Cambridge Assessment International Education

Teaching Pack

Acceleration of Free Fall

Cambridge International AS & A Level Physics 9702

Version 0.1

Cambridge Pathway

Contents

Icons used in this pack:

Briefing lesson

Planning lesson

Lab lesson

Debriefing lesson

Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

> **Important note**
> Our *Teaching packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.
>
> ***This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 3 (Advanced Practical Skills) or Paper 5 (Planning, Analysis and Evaluation).***

This is one of a range of *Teaching Packs* and each pack is based on one experiment. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson reinforces the key concepts, relevant skills, knowledge and understanding linked to the experiment.

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Planning lesson (1 hour*)
This lesson focuses on planning an experiment.
It ends with a demonstration video of the experiment.

↓

Lab lesson (1 hour*)
This lesson focuses on carrying out the experiment including the collection and recording of observations, measurements and estimates.

↓

Debriefing lesson (1 hour*)
This lesson focuses on the analysis and interpretation of data.
This includes making conclusions, evaluating methods and the quality of data and how improvements could be made.

** the timings are a guide only; you may need to adapt the lessons to suit your circumstances.*

In this pack you will find lesson plans, worksheets and teacher resource sheets.

Experiment: Acceleration of free fall

This *Teaching pack* focuses on an experiment to measure the acceleration due to free fall.

Free fall is defined as a downward motion where the only force acting is gravity. In this experiment, your learners will measure the time it takes for a ball to travel a measured distance and use equations of motion to calculate the acceleration of gravity.

This experiment has links to the following syllabus content (see syllabus for detail):

- 2.1 Equations of Motion

The experiment covers the following experimental skills, as listed in **AO3: Experimental skills and investigations:**

- plan experiments and investigations
- collect, record and present observations, measurements and estimates
- analyse and interpret data to reach conclusions
- evaluate methods and quality of data and suggest improvements.

Prior knowledge

Knowledge from the following syllabus topics is useful for this experiment.

- 1.3 Errors and uncertainties

Briefing lesson: Free fall

Resources	• Worksheet A, Worksheet B and Worksheet C • Plastic or paper cup with two holes punched on either side • Access to water • Tennis ball • Weighted tennis ball

Learning objectives	By the end of the lesson: • ***all*** learners should define free fall and explain the forces involved. • ***most*** learners should be able to make links between the variables of displacement, velocity and acceleration in the case of free fall. • ***some*** learners will be able to clearly explain why all objects fall with a constant acceleration when gravity is the only force acting.

Timings	Activity
10 min	**Starter / Introduction** Give your learners Worksheet A. Ask them to identify the three variables shown on the mystery graph. The three variables all represent the same physical situation. If learners are stuck, tell them to look at the numbers on the vertical axis. This should allow them to identify the acceleration of free fall as a starting point.
10 min	**Main lesson** Introduce the topic through recall of key concepts using quick questions with clear defined answers and discussion of open-ended questions. Encourage your learners to share their knowledge, even if unsure, and to critique and analyse each other's ideas. Draw out links between theoretical concepts and practical examples. • What is free fall? • Explain why all objects fall at the same rate when acted on by gravity alone. • Why do objects fall slower on the Moon? • Why don't all objects fall at the same rate on the Earth? • What is the transfer of energy that takes place as an object falls? • When a ball is thrown upwards, at which point is it travelling fastest? When does it travel slowest?
15 min	Give your learners Worksheet B to recap the concept of free fall and the mathematical treatment. It is common for learners to try and draw a 'thrust' type of force, but once the ball leaves the hand that has thrown it, there is no more upwards force until it begins to fall downwards. It may be worthwhile going through this with them.
5 min	A plastic or paper cup can have two holes punched (or drilled) either side. When the cup is filled with water, it runs out of these two holes. Demonstrate this first. Now, cover the holes, refill the cup with water and drop the cup. The water does not flow out of the holes as the cup falls. Ask the learners to explain this. Quite simply, the water falls with the same acceleration as the cup.
10 min	Give your learners Worksheet C to practise linking equations to linear graphs.

Timings	Activity
10 min	**Plenary** Demonstrate dropping two tennis balls. One should be empty and one should be weighted. **Safety** A tennis ball can be filled with water using a metal syringe or rice can be inserted through a small slit cut with a knife. This should be prepared safely before the lesson so that the tennis balls look identical at first glance. The balls will fall at the same rate, but it may surprise the learners to find that they have different masses. Despite being told before that all objects fall at the same rate, it often surprises learners to experience this in real life. Ask learners to explain this in terms of Newton's second law of motion.

Planning lesson: The acceleration of free fall

Resources	• *Free fall* video • Electromagnet triggered timer with ball bearing and trap door set up • Metre rule • Stopwatch • Ball • String • Mass • Sticky tack

Learning objectives	By the end of the lesson: • ***all*** learners should produce a clear and thorough method to direct them in the lab lesson. • ***most*** learners should be able to make predictions for the planned experiment. • ***some*** learners will be able to describe an experiment to determine the acceleration of free fall using a falling body.

Timings	Activity
5 min	**Starter / Introduction** Introduce the learners to the equipment they will be using in their experiment. Demonstrate how a mass on a string can be used to check whether something is vertical.
25 min	**Main lesson** Ask learners to plan how they will set up an experiment to find the acceleration of free fall using the equipment they have been given. Depending on their confidence some learners may need your support. Learners should consider: a) What measurements need to be taken and what equipment should be used. b) How the equipment should be set up. Learners should draw a diagram of this. c) What the sources of error are and how these could be limited.
10 min	Use the electromagnet triggered timer to demonstrate one method to find the acceleration of free fall. It can be used to measure the time it takes for a ball bearing to fall a set distance. Calculations of acceleration can be made using the equations of motion. Learners could discuss and identify the sources of error in this experiment and whether there are any possible improvements.
10 min	Learners can share their methods through discussion with their peers. After this, they should review and improve their methods as necessary. Learners can use the demonstration of the alternative method to start thinking about sources of error and difficulties they may face when carrying out the experiment.
5 min	Show the learners the *Free fall* video. You may want to pause the video at 1:24 to allow the learners to think about how they would use the data to find the acceleration of free fall.
5 min	**Plenary** Ask learners to evaluate their method based on the video and make any changes. They should discuss obvious sources of error based on observation of the video. This can be played again with the sound off so that learners can point out difficulties they expect to encounter when carrying out the experiment next lesson.

Lab lesson: Determining the acceleration of free fall

Resources	• Equipment as outlined in the Teacher notes • *Teacher walkthrough* video

Learning objectives	By the end of the lesson: • ***all*** learners should be able to describe an experiment to determine the acceleration of free fall using a falling body. • ***most*** learners should have recorded their values and presented them alongside observations in a clear and logical manner. • ***some*** learners will be able to explain the importance of taking repeats and understand how the data will be used to find the acceleration of free fall.

Timings	Activity
10 min	**Starter / Introduction** Recap the following through questioning of learners: • Outline of method. • Set-up of the equipment. • Obvious sources of error and how to reduce these. • Safety hazards, e.g. making sure the drop zone is empty before the ball is dropped.
40 min	**Main lesson** Ask your learners to set up the experiment and follow their method to collect and record measurements. Encourage them to note observations throughout. **Safety** Circulate the classroom at all times during the experiment so that you can make sure that your learners are safe and that the data they are collecting is accurate. Assist your learners with their set-up as needed. They may need help to ensure that the metre rules are vertical using the plumb line.
10 min	**Plenary** Ask learners to tidy up their work space and return all equipment to you.

Teacher notes

Watch the *Teacher walkthrough* video and read these notes.

Each group will require:

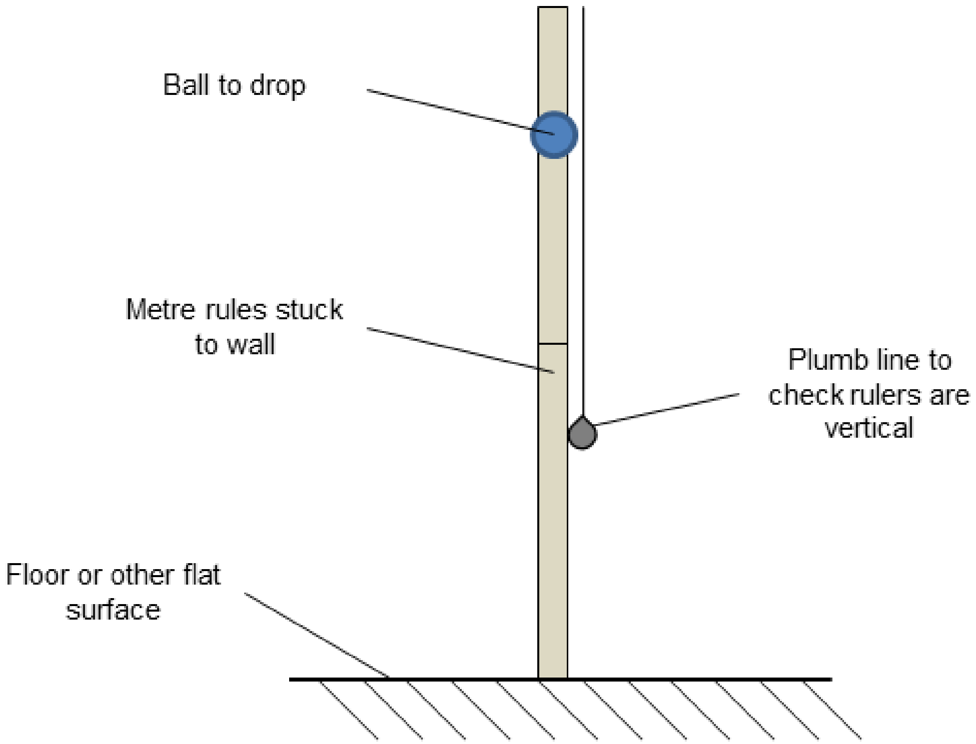
- 2 × metre rule
- stopwatch
- ball
- string
- mass
- sticky tack

Safety

- Wear a lab coat and eye protection.
- No eating or drinking in the lab.
- Do not climb on chairs or tables to drop the ball.

It is your responsibility to carry out an appropriate risk assessment for this experiment.

Experiment set-up



Teacher method

This is your version of the method for this experiment that accompanies the *Teacher walkthrough* video.

Do not share this method with learners.

Before you begin

Plan how you will group your learners during the lab lesson.

Think about:

- the number of groups you will need (group size 1–2 learners)
- the amount of equipment required
- how many sets of data you want your learners to collect.

Experiment

Walk around the learners during the experiment in case they encounter any difficulties.

Steps	Notes
1. Learners should collect the equipment they require from the front of the class.	
2. They should find a space in the classroom where the equipment can be assembled safely.	
3. The bottom metre rule should touch the floor and the second one directly above.	
4. Learners should check their metre rules are vertical.	*Learners may need to have the plumb line demonstrated and explained.*
5. Learners should record the time it takes for the ball to fall from different heights. They should take repeats to allow calculation of an average.	
6. Make sure your learners have recorded all of the relevant data ready to carry out calculations.	

Clean-up

After the experiment learners should:

- tidy up their work space
- return all equipment to you.

Debriefing lesson: The acceleration of free fall

Resources	• Worksheet D

Learning objectives	By the end of the lesson: • ***all*** learners should have calculated a value for the acceleration of free fall from their recorded measurements. • ***most*** learners should be able to evaluate their results by comparing the accepted value for the acceleration of free fall to measurements and calculations. • ***some*** learners will be able to discuss quality of data and improvements with appropriate terminology and clarity of expression.

Timings	Activity
10 min	**Starter / Introduction** Ask your learners to discuss sources of error and limitations of the experiment. Questions to prompt discussion: • The ball also feels a small force of air resistance. How would this affect results? • What was difficult or limiting about the experiment? • What was the absolute error in the measurements taken? Were these errors significant?
10 min 10 min 10 min	**Main lesson** Learners should begin the analysis of their results from the previous lesson by carrying out calculations to find the average values of time for each height the ball was dropped from. They should then plot an appropriate graph to find a value for the acceleration of free fall. Some learners may need more help. They may need the following explained to them: • Dropping the ball means that $u = 0$. • The equation of motion $s = ut + \frac{1}{2}at^2$ can thus be simplified to $s = \frac{1}{2}at^2$ where the acceleration is equal to the acceleration of free fall. Learners should plot s on the y-axis and t^2 on the x-axis. This will give a graph with a gradient equal to $\frac{1}{2}a$. Using the graph they have plotted, learners should now work to find a value for the acceleration of free fall. They should go on to consider: • What do the results suggest? • Are there any alternative interpretations? • What conclusions can we come to? Learners should calculate the error in their measurements. They should consider the absolute error, the percentage error and any compound errors in each measurement. Give your learners Worksheet D if they need support with their calculations.

Timings	Activity
10 min	Ask your learners to discuss, and subsequently make notes on, the quality of data. They should consider the following: • Were there any systematic errors and how did these affect the recorded data? • Were there any obvious random errors in measurements? • What modifications to the experimental arrangement or procedure could be made that would improve the accuracy of the experiment? Ensure that these modifications are achievable in the context of your school laboratory. Can you relate improvements to the sources of uncertainty you have already identified? • Could you extend the investigation to answer a new question?
10 min	**Plenary** Ask your learners to discuss the following points to summarise their findings: • Results. What conclusions can be drawn? Discuss the quality of data and relate this to the percentage error in the results. • Improvements. If they ran the experiment again, what would the learners do differently? How would these changes affect the results and the error in the results? Learners are likely to mention light gates and a data logger as an improvement to timing. • The precision and the accuracy of the experiment. Precision can be judged by the range in the measurements. Accuracy can be judged by calculating the percentage difference between the measured value and accepted value of 9.81 ms^{-2}.

Worksheets and answers

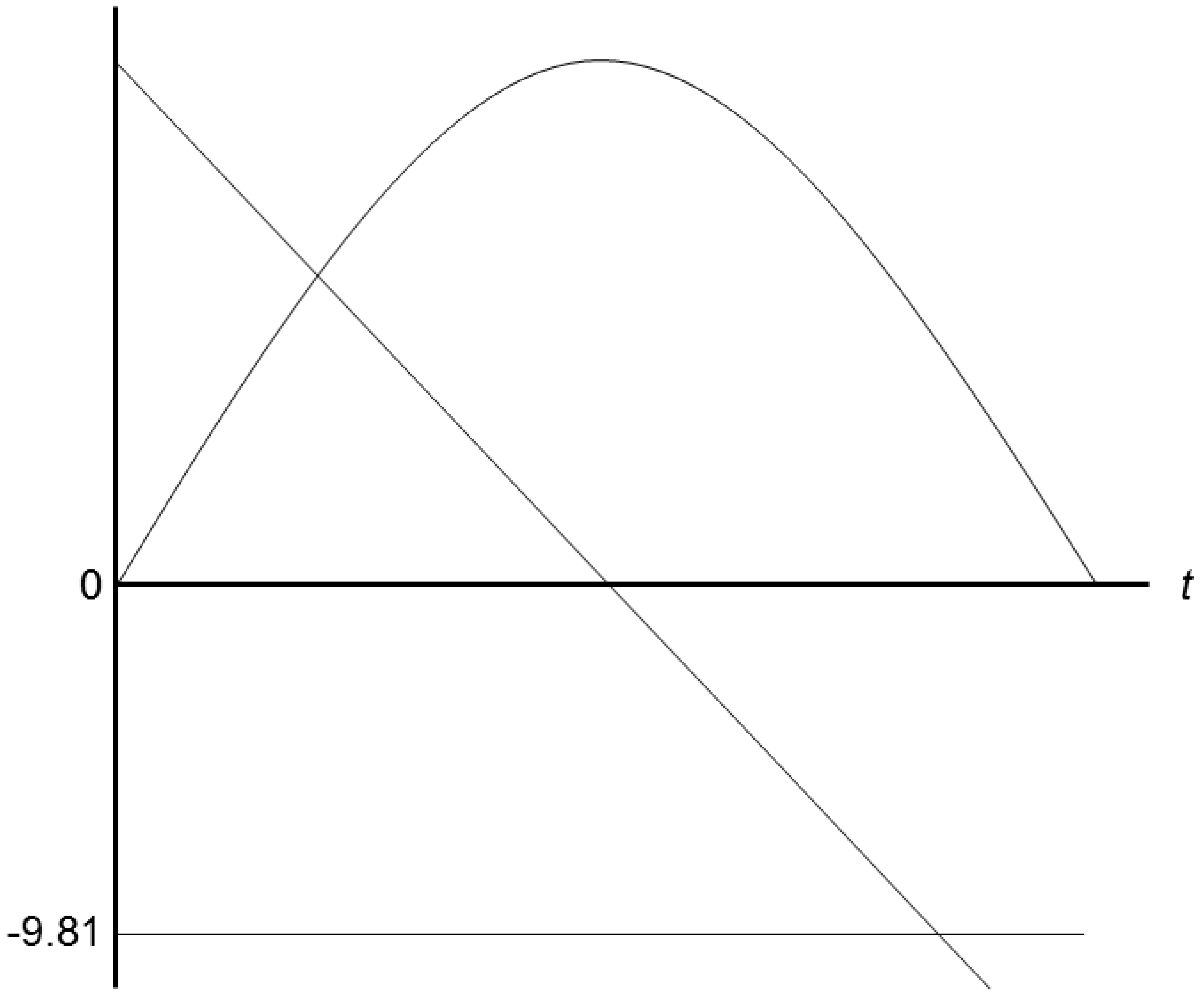
	Worksheet	Answers
For use in *Briefing lesson*:		
A: Mystery graph	**15**	**20**
B: Free fall	**16**	**21–22**
C: Equations and graphs	**17**	**23**
For use in *Debriefing lesson*:		
D: Calculating errors	**18–19**	

Worksheet A: Mystery graph

The graph below shows three different variables plotted on the same time axis. The three different variables represent the same physical situation.

Can you identify each variable on the graph?

Can you explain what is happening to the object to create a graph with these variables?



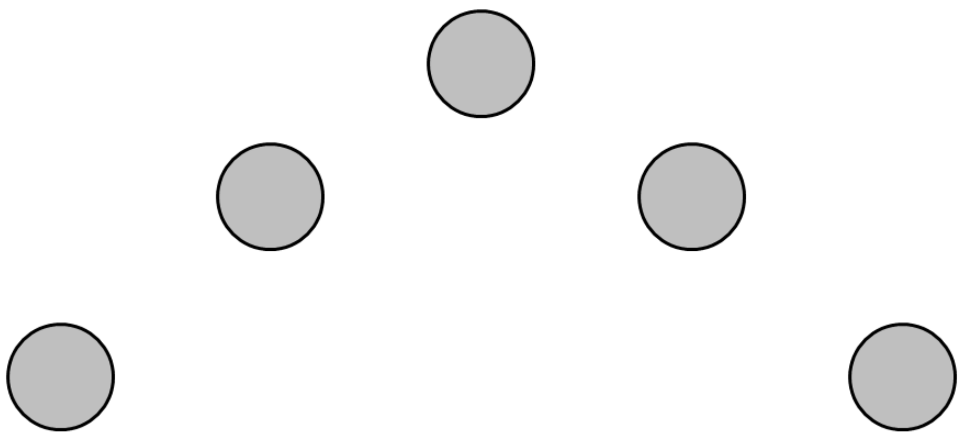
Worksheet B: Free fall

1 A ball is thrown up, moves upwards in the air and then returns back to the hand that threw it.

a. Identify the forces that act on the ball as it moves.

b. In the space below, sketch a velocity-time graph to represent the ball's motion.

c. Below are a series of diagrams that show the ball over time after it has left the hand that threw it. Add arrows to show the forces as they change over time.



2 Answer the following questions using equations of motion.

a. A ball is dropped from a tower. It takes 4 seconds to reach the ground. How high is the tower?

b. An object is thrown up at 20 ms^{-1}.

i. What's its highest point?

ii. How long does it take to reach this point?

c. An object is thrown upwards at 12 ms^{-1}. Find the total time it is in the air.

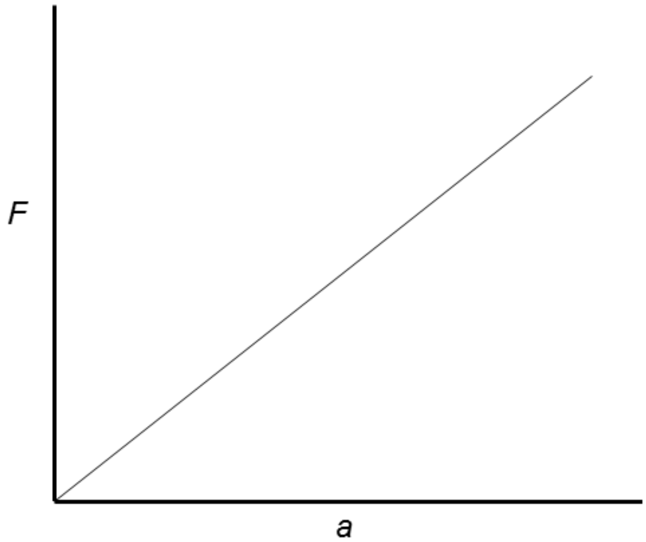
Worksheet C: Equations and graphs

In maths, you will have learnt that the equation of a straight line is $y = mx + c$.

This equation can be applied to any linear graph. The gradient is represented by m and the y-intercept is c. Any point on the line, (x, y), will complete the equation.

This can be really useful in Physics when we have taken a recorded a range of values in an experiment and want to find a missing value.

For example, if we were investigating Newton's second law of motion, which can be expressed as $F = ma$, and had recorded measurements of force and acceleration then we could think about how this could be plotted.



In this case, F can be plotted on the y-axis and a on the x-axis. The gradient of the graph will be equal to the mass of the object undergoing the acceleration produced by the force. As there are no other terms, the intercept is (0, 0).

Complete the table by identifying the missing variables:

y	***m***	***x***
distance		time
momentum		velocity
work done	force	
charge	current	
	frequency	wavelength
	capacitance	voltage
energy		frequency

Worksheet D: Calculating errors

Absolute error is defined as the $\frac{\text{range}}{2}$.

So for the values: 7.2 7.4 7.3 7.0 7.1

The range = largest value – the smallest value

Range = 7.4 – 7.0 = 0.4

Absolute error = 0.4 / 2 = 0.2

However, we must also consider the error in our instruments. Error in the instrument is defined as the smallest division. For example, for a metre rule it is $\pm$ 1 mm. If the error in the instrument is bigger than the $\frac{\text{range}}{2}$, we must use this as the **absolute error** instead.

Percentage error for a value is calculated from the absolute error. We divide the absolute error by the value and multiply by 100 to get a percentage:

$$\% \Delta A = \frac{\Delta A}{A} \times 100\%$$

Where:

ΔA = absolute error

A = *value*

If we want to find the percentage in a result which we have taken multiple measurements of, we must first take the average of the results and then calculate the percentage error.

For the original example, the average of the results is:

(7.0 + 7.1 + 7.2 + 7.3 + 7.4) / 5 = 7.2

The percentage error will be:

$$\% \Delta A = \frac{0.2}{7.2} \times 100\%$$

$$\% \Delta A = \pm 2.78\ \%$$

Worksheet D: Calculating errors, continued

When calculating the percentage error of a value such as F where $F = m \times a$ and m and a are measured variables, the percentage error in m and a must be calculated as above and then used to calculate the percentage error of F. This is known as **compound error**.

The percentage error is calculated by adding the percentage errors of all the values in the equation. Constants can be ignored when calculating compound percentage error.

Example 1: $A = BC$

What is the percentage error in A? Simply add the percentage error of B and C.

$$\%\Delta A = \%\Delta B + \%\Delta C$$

Example 2: $A = B^2$

$A = B^2$ is just $A = B \times B$ therefore

$$\%\Delta A = \%\Delta B + \%\Delta B$$

$$\%\Delta A = 2\ \%\Delta B$$

Example 3: $A = B/C$

As $A = B/C = BC^{-1}$

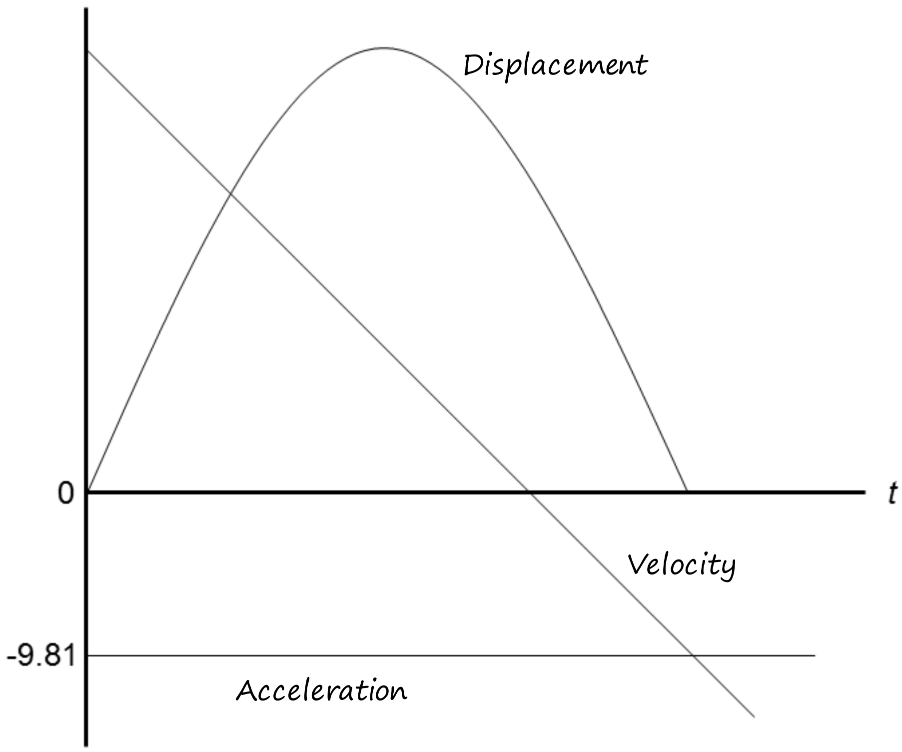
$$\%\Delta A = \%\Delta B + \%\Delta C$$

Worksheet A: Answers

The graph below shows three different variables plotted on the same time axis. The three different variables represent the same physical situation. Can you identify what is happening?

The graph below shows the displacement, velocity and acceleration for a ball being thrown upwards.

The ball starts with a high initial velocity, which decreases due to constant deceleration. The displacement starts at zero and quickly increases. As the ball decelerates, the displacement reaches a maximum (the top of the throw) and then returns to zero.

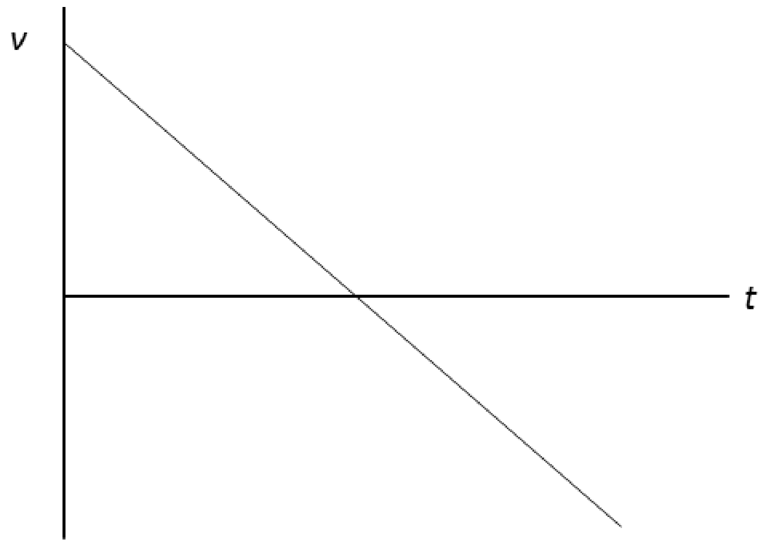


Worksheet B: Answers

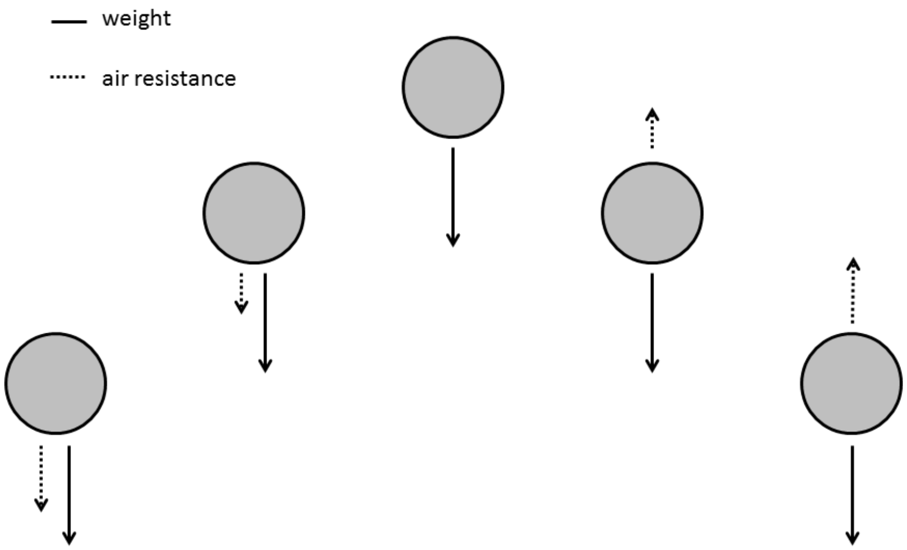
1 A ball is thrown up, moves upwards in the air and then returns back to the hand that threw it.

a. Identify the forces that act on the ball as it moves. *Weight and air resistance.*

b. In the space below, sketch a velocity-time graph to represent the ball's motion.



c. Below are a series of diagrams that show the ball over time after it has left the hand that threw it. Add arrows to show the forces as they change over time.



Worksheet B: Answers, continued

2 Answer the following questions using equations of motion.

a. A ball is dropped from a tower. It takes 4 seconds to reach the ground. How high is the tower?

$u = 0$ $a = -9.81$ ms^{-2} $t = 4$ s

Use $s = ut + \frac{1}{2}at^2$ to find $s = -78.5$ m

b. An object is thrown up at 20 ms^{-1}.

i. What's its highest point?
ii. How long does it take to reach this point?

$u = 20$ ms^{-1} $v = 0$ $a = -9.81$ ms^{-2}

Use $v^2 = u^2 + 2as$ to find $s = 20.4$ m
Use $v = u + at$ to find $t = 2.04$ s

c. An object is thrown upwards at 12 ms^{-1}. Find the total time it is in the air.

$s = 0$ $u = 12$ ms^{-1} $a = -9.81$ ms^{-2}

Use $s = ut + \frac{1}{2}at^2$ to find $t = 2.45$ s

Worksheet C: Answers

y	***m***	***x***
distance	*speed*	time
momentum	*mass*	velocity
work done	force	*distance*
charge	current	*time*
wave speed	frequency	wavelength
charge	capacitance	voltage
energy	*Planck's constant*	frequency

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