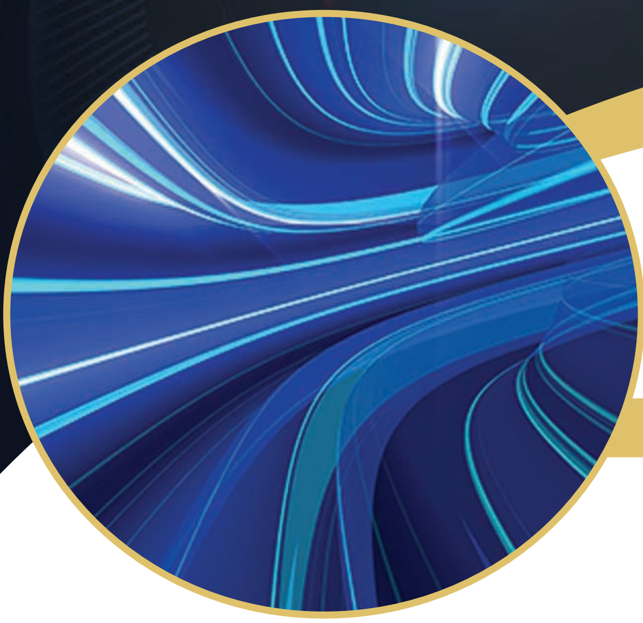


PHYSICAL SCIENCE

VERTICAL PROJECTILE MOTION

GRADE 12

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

Read to Lead
A Reading Nation is a Leading Nation

2030 NDP

Foreword

In order to improve learning outcomes the Department of Basic Education conducted research to determine the specific areas that learners struggle with in Grade 12 examinations. The research included a trend analysis by subject experts of learner performance over a period of five years as well as learner examination scripts in order to diagnose deficiencies or misconceptions in particular content areas. In addition, expert teachers were interviewed to determine the best practicesto ensure mastery of thetopic by learners and improve outcomes in terms of quality and quantity.

The results of the research formed the foundation and guiding principles for the development of the booklets. In each identified subject, key content areas were identified for the development of material that will significantly improve learner's conceptual understanding whilst leading to improved performance in the subject.

The booklets are developed as part of a series of booklets, with each bookletfocussing onlyon one specific challenging topic. The selected content is explained in detail and include relevant concepts from Grades 10 - 12 to ensure conceptual understanding.

The main purpose of these booklets is to assist learners to master the content starting from a basic conceptual level of understanding to the more advanced level. The content in each booklets is presented in an easy to understand manner including the use of mind maps, summaries and exercises to support understanding and conceptual progression. These booklets should ideally be used as part of a focussed revision or enrichment program by learners after the topics have been taught in class. The booklets encourage learners to take ownership of their own learning and focus on developing and mastery critical content and skills such as reading and higher order thinking skills.

Teachers are also encouraged to infuse the content into existing lesson preparation to ensure in-depth curriculum coverage of a particular topic. Due to the nature of the booklets covering only one topic, teachers are encouraged to ensure learners access to the booklets in either print or digital form if a particular topic is taught.

Table of Contents

2. How to use this Booklet

This booklet contains: extracts from the examination guidelines; definitions of concepts; summaries and notes on the concepts to be learned. There are also practice questions, including multiple choice questions and structured questions.

- o MULTIPLE CHOICE QUESTIONS (MCQs) are a powerful tool to assess understanding of concepts (if used properly).
- o Use the MCQs to address ALL key aspects and concepts in the section, as outlined in the Examination Guidelines.
- o With regard to MCQs, do NOT focus on the correct answer ONLY. Also look at the incorrect options and understand WHY these are incorrect.
- o Make sure you develop your skills in answering multiple choice questions. In cases where the answer is not immediately obvious, you should go through the steps of eliminating obviously incorrect answers.

NB: Please note that there will always be some statements or items that are obviously wrong. Eliminate them first.

- o Use the STRUCTURED QUESTIONS to address the various aspects pertaining to free fall.
- o Worked solutions are provided for all the practice questions. Please attempt the questions before looking at the solutions that are provided.

3. Study and Examination Tips

General guidelines

Here are some general guidelines to help you to succeed:

Prepare well in advance

You cannot ensure success if you only study the week or a few days before an exam. Plan your way to success six months before the exam (or even from the beginning of the year).

Study timetable

- Set up a study timetable, so that you systematically revise all the material on which you will be examined on. For the Physical Sciences (and Mathematics) papers, this includes aspects of your Grade 10 and Grade 11 work. Study for 3 or 4 hours every day during school time, and for 5-7 hours per day over weekends and during school holidays. Study in 50-minute blocks, with a 10-minute break in between. Breaks are important.
- Above all, stick to your timetable.
- Don’t wait until tomorrow, or next week, or next month – learning and understanding doesn’t take place magically.
- Do whatever homework is required; then study.
- Read your notes / textbook, write summaries, calculate answers, and memorise definitions every day.

Eat, sleep and exercise

Eat properly and healthily. Get enough sleep – not too little and not too much. Studying through the night doesn’t help. The brain requires sleep to fix learning into long-term memory. And sleeping more than your body requires just tires you out. Exercise daily – even if it is only for 20 minutes. A fast walk, a short jog, or some conditioning exercise all help to keep the mind fresh, active and capable of learning. Exercise that totally exhausts you is counter-productive.

Study skills to accelerate your learning

1) **Ask 'Why?' – 'Why, Why, Why?'**
   Asking "why" questions works by encouraging you to integrate a new fact with things that you already know. Doing so improves your memory for the new fact by giving you more "hooks" to retrieve it. Don't just accept it – ask yourself why you should accept it.
2) **Explain to yourself**
   After answering a problem, or reading some text, ask yourself what this means to you. What inferences can you draw? Can you connect this with some other part of the work you have studied? How would you explain this to a friend?
3) **Practise testing**
   Actively test your memory. It improves learning by exercising memory retrieval. It helps you to store the information in your long-term memory. Do on-line tests, answer questions from your textbook, etc. This works best when you can check your answers (but don't just read the answers).

Memorisation tips

- Surely you can memorise the 30 definitions you must know as part of a particular subject?
- Definitions, terms, laws, etc. form the **vocabulary** of a subject such as Physical Science and therefore it is very important to know them.
- Knowing involves two things: **understanding** and **remembering.** Of these two, understanding is far more important. You must try to understand what the various concepts and terms mean.
- Nevertheless, some things have to be committed to memory. Use these tips / tricks to help you.
- **Repetition:** You can't memorise anything without repetition – be it verbal or in writing. As you repeat a definition by saying it aloud or writing it down, think of context and meaning to focus your remembering.
- Mnemonic devices are word-tools to help you remember:
- **Acronyms:** such as ROYGBIV (What Physical Science learner has not heard of dear old Roy?) or BODMAS (in Mathematics).
- **Acrostics:** these are sentences that use the first letter of words or a list, etc., e.g. Please Excuse My Dear Aunt Susie (Parentheses, Exponents, Multiplication, Division, Addition, Subtraction). Develop your own.
- **Chunking / grouping:** Group information together and memorise it as a set. If each set has three entries, this will prod your memory if you can only remember two.
- **Associations / linking:** Link the material being memorised with images, smells, touch, personal circumstances, etc. The more senses that are involved, the better the remembering.
- **Mindmaps:** Draw a mindmap of a concept / idea / subject. Then explore the connections between concepts.
- **Key words:** Write out definitions, etc. Then highlight and memorise the key words in a definition.
- **Erase to remember:** Write out what you need to recall for an exam completely in pencil. Progressively erase words as you commit them to memory.
- **Be selective -** you cannot memorise everything.
- Work with a friend (or small group): Take turns to define a concept or term or explain a method orally. Give clues when your friend has difficulty remembering.
- **A good night's sleep.** Research shows that sleep is crucial in establishing long-term memory.

Past Papers

- Practise questions from previous examination papers.
- Instructions. Take careful note of all instructions – for the paper as a whole, and for each question.

- Don't cheat. Try to answer the questions without looking at your notes or at the solutions.
- Time yourself. Divide the time allocated (in minutes) by the total number of marks for a paper. This gives you the time per mark. In your Physical Sciences exams, you need to work at a rate of about 1 mark per minute. Practise this again and again.
- Memo. Check your working against the memo. If the answer is wrong, try it again. Note that ***understanding*** the question and answering is more important than getting the answer right.
- Why? Work with your friends and challenge each other by asking Why? Why this? Why that? Help each other to understand the question and the answer. Understanding the subject gives you the best chance of passing the exam.

In the exam venue

- When you receive the exam paper, calmly read through all the instructions at the beginning of the paper. This is very important, as you don't want to answer questions you may skip and so waste time and lose marks.
- Write all your details on the answer sheet.
- Read through each question carefully before you rush to answer it. Underline key words, and note instructions and CAPITALIZED words. Are you given any choices between questions and within questions?
- Note the mark allocation – don't spend 20 minutes on a 10-mark question.
- Number your answers correctly, beginning each new question on a new page.
- Set out your answers clearly and legibly. Leave plenty of space between questions and sections.

4. Vertical Projectile Motion

Extracts from the Examination Guidelines

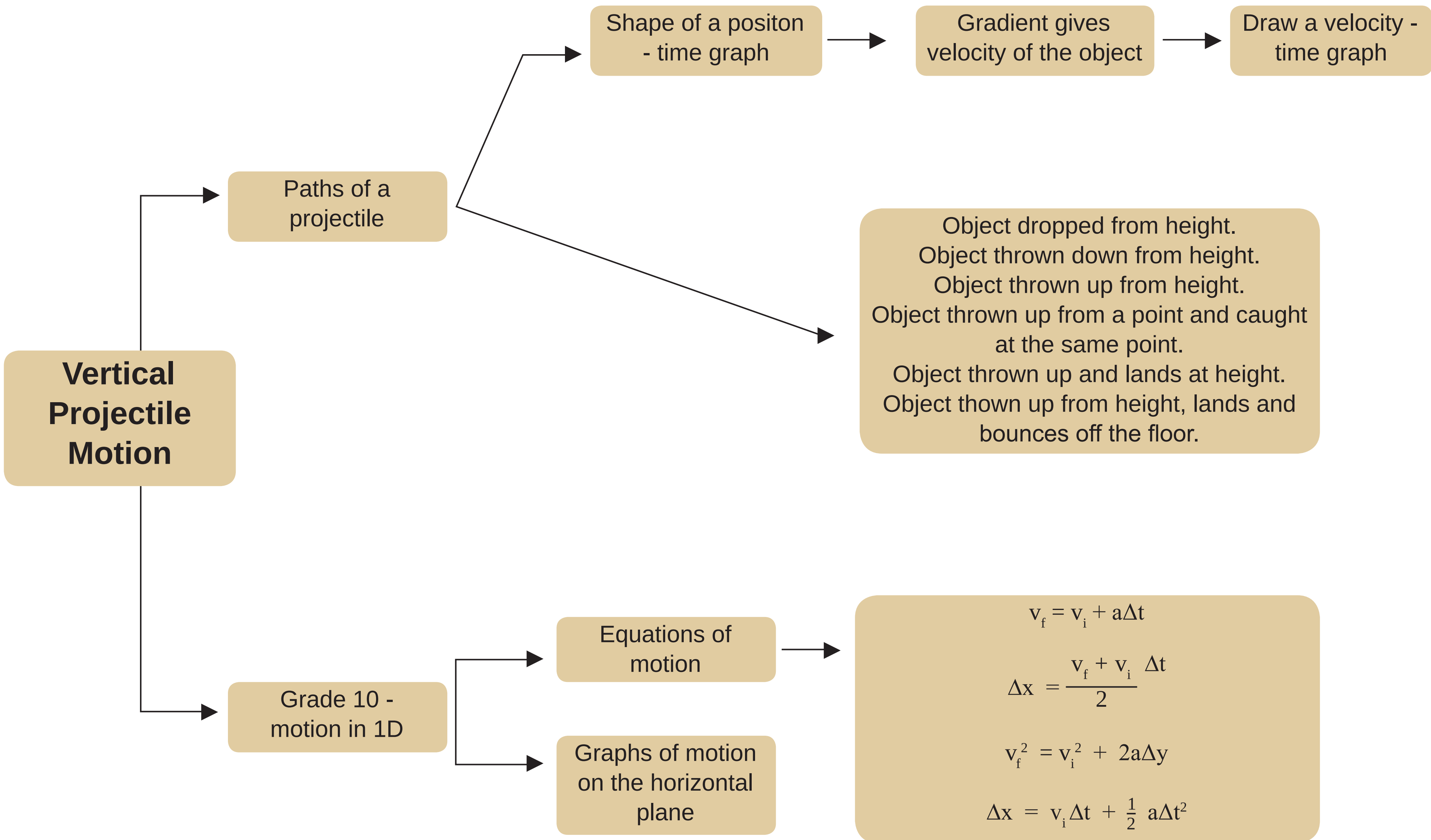
Vertical Projectile Motion in one dimension (1 D)
(This section must be read in conjunction with CAPS pp.102-103.)

- Explain what is meant by a projectile, i.e. an object upon which the only force acting is the force of gravity.
- Use equations of motion to determine the position, velocity and displacement of a projectile at any given time.
- Sketch graphs for position vs time (x vs t), velocity vs time (v vs t) and acceleration vs time (a vs t) for each of the following:
  - o A free-falling object.
  - o An object thrown vertically upwards.
  - o An object thrown vertically downwards.
  - o Bouncing objects (restricted to balls).
  - • For a given graph for x vs t, v vs t or a vs t, determine the following:
  - o Position
  - o Displacement
  - o Velocity or acceleration at any time (t).

- For a given x vs t, v vs t or a vs t graph, describe the motion of the object for the following:
  - o Bouncing.
  - o Thrown vertically upwards.
  - o Thrown vertically downwards.

VERTICAL PROJECTILE MOTION: DEFINITIONS OF CONCEPTS

Grade 10 MOTION IN ONE DIMENSION	
Definitions in the form of an equation	**Definitions in words**
Acceleration: $a = \frac{\Delta v}{\Delta t}$	**Acceleration** is the rate of change of velocity.
Average speed: $v = \frac{d}{t}$	**Average speed** is the total distance travelled per unit of time.
Average velocity: $v = \frac{x}{t}$	**Average velocity** is the total displacement per unit of time.
	Displacement is the change in position of an object from a point of reference. (The length and direction of the straight line drawn from the beginning point to the end point.)
	Distance is the total length of the path travelled by an object.
	Frame of reference is a set of axes from which a position or motion can be measured.
	Frame of reference is the speed at a specific moment.
	Instantaneous velocity is the velocity at a specific moment.
	Position is the place occupied by an object, i.e. the measurement of a location with reference to an origin.
Speed: $v = \frac{\Delta x}{\Delta t}$	**Speed** is the rate of change of distance.
Velocity: $v = \frac{\Delta x}{\Delta t}$	**Velocity** is the rate of change of position.
Grade 12	
	A projectile is an object upon which the only force acting is the force of gravity.
	Free fall (motion) is when the object falls and the only force acting on the object is the force of gravity.


Vertical Projectile Motion
Paths of a projectile
Shape of a positon - time graph
Gradient gives velocity of the object
Draw a velocity - time graph
Object dropped from height.
Object thrown down from height.
Object thrown up from height.
Object thrown up from a point and caught at the same point.
Object thrown up and lands at height.
Object thown up from height, lands and bounces off the floor.
Grade 10 - motion in 1D
Equations of motion
Graphs of motion on the horizontal plane
$v_f = v_i + a\Delta t$
$\Delta x = \frac{v_f + v_i}{2}\Delta t$
$v_f^2 = v_i^2 + 2a\Delta y$
$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$

5. Vertical Projectile Motion

5.1 MOTION IN 1D – GRADE 10

5.1.1 Equations of Motion

Old symbols	New symbols
$v = u + at$	$v_f = v_i + a\Delta t$
$v^2 = u2 + 2as$	$v_f^2 = v_i^2 + 2a\Delta x$
$s = ut + \frac{1}{2}at^2$	$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$
$s = \frac{u+t}{2} t$	$\Delta x = \frac{v_i + v_f}{2} \Delta t$

Steps to using the equations:

a) Draw a diagram of the motion of the object.
b) Identify each stage of the motion, **where the acceleration has changed.**
c) Choose a positive direction and use the same convention throughout.
d) Record the information given and the value required, by writing next to each variable. Check the unit and direction.
e) Select the correct equation and solve for unknown.
f) Include units and direction in your answers.

Remember:
'Starting from rest' means: u or $v_i = 0$
'Comes to a stop' means: v or $v_f = 0$
'Slowing down' means: acceleration is negative ($a < 0$), while still moving in a positive direction.
'Constant velocity' means: $a = 0$, $u = v$ or $v_i = v_f$
Use a new set of variables for each stage of the motion.
Conversion of units: 1 $m.s^{-1}$ = 3,6 $km.h^{-1}$.

Calculations:

A racing car starts from rest on the grid, travels straight along the track, and reaches the 400 m mark after 8,6 s.

a) What was its average acceleration?
Let forward be positive.

$$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$$
$$400 = 0\,(8{,}6) + \frac{1}{2}a(8{,}6)^2$$
$$a = 10{,}82\ m.s^{-2}$$

b) What was its velocity at the 400 m mark?

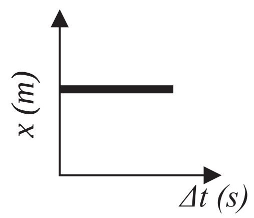
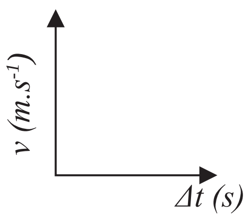
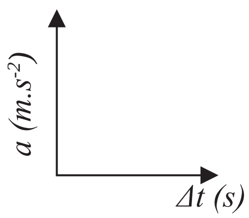
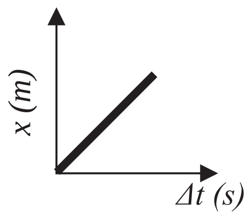
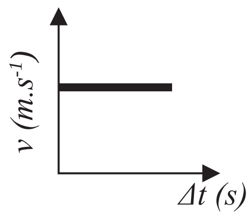
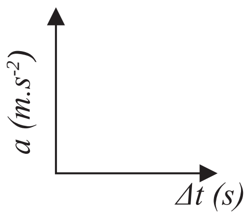
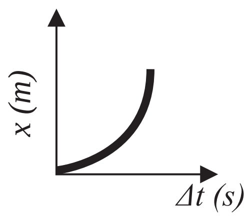
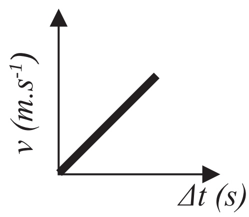
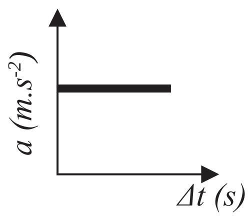
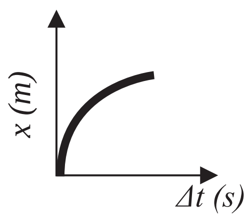
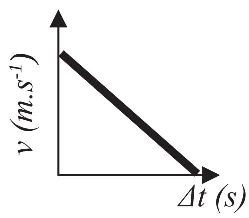
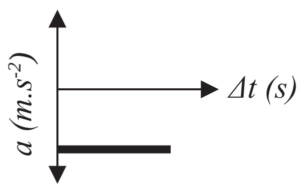
$$v_f = v_i + a\Delta t$$
$$v_f = 0 + (10{,}82)\,(8{,}6)$$
$$v_f = 93{,}05\ m.s^{-1}$$

c) At the 400 m mark, the brakes are applied, and the car slows down at 2 $m{\cdot}s^{-2}$ and comes to rest. Calculate the time it takes for the car to stop.

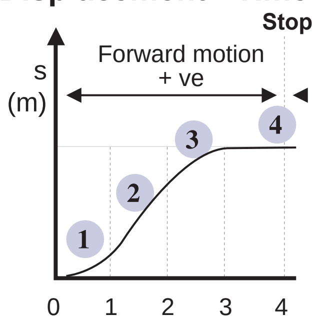
NB! New stage of motion. Find the new value of each variable.
Let forward be positive.

+
+
46,53 s

5.1.2 Graphs of motion for motion on a horizontal plane

Position vs Time	Velocity vs Time	Acceleration vs Time
Object is stationary (velocity = 0 m·s−1)		
		
Object is moving at a constant velocity (acceleration = 0 m·s^{-2})		
		
Object is moving with increasing velocity (constant non-zero acceleration)		
		
Object is moving with decreasing velocity (constant non-zero acceleration)		
		

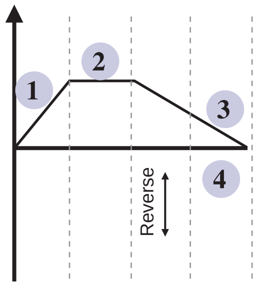
Displacement - Time



- 1 is positive acceleration
- 2 is constant velocity
- 3 is negative acceleration
- 4 is at rest

Gradient: Velocity
Area Below Graph: n/a

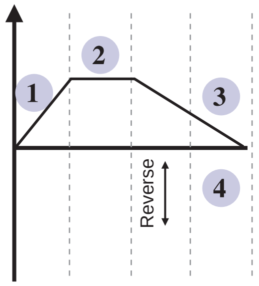
Velocity – Time



- 1 is positive acceleration
- 2 is constant velocity
- 3 is negative acceleration
- 4 is at rest

Gradient: Acceleration
Area Below Graph: Displacement

Acceleration - Time



- 1 is positive acceleration
- 2 is constant velocity (a = 0)
- 3 is negative acceleration
- 4 is at rest

Gradient: n/a
Area Below Graph: Velocity

5.2 VERTICAL PROJECTILE MOTION EXPLAINED

5.2.1 PROJECTILE MOTION

A **projectile** is an object that moves freely under the influence of gravity only. It is not controlled by any mechanism (pulley or motor). The object is in **free fall**, but may move upwards (thrown up) or downwards.

Forces on a projectile
In the absence of friction, the gravitational force of the Earth is the only force acting on a free falling body. This force always acts downwards.
Because the gravitational force is always downward, a projectile that is moving upward, must slow down. When a projectile is moving downward, it moves in the direction of the gravitational force, therefore it will speed up.

Acceleration due to gravity
All free falling bodies have the same acceleration, due to gravity. This acceleration is 9,8 m·s−2 downward.
Ignoring air resistance/ friction: if a marble and a rock are released from the same height at the same time, they will strike the ground simultaneously, and their final velocity will be the same.
Their momentum (mv) **and kinetic energ**y ($\frac{1}{2}mv^2$) are n**ot the same, due to a difference in mass.**
If two objects are released from different heights, they have the same acceleration, but they strike the ground at different times and have a different velocity.

$v_f = v_i + a\Delta t$
$v_f^2 = v_i^2 + 2a\Delta y$
$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$
$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$

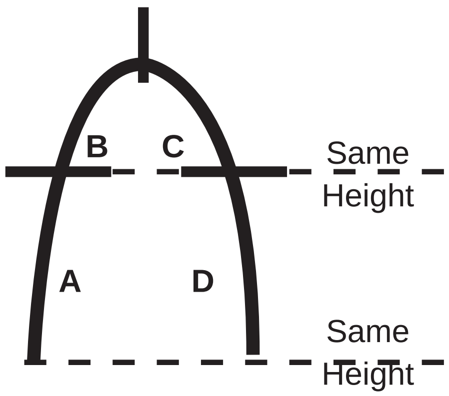
Δy = displacement (m)
Δt = time (s)
v_i = initial velocity (m·s−1)
v_f = final velocity (m·s−1)
a = acceleration (m·s−2) (9,8 m·s−2 downwards)

REMEMBER:
1. Draw a sketch diagram.
2. Write down the given variables.
3. Choose a positive direction.
4. Solve.

5.2.2 PARTS OF A PROJECTILE PATH

The path of projectile motion can be analysed using the 4 sections, as shown below. The combination of these 4 parts will depend on the actual path travelled by the projectile.

Example:
A dropped projectile will fall into sections C and D only.
An object thrown upwards that falls on a roof will fall into sections A to C.



Time:
$t_A = t_D$
$t_B = t_C$

Displacement:
$\Delta y_A = \Delta y_D$
$\Delta y_B = \Delta y_C$

Velocity:
$v_{ia} = v_{id}$
$v_{fa} = v_{fd}$

$v_{iB} = v_{iC}$
$v_{fB} = v_{fC}$

EXAMPLE:
An object is projected vertically upwards. 4 seconds later, it is caught at the same height (point of release) on its way downwards. Determine how long it took the ball to pass a height of 8 m in the upward direction. Choose downward as the positive direction.

$v_f = v_i + a\Delta t$
$0 = vi + (9,8)(2)$
$vi = -19,6$
♦ $vi = 19,6 \text{ m. s}^{-1}$ up

$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$
$-8 = -19,6 \Delta t + \frac{1}{2}(9,8)\Delta t^2$
$0 = 4,9t^2 - 19,6t + 8$

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = \frac{-(-19,6) \pm \sqrt{(-19,6)^2 - 4(4,9)(8)}}{2(4,9)}$$

$t = 0,46 \text{ s OR } 3,54 \text{ s}$
♦ $t = 0,46$ s

5.2.3 GRAPHS OF PROJECTILE MOTION

There are basically three types of graphs, namely, the displacement-time graph, the velocity-time graph and the acceleration-time graph. In order to understand how the shapes of these graphs are orientated, when upward or downward motion is chosen, we are going to integrate and compare their shapes with those from Mathematics .Consider the following equation:

$$v_f = v_i + g\Delta t$$

Rearranging we get:

$$v_f = v_i + g\Delta t$$

Now let us compare the last equation with the y-form for a straight line:

$$y = mx + c$$

On comparing the two equations, it clear that:

$$y = v_f\,,\; m = g \text{ and } c = v_i$$

If upwards is chosen as positive, g is negative as m is also negative.
If the gradient is negative, the straight line will be oriented as follows:

If downwards is chosen as positive, g is positive as m is also positive. If the gradient is positive, the straight line is orientated as follows:

Consider the following equation of motion:

$$\Delta y = v_i\,\Delta t + \tfrac{1}{2}\,g\Delta t^2 + 0$$

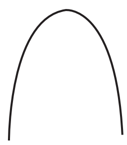
Rearranging we get:

$$\Delta y = \tfrac{1}{2}\,g\Delta t^2 + v_i\,\Delta t + 0$$

Now let us compare the last equation with the y-form for a parabola:

$$y = ax^2 + bx + c$$

It is clear that g = a, $v_i = b$ and $c = 0$
If upwards is chosen as negative, $a < 0$ (♦ $g < 0$) and the shape of the parabola is concave down as shown below.

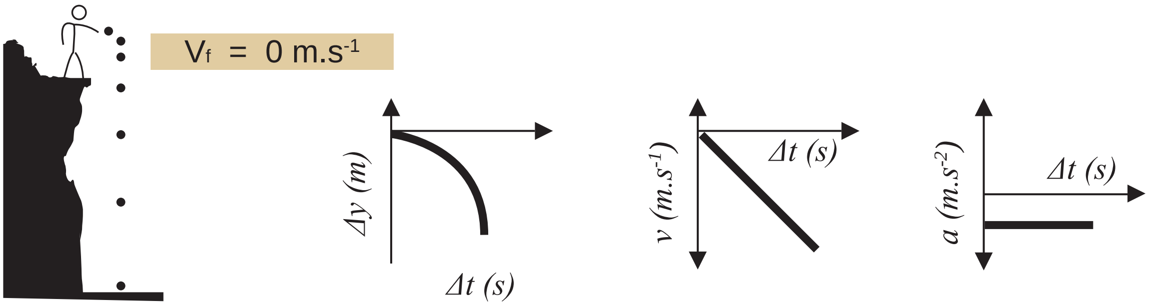


If downwards is chosen as positive, $a > 0$ ($g > 0$) and shape of the parabola is concave up as shown below:

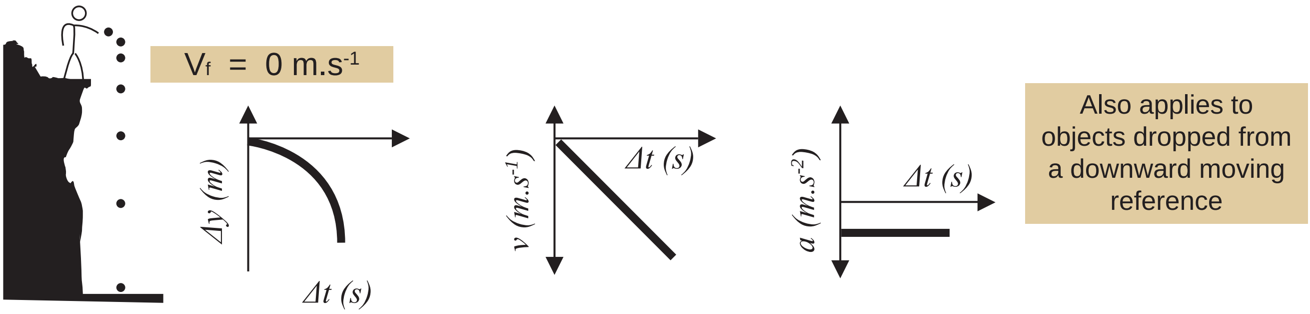
5.2.4 PATHS OF A PROJECTILE

In the examples below, A, B, C and D refer to the parts in section 5.2.1 above.

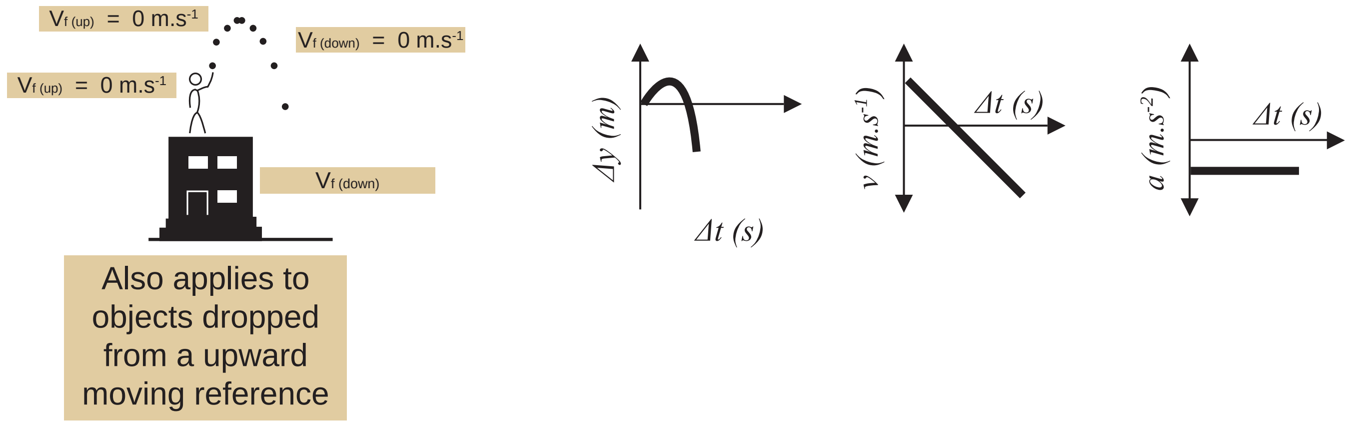
OBJECT DROPPED FROM HEIGHT (C+D)



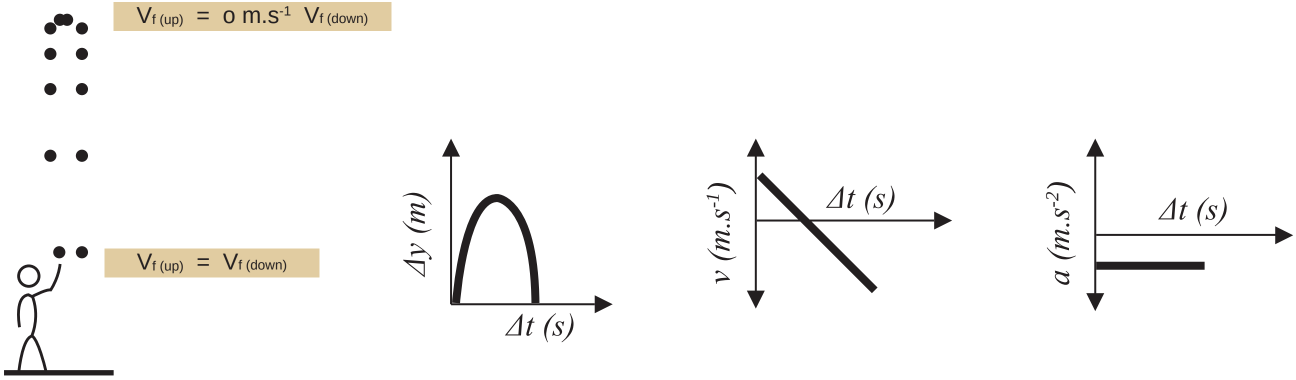
OBJECT THROWN DOWN FROM HEIGHT (D)



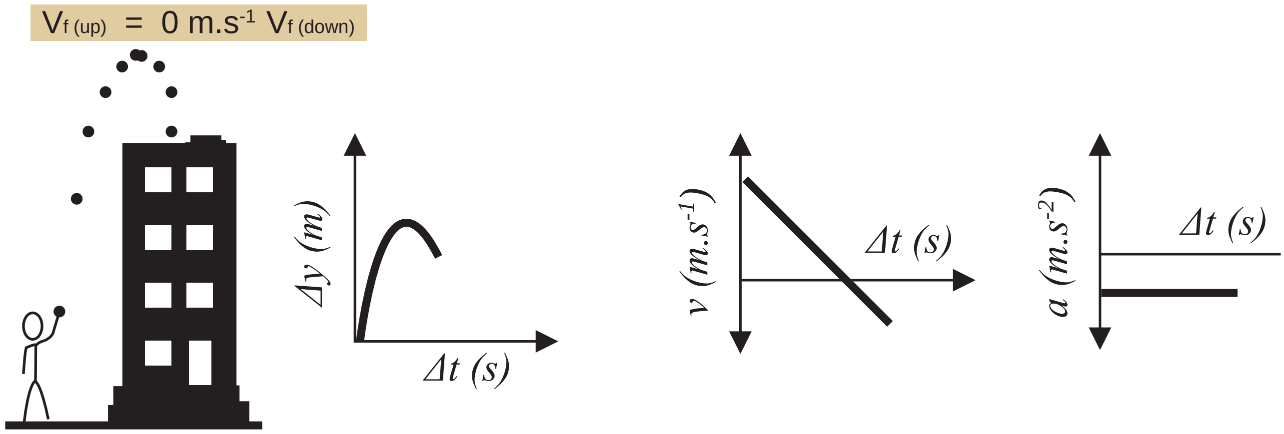
OBJECT THROWN UP FROM HEIGHT (B+C+D)



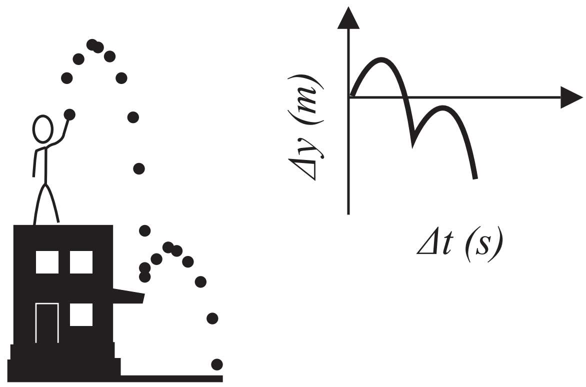
OBJECT THROWN UP AND CAUGHT (A+B+C+D)

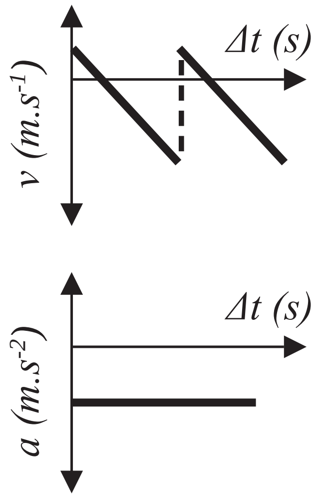


OBJECT THROWN UP AND CAUGHT (A+B+C+D)



OBJECT THROWN UP FROM HEIGHT BOUNCES (A+B+C)





If the collision is perfectly elastic, the downward velocity before the bounce and the upward velocity after the bounce are equal in magnitute.

Please treat 2 projectile paths (before and after bounce) as seperate paths.

5.2.5 SPECIAL PROJECTILE PATHS

A. HOT AIR BALLOON

When an object is dropped from a moving reference (hot air balloon), the initial velocity will be equal to that of the reference.
The acceleration of the object will be downwards at 9,8 $m \cdot s^{-2}$, regardless of the acceleration of the reference.

EXAMPLE:
A hot air balloon ascends with a constant velocity of 5 $m \cdot s^{-1}$. A ball is dropped from the hot air balloon at a height of 50 m and falls vertically towards the ground.
Determine the following:

(a) The distance between the hot air balloon and the ball after 2 seconds.
(b) The velocity of the ball when it reaches the ground.

Solution
(a) Take downwards as positive.

$$\Delta y = v_i \Delta t + \tfrac{1}{2} \Delta t^2$$
$$= (-5)(2) + \tfrac{1}{2}(0)(22)$$
$$= -10$$

♦ $\Delta y = 10$ m up

Distance travelled by ball:

$$\Delta y = v_i \Delta t + \tfrac{1}{2} \Delta t^2$$
$$= (-5)(2) + \tfrac{1}{2}(9,8)(22)$$
$$= -10 + 19,6$$

♦ $\Delta y = 10$ m down

♦ total distance = 10 + 9,6 = 19,6 m apart

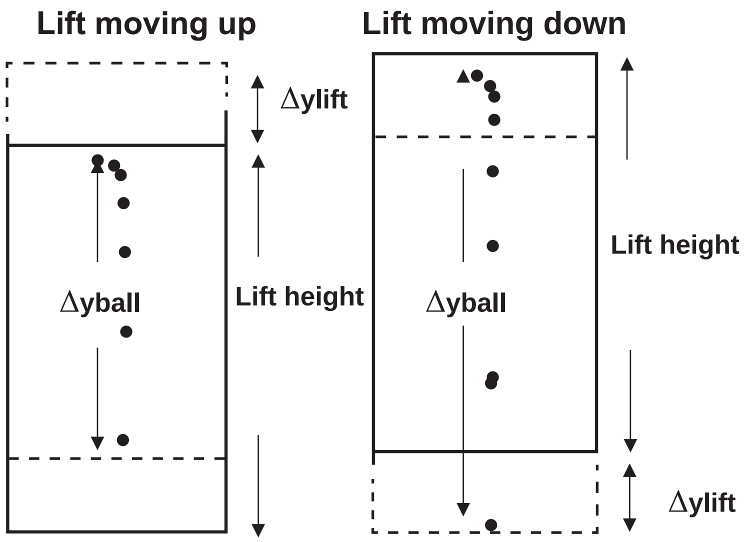
(b) Take downwards as positive.

$$v_f^2 = v_i^2 + 2a\,\Delta y$$
$$v_f^2 = (-52) + 2(9,8)(50)$$
$$v_f = 25 + 980$$
$$v_f = 31,70 \text{ m.s}^{-1} \text{ downward}$$

B. LIFT EXAMPLE:

A lift accelerates upwards at a rate of 1,4 m·s−2. As the lift starts to move, a light bulb falls from the ceiling of the lift.

Determine how long it takes the light bulb to reach the lift's floor. The height from the ceiling of the lift to the floor of the lift is 3 m.



$$\Delta y_{bulb} = \text{Liftheight} + \Delta y_{lift}$$

Simultaneous equations are needed, because there are 2 unknown variables:

- Distance that the lift moved.
- Time to reach the floor.

Take downwards as positive.

Movement of elevator:

$$\Delta y_{lift} = v_i \Delta t + \tfrac{1}{2} \Delta t^2$$

$$\Delta y_{lift} = (0)\Delta t + \tfrac{1}{2} (-1{,}4)\, a\Delta t^2$$

$$\blacklozenge\ \Delta y_{lift} = -0{,}7\, a\Delta t^2$$

Movement of bulb:

$$\Delta y_{bulb} = v_i \Delta t + \tfrac{1}{2} \Delta t^2$$

$$3 + \Delta y_{lift} = (0)\Delta t + \tfrac{1}{2} (9{,}8)\Delta t^2$$

$$3 + \Delta y = 4{,}9\, \Delta t^2$$

$$\blacklozenge\ \Delta y_{lift} = 4{,}9\Delta t^2 - 3$$

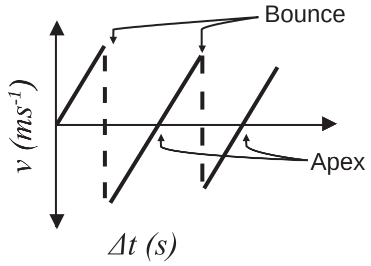
$$-0{,}7\Delta t^2 = 4{,}9\Delta t^2 - 3$$

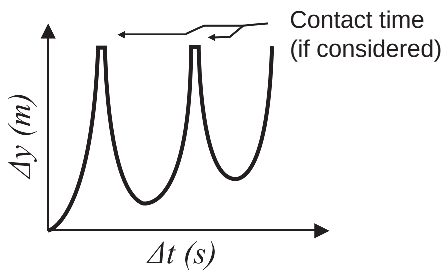
$$-5{,}6\Delta t^2 = -3$$

$$\Delta t^2 = 0{,}54$$

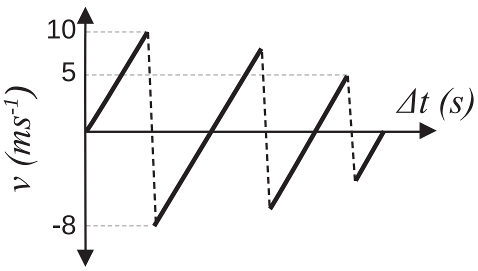
$$\blacklozenge\ \Delta t^2 = 0{,}73 \text{ s}$$

C. BOUNCING BALL





EXAMPLE:
The velocity-time graph below represents the bouncing movement of a 0,1 kg ball.
Use the graph to answer the questions that follow:



a) Which direction of movement is positive?
Downwards

b) How many times did the ball bounce?
3 times

c) What does the gradient of the graph represent?
Acceleration of the ball.

d) Are the collisions between the ball and the ground elastic or inelastic?
After each bounce, there is a change in the velocity of the ball, and therefore a change in kinetic energy. The collisions are inelastic, as kinetic energy is not conserved.

e) Determine the impulse on the ball, if the ball is in contact with the ground for a duration of 0,08 s.

Impulse $= \Delta p$
$= m(v_f - v_i)$
$= (0,1)(-8 - 10)$
$= -1,8$
♦ **Impulse = 1,8 N . s upwards**

f) Suggest why the ball stopped moving.
It stops on the apex, ♦ it was most likely caught.

5.3 PRACTICE QUESTIONS

Question 1: Multiple Choice Questions

1.1 A ball is thrown vertically upwards. Which ONE of the following physical quantities has a non-zero value at the instant the ball changes direction?

A. acceleration
B. momentum
C. kinetic energy
D. velocity

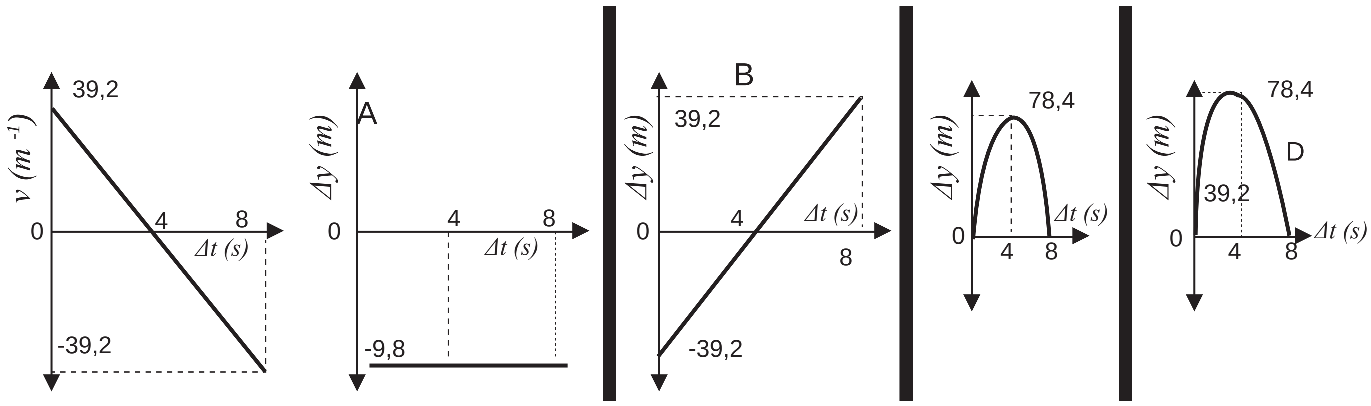
1.2 A 30 kg iron sphere and a 10 kg aluminium sphere with the same diameter fall freely from the roof of a tall building. Ignore the effects of friction. When the spheres are 5 m above the ground, they have the same ...

A. momentum
B. kinetic energy
C. acceleration
D. Potential energy

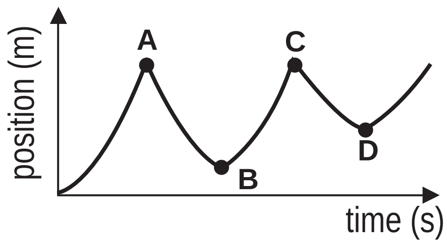
1.3 When a projectile is moving vertically upwards, it …

A. has zero acceleration
B. accelerates downwards with a constant acceleration
C. loses its mass
D. has maximum velocity at its highest point.

1.4 Norma hits the cricket ball from the ground straight up in the air. A graph of velocity vs time was drawn. Upwards is taken as positive. Which of the following graphs represents the corresponding position vs time graph?



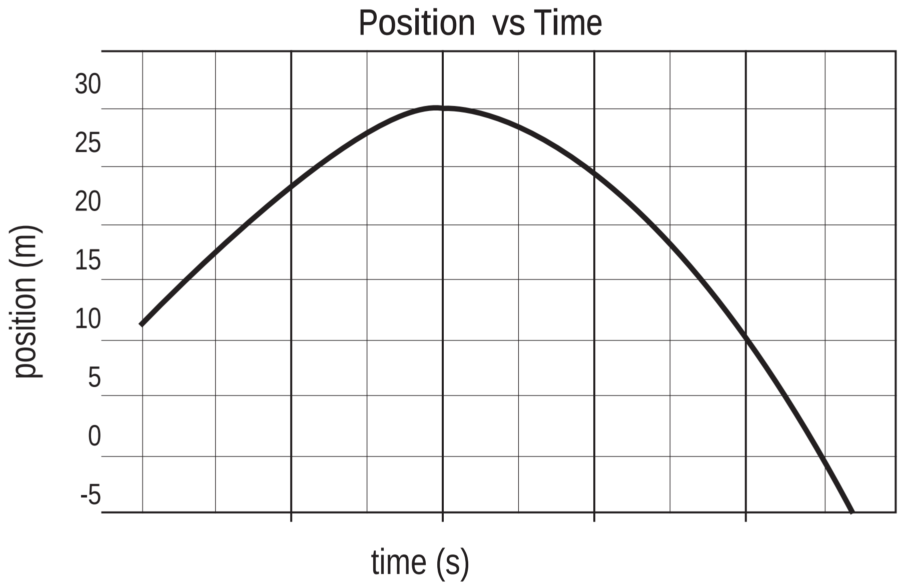
1.5 A ball is released from rest from a certain height above the floor and bounces off the floor a number of times. The position-time graph represents the motion of the bouncing ball from the instant it is released from rest.



When ignoring air resistance, which point (A, B, C or D) on the graph represents the position-time coordinates of the maximum height reached by the ball after the SECOND bounce?

A. A   B. B   C. C   D. D

1.6 The graph below is applicable to questions 1.6 – 1.7. It shows the motion of a stone thrown vertically upwards. The time taken by the stone to reach maximum height is …



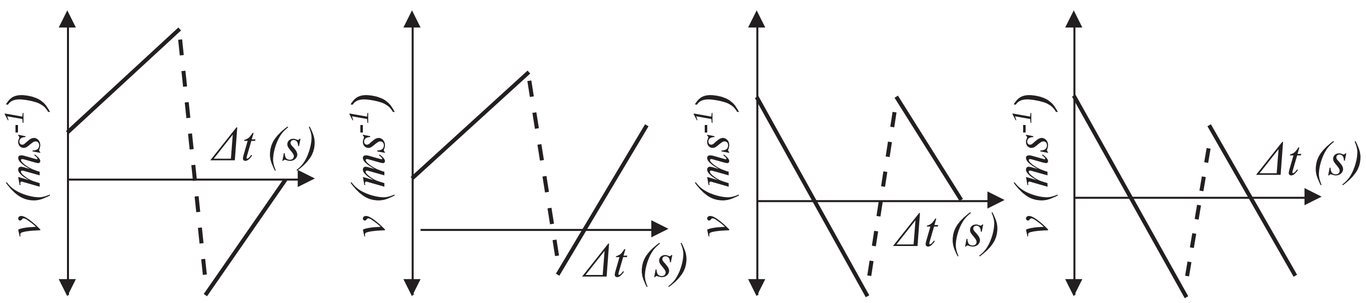
A. 0,5 s   B. 2 s   C. 1,5 s   D. 4 s

1.7 Refer to the graph provided in 1.6. What is the initial velocity of the stone?
A. 9,9 m·s-1   B. 29,6 m·s-1   C. 19,6 m·s-1   D. 14,5 m·s-1

1.8 An object is observed and a graph of its distance versus time is constructed. The graph has a slope of +5,0, when the distance is measured in metres and the time is measured in seconds. The object was …

A. motionless
B. decelerating
C. moving at a constant speed of 5,0 m/s
D. accelerating at 5,0 m/s^2

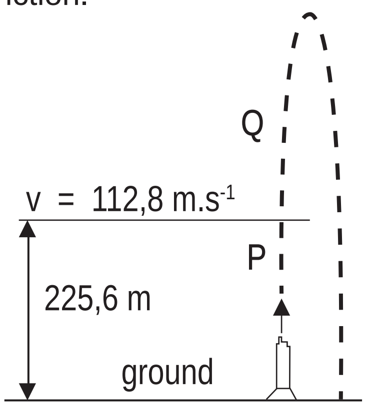
1.9 An object is thrown vertically downwards towards the ground from height h, with a velocity v. The object strikes the ground and bounces upwards. It is caught when it reaches its maximum height after the bounce. Which ONE of the following graphs for velocity versus time best represents the motion of the object?



Structured Questions

Question 2

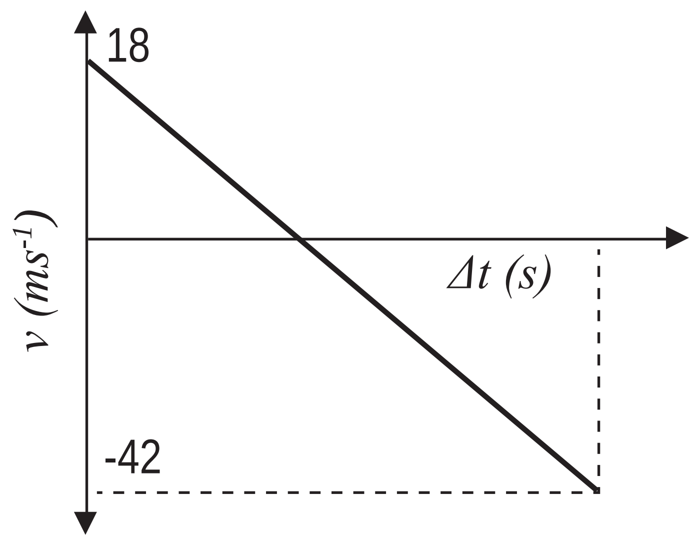
A stationary rocket on the ground is launched vertically upwards. After 4 s, the rocket's fuel is used up and it is 225,6 m above the ground. At this instant, the velocity of the rocket is 112,8 m·s-1. The diagram below shows the path followed by the rocket. Ignore the effects of air friction.



2.1 Write down the direction of the acceleration of the rocket at point:
   2.1.1 P
   2.1.2 Q
2.2 At which point (P or Q) is the rocket in free fall? Give a reason for your answer.
2.3 TAKING UPWARD MOTION AS POSITIVE, USE EQUATIONS OF MOTION to calculate the time taken from the moment the rocket is launched until it strikes the ground.
2.4 Sketch a velocity versus time graph for the motion of the rocket from the moment it runs out of fuel until it strikes the ground. Take the time when the rocket runs out of fuel as t = 0 s. Indicate the following values on the graph.
   - Velocity of the rocket when it runs out of fuel.
   - Time at which the rocket strikes the ground.

Question 3

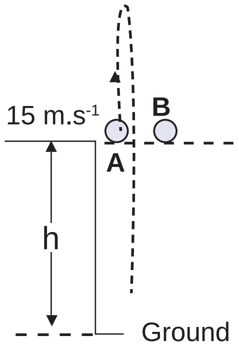
The velocity time graph describes the motion of an object that is projected vertically. Study the graph and answer the following questions:



3.1 After how many seconds does the object reach maximum height?
3.2 What height above its starting point does the object reach?
3.3 How many seconds after its launch does the object hit the ground?
3.4 Calculate the initial height of the object when it was projected.

Question 4

A ball **(A)** is thrown vertically upward from a height, h, with a speed of 15 $m \cdot s^{-1}$. AT THE SAME INSTANT, a second identical ball **(B)** is dropped from the same height as ball **A,** as shown in the diagram below. Both balls undergo free fall and eventually hit the ground.



4.1 Explain the term free fall.
4.2 Calculate the time it takes for ball A to return to its starting point.
4.3 Calculate the distance between ball A and ball B when ball A is at its maximum height.
4.4 Sketch a velocity-time graph in your ANSWER BOOK for the motion of ball A from the time it is projected until it hits the ground. Clearly show the following on the graph: the initial velocity; the time it takes to reach its maximum height; the time it takes to return to its starting point.

Question 5

A cricket ball with a mass of 156 g, is dropped from point A on a tall building that is 15 m high. It strikes the concrete pavement and then bounces to a maximum height of 4 m.

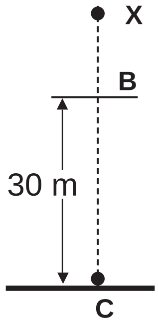
5.1 Calculate the velocity with which the cricket ball strikes the pavement.
5.2 If the effects of air friction are NOT ignored during the fall of the ball, how would the value you calculated in the previous question change? Write HIGHER, LOWER or STAYS THE SAME.
5.3 The cricket ball is in contact with the concrete pavement of 0,8 s. Ignore the effects of air friction. Take DOWNWARD motion as POSITIVE.
5.3.1 Calculate the impulse of the cricket ball on the pavement.
5.3.2 Calculate the (net) average force exerted by the pavement on the cricket ball.
5.4 Sketch the position versus time graph for the motion of the cricket ball from the moment it is dropped until it reaches its maximum height after the bounce. USE POINT A AS THE ZERO POSITION.
Indicate the following on the graph:
- The height from which the cricket ball is dropped.
- The height reached by the cricket ball after the bounce.
- The length of time that the cricket ball is in contact with the concrete pavement

5.5 The cricket ball is now replaced with a softer ball of similar mass. State how the (net) average force exerted by the concrete pavement on the softer ball compares with your answer in question

5.3.2. (Write down only GREATER, SMALLER or STAYS THE SAME). Use physics principles to explain your answer.

Question 6

An object is released from rest from a point **X,** above the ground, as shown in the diagram. It travels the last 30 m **(BC)** in 1,5 s, before hitting the ground. Ignore the effects of air friction.



6.1 Name the type of motion described above.
6.2 Calculate the:
6.2.1 The magnitude of the velocity of the object at point **B.**
6.2.2 The height of point **X** above the ground.
After hitting the ground, the object bounces once and then comes to rest on the ground.
6.3 Sketch an acceleration-time graph for the entire motion of the object.

6. Check your answers

Solutions for Vertical Projectile Motion

1.1 A. Even as it changes direction, a projectile is under the influence of gravitational attraction, with a = -9,8 m·s^{-2}, if upward is the positive direction.
1.2 C – acceleration. Both spheres experience the same gravitational attraction, which is independent of the mass of the object being attracted. All the other concepts, momentum, kinetic and potential energy are all dependent on mass
1.3 B. A projectile is defined as moving under the influence of gravity only, and gravity acts in the direction of the
centre of the Earth, even while the projectile is moving vertically upward.
1.4 C – v_i = -v_f ♦ starting and end position are the same. Gravitational acceleration applies; therefore, position/ time is not a straight line.
1.5 D. In this graph, downward is taken as positive, and the initial position, before the projectile drops, is the zero position. Point A represents the point at which the ball reaches the ground the first time. It then bounces back up to point B and hits the ground a second time at point C. D is the maximum height after the second bounce.
1.6 B – 2 s
1.7 $v_f = v_i + a\Delta t$, with v_f = 0 m·s-1, Δt = 2 s and a = -9,8 m·$^{s-2}$.
Therefore: v_i = 0 – (-9,8)(2) = 19,6 m·$^{s-1}$
1.8 C. The slope of a distance vs time graph represents velocity (v = Δx/Δt), and if the line is straight, it is a constant velocity.
1.9 A. The ball is thrown downwards, hence its velocity increases (therefore, not point C or D). The downward velocity just before hitting the ground is the same as the upward velocity just after the bounce (assuming an elastic collision); therefore, not point B.

Structured Questions

Question 2

1.1.1 Acceleration is upwards due to the rocket engines.

1.1.2 Once the rocket fuel has been used up, the rocket is a projectile that is moving only under the influence of gravity, i.e. acceleration is downwards.

2.2 At point Q, the only force acting on the rocket (ignoring air resistance) is the force of gravity.

2.3 Apply equations of motion from the moment the rocket fuel is used up, with: upward as positive; initial velocity = +112,8 m·s^{-1} , Δy (from when the fuel is used to when it strikes the ground) = -225,6 m; acceleration = g = -9,8 m·s^{-2}. To avoid solving quadratic equations, first calculate the final velocity.

$$v_f^2 = v_i^2 + 2a\Delta y$$
$$v_f2 = (112,8)^2 + 2(-9,8)(-225,6)$$
$$♦\ v_f = 130,941 \text{ m.s}^{-1}$$

Now calculate the time taken, then add the 4 seconds for the first part of the journey.

$$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$$

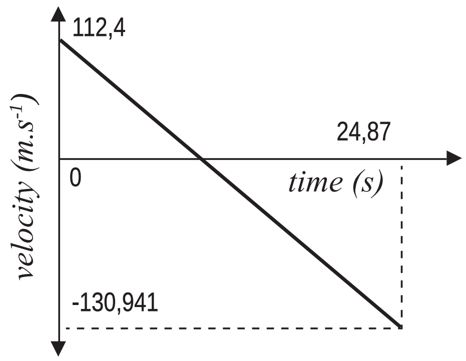
$$-225,6 = \left(\frac{-130,941 + 112,8}{2}\right)\Delta t$$

$$♦\ \Delta t = 24,872 \text{ s}$$

(As an alternative, you can calculate: time taken to maximum height (11,51 s); maximum height (874,78 m). Then use these values to calculate the time taken from maximum height to when it strikes the ground (13,36 s). Add these time intervals to the original 4 s under rocket power, to get total time taken as 28,87 s.

Total time taken = 24,872 + 4 = 28,872 s

2.4 Note: When fuel is used up, the rocket is a projectile; thus, acceleration is constant, and the graph must be a straight line with a gradient = acceleration of – 9,8 m.s^{-2}.



Question 3

3.1 Maximum height is reached when the velocity of an object is zero, i.e. after 1,84 seconds.

3.2 Height above the starting point = area under the graph up to 1,84 s. Thus: height = $\frac{1}{2}$ (18)(1,84) = 16,56 m

3.3 First calculate the time is takes the object to fall from maximum height to the ground. Take upward as positive.

$$v_f = v_i + a\Delta t$$
$$-42 = 0 + (-9,8)\Delta t$$
$$♦\ \Delta t = 4,286 \text{ s}$$

Total time from launch = 1,84 + 4,286 = 6,126 s

3.4 Distance object falls downwards:

$$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$$
$$\Delta y = 0 + \frac{1}{2}(-9,8)(4,286)^2$$
$$\Delta y = -90,01 \text{ m or } 90,01 \text{ m downwards}$$

If the object travelled 16,56 m upward first, the height of the launch must be equal to 90,01 – 16,56 = 73,45 m.

Question 4

4.1 Free fall occurs when an object moves under the influence of gravity alone (i.e. excluding air resistance). It is also called projectile motion. Note that the object can move upwards during free fall, as when a ball is thrown upwards. As soon as the ball leaves the hand of the person throwing it, it is in free fall.

4.2 Take upward as positive. There are different, equally valid, ways of calculating the time. Projectile motion is symmetrical: the upward velocity when thrown = downward velocity at same point or

$$v_f = v_i + a\Delta t$$
$$-15 = 15 + (-9,8)\Delta t$$
$$\blacklozenge \ \Delta t = 3,061 \text{ s}$$

4.3 Ball A reaches maximum height at 1,53 s:

$$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$$
$$\Delta y = (15)(1,53) + \frac{1}{2}(-9,8)(1,53)^2 = 11,48 \text{ m}$$

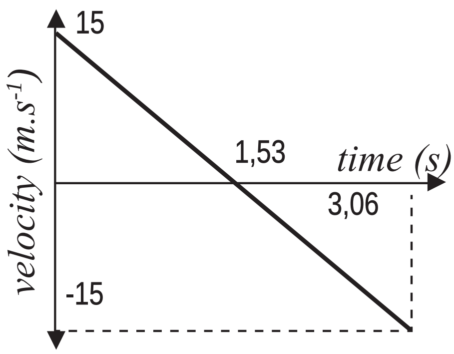
At this point, ball B has fallen downwards:

$$\Delta y = 0 + \frac{1}{2}(-9,8)(1,53)^2 = 11,47 \text{ m}$$

i.e. 11,47 m downwards

♦ The distance between A and B is then 11,48 + 11,47 = 22,95 m

4.4 Taking upward as positive:



Question 5

5.1 Take upwards as positive, then g = -9,8 m.s-2 and = -15 m

$v_f^2 = v_i^2 + 2a\Delta y$

$v_f^2 = 0 + 2(-9,8)(-15)$

♦ $v_f = 17,15$ m.s^{-1}

5.2 Yes, it would change. The velocity would be lower, since the force due to air resistance (friction) opposes the downward motion due to gravity.

5.3.1 Take downward as positive, as instructed.

Before calculating the impulse, we need to know the velocity with which the cricket ball rebounds off the floor. Remember, upward displacement is now negative.

$v_f^2 = v_i^2 + 2a\Delta y$

$0 = vi2 + 2(9,8)(-4)$

$vf = 8,854$ m.s^{-1}

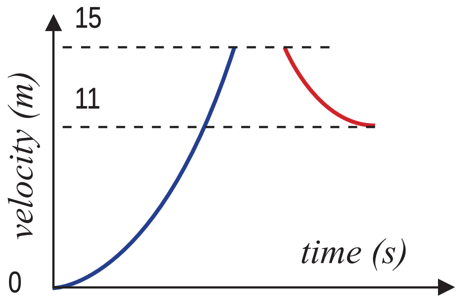
Now calculate the impulse of: $F_{net.}\ \Delta t$

$F_{net.}\ \Delta t = \Delta p = m(vf - vi) = (156x10^{-3})(-8,85 - 17,15) = -4,056$ kg.m.s^{-1}

The change in momentum is 4,056 kg.m.s^{-1} upwards.

5.3.2 $F_{net.}\ \frac{\Delta p}{\Delta t} = \frac{-4,056}{0,8} = -5,07\ N$ or 5,07 N upwards

5.4 Taking downwards as positive, and taking point A as the zero position:



5.5 A softer ball will deform on impact with the ground and thus stay in contact with the ground for a longer period of time. If the change in momentum of the softer ball is the same as that for the harder cricket ball, then the force must decrease, given

$Fnet = \frac{\Delta p}{\Delta t}$

Question 6

6.1 Projectile motion or free fall.

6.2.1 Take downward as positive. Then use equations of motion:

$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$

$(30) = v_f\ (1,5)\ \frac{1}{2}(9,8)(1,5)^2$

♦ $v_f = 12,65$ m.s^{-1}

6.2.2 The velocity at B is now the final velocity and initial velocity = 0. (Again, take downwards as positive.)

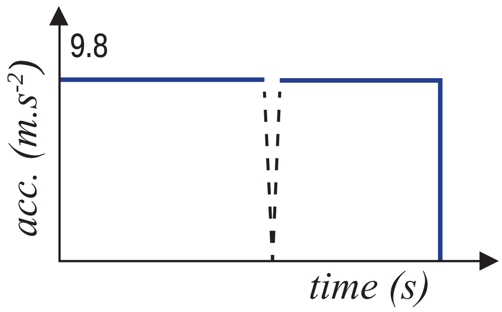
$v_f^2 = v_i^2 + 2a\Delta y$

$(12,65)^2 = 0 + 2(9,8)\Delta y$

♦ $\Delta y = 8,16$ m

Point X is 8,16 m above B; thus 8,16 + 30 = 38,16 m above ground.

6.3 Note: You are asked to draw an acceleration-time graph. The acc. is a constant 9,8 m•s-2 for the whole motion, except the moment of bounce. Indicate this via a dotted line. In this graph, downward is taken as positive.



7. Message to Grade 12 learners from the Writers

Success comes to those who believe in themselves and are prepared to win.
Good luck and tons of best wishes.

8. Thank you and acknowledgements

The Physical Sciences Revision Booklet on Vertical Projectile Motion was developed by Mr Themba Ngcobo (Subject Specialist, PED: KwaZulu-Natal). Special acknowledgement is made of Ms JSK Maharaj (Veena), the DBE curriculum specialist, who co-ordinated and finalised the process, in addition to her contribution to the development of the booklet.

These officials contributed their knowledge, experience and (in some cases) unpublished work, which they have gathered over the years, in order to develop this resource. The Department of Basic Education (DBE) gratefully acknowledges these officials for giving up their valuable time to develop this resource for the children of our country.

Administrative and logistical support was provided by Mr Esrom Fourie. This official was instrumental in the smooth and efficient management of the logistical processes involved in this project.

9. Guidance/ Best practice/ Helpful hints
FOR IMPROVED PERFORMANCE IN THIS SECTION

- You need to learn theory. There are obvious definition statements/ theories/ laws/ principles/ processes that must be learnt, as stated in the Examination Guidelines.
- You need to learn the laws, definitions and principles. These are ‘easy marks’ that learners can get.
- N.B. Two marks are awarded for a correct definition/ law/ principle. No marks are awarded for an incorrect or partially correct definition.

CALCULATIONS:
- You must always start with the formula/ equation exactly as shown on the formulae sheet.
- Marks will be awarded for: correct formula, correct substitution and correct answer with unit.
- You may not manipulate the formula before the substitution.
- No marks will be awarded if an incorrect or inappropriate formula is used, even though there may be relevant symbols and applicable substitutions.
- When an object is dropped from a moving reference (hot air balloon), the initial velocity will be equal to that of the reference. The acceleration of the object will be downwards at 9,8 m•s−2, regardless of the acceleration of the reference.

EXPLANATIONS AND INTERPRETATIONS:
- You need to learn theory in order to correctly answer questions that require interpretation or explanation.
- You need to learn the symbols so that you know their meanings and can therefore use the correct equation. Make sure you know which symbols are vectors – these symbols will therefore also have a direction.
- You need to read questions slowly and thoroughly. Be sure you know what information has been given and what it is you have to calculate.
- You must make sketches to make things easier. Fill in as much information as possible on the sketches.
- If objects move in opposite directions, e.g. up and down, you must allocate symbols for the

directions before you do any calculations. Then stick to your choice of direction.
• You need to make sure whether friction can be ignored or if it is present.
- You must know the appropriate graphs. Make a summary of all the graphs and study them.
- Graphs must be labeled/ named.

STEPS TO USING THE EQUATIONS:

a)Draw a diagram of the motion of the object.
b)Identify each stage of the motion.
c)Choose a positive direction and use the same convention throughout.
d)Record the information given and the value required by writing next to each variable. Check the unit and direction.
e)Select the correct equation and solve for the unknowns.

PHYSICAL SCIENCE

VERTICAL PROJECTILE MOTION

GRADE 12

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