Cambridge Assessment International Education

Teaching Pack

Conservation of Momentum

Cambridge International AS & A Level Physics 9702

Version 1

Cambridge Pathway

Contents

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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.

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

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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: Conservation of momentum

This *Teaching Pack* focuses on an experiment to demonstrate the conservation of momentum.

Momentum is defined as the product of a moving object's mass and velocity. In a closed system with no external forces, the momentum before a collision equals the momentum after the collision. In this experiment, your learners investigate the transfer and conservation of momentum between moving objects. They will also investigate the conservation of kinetic energy in elastic collisions.

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

- 3.3 Linear momentum and its conservation

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
- 3.1 Momentum and Newton's laws of motion

Briefing lesson: Momentum and energy

Resources	• Skateboard, or video of person on skateboard (see lesson plan) • Football (or basketball) and tennis ball • Worksheet A

Learning objectives	By the end of the lesson: • ***all*** learners should recall the definition of momentum and be able to carry out calculations using the conservation of momentum. • ***most*** learners should be able to clearly explain the conservation of momentum and energy in collisions. • ***some*** learners will be able to make links between the theory covered in this lesson and varied practical examples.

Timings	Activity
10 min	**Starter / Introduction** Introduce the topic through recall of key concepts, quick questions with clear defined answers and discussion of open-ended questions. Encourage 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 momentum? • Explain which is likely to have momentum: a kicked football or a lorry on a motorway? • What is the conservation of momentum? • Use the conservation of momentum to explain how an astronaut can use a compressed gas to move around in a spacewalk. • What is kinetic energy? • Why is a perfectly elastic collision silent? • Give and explain an example of a perfectly elastic collision.
10 min	**Main lesson** Recap theory with learners. Ensure they have clear notes on momentum, kinetic energy, conservation of momentum and conservation of kinetic energy. Encourage learners to add examples and diagrams, for example: • A billiard ball moving towards a stationary billiard ball. After the collision, the first ball is stationary while the second one moves off. This is an example of an elastic collision. While momentum and kinetic energy should be conserved in an elastic collision, energy will be lost in the form of heat and sound. • A train moving towards a stationary carriage. They connect on impact and move off at a slower speed. Consider why the speed after the collision is slower than the speed before the collision. This is an example of an inelastic collision. Momentum is conserved, but kinetic energy is not. • A charged particle moving towards a second charged particle also moving, but from the opposite direction. This is an example of a perfectly elastic collision. As the particles are charged, they will repel and move away from each other before the physical collision and no energy will be lost to heat or sound. Both momentum and kinetic energy are conserved in this example.

Timings	Activity
10 min 20 min	Demonstrate, or show a video of someone, stepping off the front edge of a skateboard and the skateboard moving backwards. This is an example of an 'explosion'. **Safety** It is easy to lose balance in this demonstration, so ensure flat shoes are worn and the area is clear of tables or other objects the demonstrator could hit if they fell. Give your learners Worksheet A so they can practise the calculation of momentum and energy.
10 min	**Plenary** Demonstrate dropping a tennis ball and a football together. Ensure the tennis ball is directly above the football such that they fall together. The football should hit the floor first before it then hits the tennis ball. The football transfers its momentum to the tennis ball. As the tennis ball has a significantly lower mass than the football, the tennis ball moves upwards (or sometimes at an angle) with a large velocity. **Safety** This demonstration is best done outside or in a large open space. The tennis ball may move off with significant velocity, so ensure observers stand back and there is nothing breakable nearby. Encourage your learners to discuss the transfer and conservation of momentum in the demonstration. There are many possibilities to extend the discussion. Ask learners: • To explain whether momentum and kinetic energy are conserved. • How would the motion of the tennis ball change if a heavier football was used? • How does the floor surface that the football hits affect the transfer of momentum? What would be the outcome of a harder / softer surface?

Planning lesson: Momentum and energy

Resources	• Newton's cradle or a video of a Newton's cradle • Worksheet B • Top pan balance • Air track and air track gliders with magnetic, elastic band and solid attachments • Light gates and data logger • Retort stands, clamps and bosses • Spirit level • *Conservation of momentum* video

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 their planned experiment. • ***some*** learners will be able to explain the conservation of momentum and energy for their planned experiment.

Timings	Activity
10 min	**Starter / Introduction** Demonstrate a Newton's cradle. There are lots of good videos of demonstrations online. Ask your learners to explain the Newton's cradle using the concepts of conservation of momentum and conservation of energy. Questions to prompt further discussion: • What happens if one ball is lifted on one side while two are lifted on the other side? • What happens if the ball in the centre is held out of the way and one ball from each side is lifted and dropped? • Why does the Newton's cradle stop moving eventually? • How would the Newton's cradle behave if the balls were made of different materials?
5 min	Show your learners the set-up of the light gates and data logger. There are many variations of programs / apps, so ensure you are familiar with yours.
20 min	**Main lesson** Ask your learners to plan how they will set up and investigate elastic and inelastic collisions. They should consider different scenarios. Depending on the confidence of your learners, they may need more or less of the support shown below. If your learners are unsure where to start, suggest the following scenarios: 1. Elastic collision of gliders with identical masses; one moving and one stationary. 2. Elastic collision of gliders with identical masses; both gliders collide from opposite directions but with similar speeds. 3. Inelastic collision of gliders with identical masses; one moving and one stationary. For further scaffolding, they could consider: 1. Measurements that need to be taken and what equipment should be used. 2. Set up of light gates, e.g. relative position of gliders and light gates before and after the collision. Suggest drawing diagrams for this. 3. Sources of error and how to limit these.

Timings	Activity
     10 min 5 min 5 min	Give your learners Worksheet B if you feel they are struggling or need more support. If learners have access to the equipment during this lesson, they can make predictions of relative velocities for collisions by taking measurements of the mass of the gliders e.g. if glider A moves with velocity, *u*, and transfers all momentum to stationary glider B, glider B should move with velocity, *v*. These calculations can then be compared to measurements next lesson. Learners can share ideas for methods through open discussion with their peers. Learners should then review and improve their methods as necessary. Can the learners share their ideas and knowledge to produce a clear and thorough method? Test some of the estimations learners have made using the PhET Interactive Simulation (see link below). Type in specific values of mass and velocity and then 'play' the simulation. You can also adjust and investigate other variables. Learners should identify obvious discrepancies between the theoretical simulation and the likely outcomes of a practical experiment. https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html Show the learners the *Conservation of momentum* video.
5 min	**Plenary** Ask your learners to evaluate their method based on the video and make any changes necessary. Ask them to discuss obvious sources of error based on their 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 in the next lesson.

Lab lesson: Conservation of momentum and energy

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

Learning objectives	By the end of the lesson: • ***all*** learners should have recorded values of velocity and mass. • ***most*** learners should be able to present their recorded values and observations in a clear and logical manner. • ***some*** learners will be able to relate estimates made in the previous lesson to the results collected in this lesson.

Timings	Activity
10 min	**Starter / Introduction** Recap the following by questioning your learners: • Outline of method. • Light gates and data logger set-up. • Obvious sources of error and how to reduce these. • Safety hazards, e.g. take care when moving the air track around the room.
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 any learners with their set-up as needed. They may need help ensuring the air track is horizontal and in setting up the light gates and data logger.
10 min	**Plenary** Ask your learners to tidy up their work space and return all equipment to you.

Teacher notes

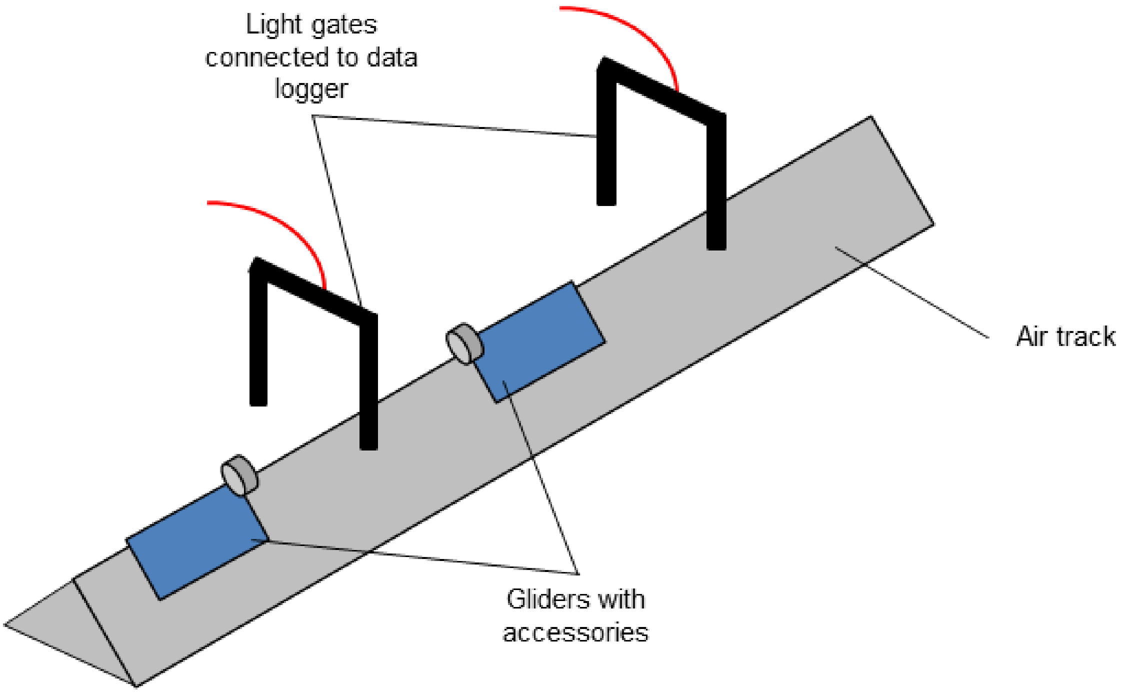
Watch the *Teacher walkthrough* video and read these notes.

Each group will require:
- top pan balance
- air track and air track gliders with magnetic, elastic band and solid attachments
- light gates and data logger
- 2 × retort stands, clamps and bosses
- spirit level.

Safety
- Wear a lab coat and eye protection.
- No eating or drinking in the lab.

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 experiment session. Think about:

- the number of groups you will need (group size 2–4 learners)
- the amount of equipment required
- how many different scenarios the learners are investigating.

Experiment

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. Make sure your learners can switch on the equipment they are using and can set up the relevant program / app.	*Remind learners of the specific set up for light gate and data logging equipment you are using.*
4. Learners should check the air track is level using the spirit level.	*Learners may need to have the spirit level shown to them.*
5. Learners should push the gliders along the air track several times in order to ensure that they travel smoothly.	
6. Learners should record the velocities of the glider travelling along the air track using the light gates and data loggers.	
7. Learners should check they have recorded all of the relevant data ready to carry out calculations of momentum and energy before they move onto the next scenario.	

Clean-up

After the experiment learners should:

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

Debriefing lesson: Conservation of momentum

Resources	• Worksheet C

Learning objectives	By the end of the lesson: • ***all*** learners should have calculated values of momentum and kinetic energy using measurements from the lab lesson. • ***most*** learners should be able evaluate their results by comparing theoretical estimates 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 for sources of error and limitations of the experiment. Possible prompts: • The air track is not frictionless; how does this affect the conservation of momentum and energy? • Which type of collision, elastic or inelastic, would you expect to note the most significant losses of momentum and / or energy? • What was the absolute error in the measurements taken? Were these errors significant? • What was difficult or limiting about the experiment?
10 min	**Main lesson** Learners should begin the analysis of their results from the previous lesson by carrying out calculations of momentum and energy before and after the collisions.
10 min	Using the calculations they have carried out on momentum and energy, learners should now work to discern whether momentum and / or energy was conserved in the scenarios they tested. Learners should go on to consider: • What do the results suggest? • Are there any alternative interpretations? • What conclusions can we come to?
10 min	Learners should calculate the error in their measurements. They should consider the absolute error in each measurement, the percentage error and any compound errors. Give your learners Worksheet C if they need support with their calculations.
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? 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?

Timings	Activity
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 they do differently? How would these changes affect the results and the error in the results? • The precision and the accuracy of the experiment. How can we judge the precision and the accuracy of the experiment? Was it possible to take repeats of the same scenario?

Worksheets and answers

Worksheet A: Momentum calculations

Complete full calculations for the following questions.

Drawing a diagram may help you to visualise the scenarios.

Take care with directions. Recall that momentum is a vector, but energy is a scalar.

1 Calculate the momentum of an air track glider with a mass of 500 g moving at 4.0 ms^{-1}.

2 A lorry with a mass of 3500 kg hits a stationary car with a mass of 1200 kg. The lorry has a velocity of 30 ms^{-1}.

   a. Calculate the total momentum before the collision.

   b. Calculate the total momentum after the collision.

   c. Calculate the common velocity of lorry and the car after the collision.

   d. Calculate the loss of kinetic energy in this collision.

3 A bowling ball with a mass of 6.0 kg moves with a velocity of 7.0 ms^{-1} and collides with a stationary bowling pin with a mass of 1.5 kg.

   a. Calculate the momentum before the collision.

   b. Calculate the kinetic energy before the collision.

   c. Calculate the momentum after the collision.

   d. The bowling ball continues to move, but with a lower velocity of 4.2 ms^{-1}.
   Calculate the velocity of the bowling pin after the collision.

   e. Verify whether the kinetic energy is conserved in this collision and explain your answer.

4 A football with a mass of 40 g moves with a velocity of 25 ms^{-1} and collides with a basketball. The basketball has a mass of 60 g and is moving with a velocity of 20 ms^{-1} in the opposite direction to the football.

   a. Calculate the momentum before the collision.

   b. Calculate the kinetic energy before the collision.

   c. Calculate the momentum after the collision.

   d. After the collision, the basketball moves back in the direction it came from with a velocity of 16 ms^{-1}. Calculate the velocity of the football after the collision.

   e. Verify whether the kinetic energy is conserved in this collision and explain your answer.

Worksheet B: Planning the experiment

1 Complete the table below.

Example collision	Is momentum conserved?	Is kinetic energy conserved?	Are the two objects stuck together afterwards?
Elastic collision between two molecules			
Elastic collision between two billiard balls			
Inelastic collision between two cars			

2 It is suggested that you investigate the following scenarios:

a. Elastic collision of gliders with identical masses; one moving and one stationary.

b. Elastic collision of gliders with identical masses; both gliders collide from opposite directions but with similar speeds.

c. Inelastic collision of gliders with identical masses; one moving and one stationary.

If you are unsure where to start, consider the following questions for each scenario:

a. What measurements need to be taken and which pieces of equipment should be used to take these measurements?

b. How will you set up the equipment? Draw a before and after diagram for each scenario to identify the necessary location of the light gates.

c. What are the sources of error in this experiment and how can they be limited?

3 Consider alternative scenarios.

a. How would the suggested scenarios change if the gliders had significantly different masses?

b. If a 'dart' was thrown towards the stationary glider such that it stuck to the glider and then they moved together through a light gate with a common velocity, how could the velocity of the dart be calculated without using a light gate?

c. Are there other scenarios you could set up to prove the conservation of momentum?

Worksheet C: 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, the smallest division on a metre rule is ± 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*

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.

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

Worksheet A: Answers

1 $p = m\,v = 0.500 \times 4 = 2\,\text{kgms}^{-1}$

2

a. $p = m\,v = 3500 \times 30 = 105\,000\,\text{kgms}^{-1}$

b. $p = m\,v = 105\,000\,\text{kgms}^{-1}$

c. $p = m\,v$ $105\,000 = (3500 + 1200) \times v$ $v = 22\,\text{ms}^{-1}$

d. Before: $KE = ½\,m\,v^2 = ½ \times 3500 \times 30^2 = 1575\,\text{kJ}$
After: $KE = ½\,m\,v^2 = ½ \times (3500 + 1200) \times 22^2 = 1137\,\text{kJ}$
Difference = 440 kJ

3

a. $p = m\,v = 6.0 \times 7.0 = 42\,\text{kgms}^{-1}$

b. $KE = ½\,m\,v^2 = ½ \times 6.0 \times 7.0^2 = 147\,\text{J}$

c. $p = m\,v = 42\,\text{kgms}^{-1}$

d. $p = m\,v$ $42\,\text{kgms}^{-1} = m_b\,v_b + m_p + v_p = 6.0 \times 4.2 + 1.5\,v$ $v = 11.2\,\text{ms}^{-1}$

e. $KE = ½\,m\,v^2 = ½ \times 1.5 \times 11.2^2 = 94\,\text{J}$
Energy is lost during the collision to heat and sound.

4

a. $p = m_f\,u_f + m_b + u_b = (0.040 \times 25) + (0.060 \times -20) = -0.2\,\text{kgms}^{-1}$

b. $KE = ½\,m\,v^2 = ½ \times 0.040 \times 25^2 + ½ \times 0.060 \times 20^2 = 24.5\,\text{J}$

c. $p = -0.2\,\text{kgms}^{-1}$

d. $p = m_f\,v_f + m_b + v_b = (0.040 \times v_f) + (0.060 \times 16) = -0.2\,\text{kgms}^{-1}$
$v = -29\,\text{ms}^{-1}$

e. Before: $KE = ½\ 0.040 \times 25^2 + ½ \times 0.060 \times (-20)^2 = 24.5\,\text{J}$
After: $KE = ½\ 0.040 \times (-29)^2 + ½ \times 0.060 \times 16^2 = 24.5\,\text{J}$
Energy is conserved in this elastic collision.

Worksheet B: Answers

1 Complete the table below.

Example collision	Is momentum conserved?	Is kinetic energy conserved?	Are the two objects stuck together afterwards?
Elastic collision between two molecules	Y	Y	*N*
Elastic collision between two billiard balls	Y	*N*	*N*
Inelastic collision between two cars	Y	*N*	Y

Notes: Kinetic energy transfers to heat and sound. Momentum is always conserved.

2

a. Measurements: mass, distance and time (and / or velocity).
   Equipment: top pan balance, ruler, stop clock, data logger.

b. For the scenario where there is an:
   i. Elastic collision of gliders with one moving and one stationary, one light gate should be placed to record the initial velocity of the moving glider just before the collision and the second light gate should be placed as close to the collision to record the velocity of the glider that was stationary as it moves off.
   ii. Elastic collision of gliders with both gliders colliding from opposite directions but with similar speeds, each glider will need to have its own light gate such that each light gate records the initial velocities, the collision occurs in between the light gates and then the final velocities are recorded as the gliders move back through the light gates in the opposite direction to that which they came.
   iii. Inelastic collision of gliders with one moving and one stationary, one light gate should record the initial velocity of the first glider and the second light gate should record the common velocity of the two gliders. Only the first glider should have an interrupt card in this scenario or the light gates must be programmed with different lengths.

c. Human reaction time will affect measurements of time with the stop clock, hence ideally the light gates and data logger will be used. The air track is not perfectly frictionless so the velocity of the gliders will decrease over time. To avoid this, ensure measurements of velocity are taken close to the collision. Also ensure that the air track is horizontal using a spirit level.

3

a. Different masses would change the velocities e.g. if one glider collides with a second, where the second has double the mass, then the second will move away with half of the velocity of the first.

b. Recording the common velocity of the glider and the dart (this can simply be a lump of sticky tack or any material that can stick to the glider easily) after the collision and their separate masses will give enough information to calculate the dart's initial velocity.

c. Explosions could be investigated using like magnets.

Cambridge Assessment International Education
The Triangle Building, Shaftesbury Road, Cambridge, CB2 8EA, United Kingdom
t: +44 1223 553554   f: +44 1223 553558
e: info@cambridgeinternational.org   www.cambridgeinternational.org