due to the constant gravitational force.
- ○ **D** has changing kinetic energy.

(1 mark)

2. A jumping spider launched itself at 2.43 m s^{-1} and reached a maximum height of 43.0 mm above the launch position.

The launch angle of the spider was

- ○ **A** 22.2°
- ○ **B** 20.3°
- ○ **C** 17.7°
- ○ **D** 6.00°

(1 mark)

3. A 70.0 kg skydiver leaps from a plane and reaches terminal velocity after falling vertically downwards for several seconds.

Upon reaching terminal velocity, the resultant force on the skydiver in the vertical dimension is

- ○ **A** 686 N, downwards
- ○ **B** 686 N, upwards
- ○ **C** 70.0 N, downwards
- ○ **D** 0 N

(1 mark)

4. A 57.0 g tennis ball is served with a force of 36.0 N over a contact time of 0.045 seconds

The launch velocity of the tennis ball is:

- ○ **A** 11.0 m s^{-1}
- ○ **B** 18.0 m s^{-1}
- ○ **C** 28.4 m s^{-1}
- ○ **D** 33.6 m s^{-1}

(1 mark)

5. A 4.00 kN force causes a spring to compress by 4.00 cm.

The spring constant (k) is

- ○ **A** 1.00×10^{2} N m^{-1}
- ○ **B** 1.00×10^{3} N m^{-1}
- ○ **C** 1.00×10^{4} N m^{-1}
- ○ **D** 1.00×10^{5} N m^{-1}

(1 mark)

Question 11

A popular amusement park ride is illustrated in the diagram below.

In this ride, riders sit in a swing that is suspended from a rotating arm.

Riders are at a distance of 12.0 m from the axis of rotation and move with uniform circular motion at a speed of 11.2 m s^{-1}.

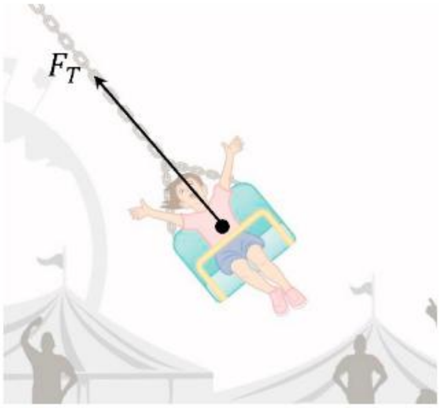
(a) Calculate the period, T of one revolution of the ride.

(2 marks)

(b) Calculate the centripetal acceleration of the riders.

(2 marks)

(c) The diagram below shows the tension force on the rider in their circular path.

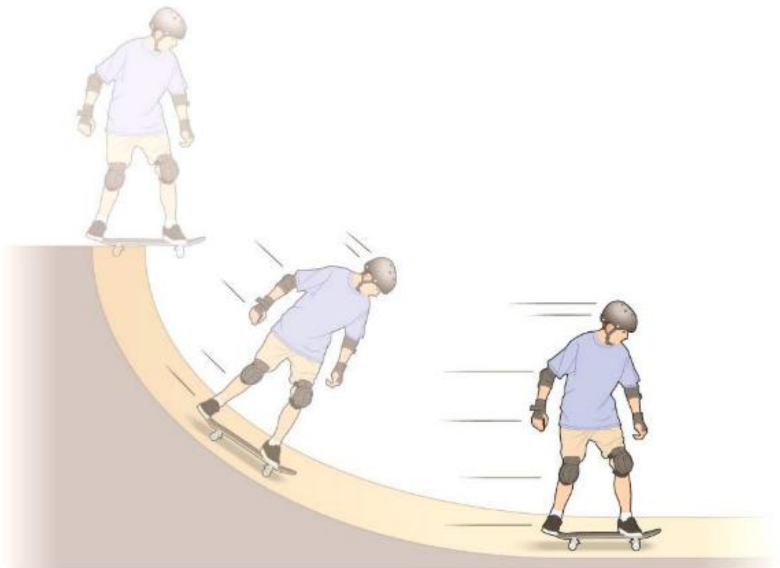


Explain how banking the rider at an angle causes them to move in a uniform horizontal circular path.

(2 marks)

Question 12

A 58.0 kg skateboarder is at rest 3.50 m above the surface of a ramp.



(a) The skateboarder has gravitational potential energy at the top of the ramp.

Calculate the gravitational potential energy of the skateboarder.

(2 marks)

(b) Gravitational potential energy is transformed into kinetic energy as the skater descends.

Use the Law of Conservation of Energy to calculate the speed of the skateboarder at the base of the ramp.

(2 marks)

(c) The motion of the skateboarder is opposed by friction.

Use the work-energy theorem to explain why the speed of the skateboarder at the base of the ramp is less than the value calculated in (b).

(2 marks)

(d) The skateboarder then moves horizontally at a constant speed.

Use Newton's First Law of Motion to describe the forces on the skateboarder when they travel horizontally at a constant speed.

(2 marks)

Question 13

Astronauts servicing satellites often perform tasks outside the shuttle.

The diagram below shows an astronaut on a spacewalk outside the shuttle.

(a) To return to the shuttle, the astronaut throws a small tool directly away from the shuttle.

Using the Law of conservation of momentum, explain why throwing the tool away enables the astronaut to return to the shuttle.

(3 marks)

(b) The 85.0 kg astronaut at rest throws a 5.00 kg tool at 10.0 m s^{-1}, away from the shuttle.

Use the Law of Conservation of Momentum to calculate the final speed of the astronaut.

(4 marks)

(c) Use Newton's Second and Third Laws of Motion to describe the forces and accelerations on the astronaut and tool when the astronaut throws the tool.

(2 marks)

(d) Explain one method of the astronaut increasing their final speed calculated in part (b).

(2 marks)

Question 14

A group of students conducted an experiment to investigate the Law of Conservation of Energy. A glider was placed on an air track and positioned in front of a spring (k = 250 N m^{-1}), which was compressed to various extents (x). The spring was released, and the glider was launched along the track, passing through a motion sensor that recorded the glider's launch speed (v).

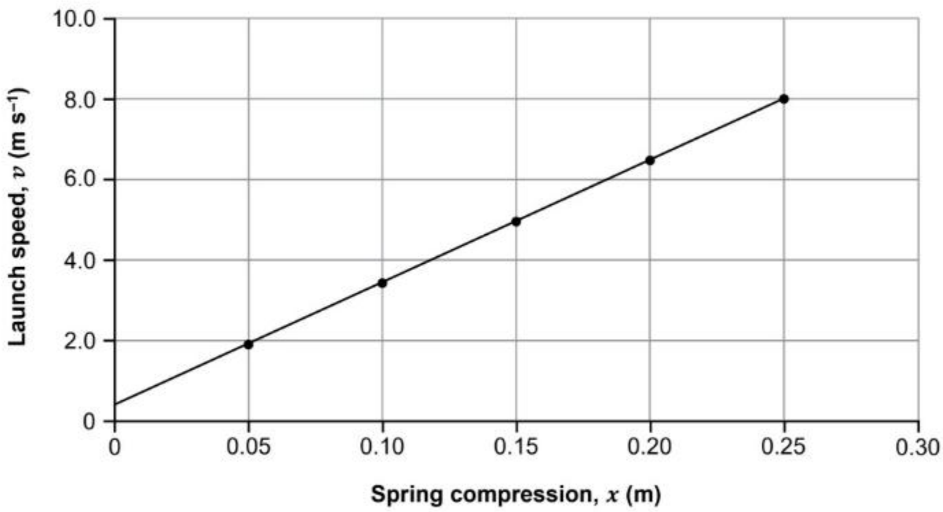
(a) State the independent variable in the student's investigation.

(1 mark)

(b) Identify one factor held constant in this investigation and explain why it is controlled.

(2 marks)

(c) The results of the investigation are shown in the graph below.



The gradient of the line of best fit is 29.6.

i. State the type of error evident in the results and give a reason for your answer.

(2 marks)

ii. Describe one source of the error identified in (c) (i).

(2 marks)

iii. The equation of the line of best fit is

$$v = \sqrt{\frac{k}{m}}x$$

Calculate the mass of the glider.

(2 marks)

Question	Part	Author's response	Marks
1		A	1
2		B	1
3		D	1
4		C	1
5		D	1
6		A	1
7		C	1
8		C	1
9		D	1
10		B	1
11	(a)	$T = \frac{2\pi r}{v}$ $T = \frac{2\pi(12.0)}{11.2}$ $T = 6.73\text{ s}$	1 1
	(b)	$a = \frac{v^2}{r}$ $a = \frac{(11.2)^2}{12.0}$ $a = 10.5\text{ m s}^{-2}$	1 1
	(c)	The horizontal component of tension is perpendicular to the velocity of the rider, so it causes the direction of travel to change but not the speed. Thus, the force causes a centripetal acceleration, resulting in uniform circular motion.	1 1
12	(a)	$U = mgh$ $U = 58.0 \text{ x } 9.80 \text{ x } 3.50$ $U = 1.99 \text{ x } 10^3\text{ J}$	1 1
	(b)	$mgh = \frac{1}{2}mv^2$ $v = \sqrt{2gh}$ $v = \sqrt{2(9.80)(3.50)}$ $v = 8.28\text{ m s}^{-1}$	1 1
	(c)	The skateboarder does work overcoming friction. The work done reduces the skateboarder's kinetic energy in accordance with the work-energy theorem, decreasing their speed.	1 1
	(d)	Newton's First Law of Motion states the skateboarder has a constant speed when the resultant force acting in the horizontal is zero. Hence, the force in the direction of motion is equal in magnitude to the sum of all forces in the opposite direction to their motion.	1 1
13	(a)	The astronaut and tool are an isolated system, so their total momentum is constant (Law of Conservation of Momentum). When the tool is thrown, it gains momentum in the opposite direction to the shuttle. For total momentum to be conserved, the astronaut gains an equal magnitude of momentum towards the shuttle.	1 1 1