Cambridge Assessment International Education

Teaching Pack

Investigating coplanar forces

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.

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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.

↓

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: Investigating coplanar forces

This *Teaching Pack* focuses on an experiment to investigate the coplanar forces that produce equilibrium.

Objects are in equilibrium when all of the forces acting on the object are balanced. In this experiment, a vertical force of weight, a horizontal force of tension and a diagonal force measured by a newton meter all act on an object to produce equilibrium.

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

- 4.2 Equilibrium of forces

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.

- 1.4 Scalars and vectors
- 4 Forces

Briefing lesson: Equilibrium

Resources	• Worksheet A • Ramp and block • Mass hanger, string and retort stands • Glass, card, scissors and access to water

Learning objectives	By the end of the lesson: • ***all*** learners should be able to identify the forces in a free body force diagram. • ***most*** learners should be able to calculate the magnitude and direction of forces in a free body force diagram. • ***some*** learners will be able to draw accurate free body force diagrams.

Timings	Activity
15 min	**Starter / Introduction** Use Activity 1 and 2 on Worksheet A to recap basic ideas on vectors and equilibrium. Mind map variables in Physics and then sort them into scalars and vectors. Discuss methods for identifying variables as scalars or vectors: consider units, the definition, real world examples, how it is measured, etc. Define equilibrium before setting the learners to brainstorm examples. These can then be labelled as free body force diagrams and considered in more depth by the learners.
35 min	**Main lesson** Use activities 3 and 4 on Worksheet A to practise calculations and scale diagrams. Learners find drawing scale free body force diagrams time-consuming and difficult. Help learners through the questions on Worksheet A to ensure learners are confident and accurate in their work. Understanding these diagrams will be crucial in the upcoming experiment. Some simple examples could be set in the lab e.g. blocks on a ramp or masses on strings.
10 min	**Plenary** Demonstrate and discuss a simple example of equilibrium. Use the glass and card to demonstrate an example of equilibrium. Fill the glass with water and cut the card so it is bigger than the cup. Place the card on top of the glass and gently flip the glass upside down. Take your hand away carefully and the water should stay in place. Ask learners to identify and explain the forces producing the equilibrium of the stationary water.

Planning lesson: Coplanar forces

Resources	• equipment as outlined in the Teacher notes – only one set for demonstration purposes
Learning objectives	By the end of the lesson: • ***all*** learners should produce a method to follow for the lab lesson. • ***most*** learners should be able to draw the free body force diagram for the experiment. • ***some*** learners will be able to identify potential sources of error for the experiment.

Timings	Activity
15 min	**Starter / Introduction** Introduce your learners to the equipment they will be using in the experiment. You should set up the equipment step by step to model the process. Encourage your class to make notes and ask questions during the process.
30 min	**Main lesson** Ask learners to identify the forces present in the set up equipment. Learners should draw a free body force diagram of the equipment. Distribute Worksheet B to learners. Learners assess their own diagram in comparison to the diagram on Worksheet B. Alternatively, if the equipment cannot be set up for this lesson, start by giving out Worksheet B and identifying the forces on the diagram. Now direct learners to write two mathematical expressions to describe the horizontal and vertical forces separately as shown in the diagram. Explain that the learners will use this equipment to investigate coplanar forces next lesson. Ask learners to identify what measurements must be taken to investigate the relationship between the vertical force and the diagonal force. Ask learners to identify sources of error and how to reduce them during the experiment. Discuss use of repeat readings and how they can eliminate random error. Direct learners to write a full method for the experiment.
5 min	**Video** Show your learners the master video.
10 min	**Plenary** Ask learners to evaluate their method based on the video and make any changes. Ask learners to additional 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: Investigating coplanar forces

Resources	• equipment as listed in the Teacher notes
Learning objectives	By the end of the lesson: • ***all*** learners should follow their method to collect results. • ***most*** learners should be able to discuss how the results relate to each other via a free body force diagram. • ***some*** learners will consider how to minimise potential sources of error during the experiment.

Timings	Activity
10 min	**Starter / Introduction** Recap the following through questioning of learners or small group discussion: • equipment set up • outline of method • sources of error and how to reduce these • safety hazards e.g. take care with mass hangers to avoid them falling and ensure learners wear suitable footwear in the laboratory.
40 min	**Main lesson** Direct learners to set up the experiment and follow their method to collect and record measurements. Encourage the learners to note observations throughout. Assist learners with set up as needed. **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.
10 min	**Plenary** Ask the learners to tidy up their workspace and return all equipment to you. They could then spend time discussing the data they have collected and the issues they encountered in preparation for the next lesson.

Teacher notes

Watch the Equilibrium of Forces video (teacher version) and read these notes.

Each group will require:

- ball of string
- scissors
- set squares (x2)
- metre rules (x2)
- retort stand, boss and clamp (x2)
- G clamps (x2)
- 100g masses and hanger
- Newtonmeters
- free-standing vertical board
- graph paper
- adhesive tape
- bright lamp
- protractor

Safety

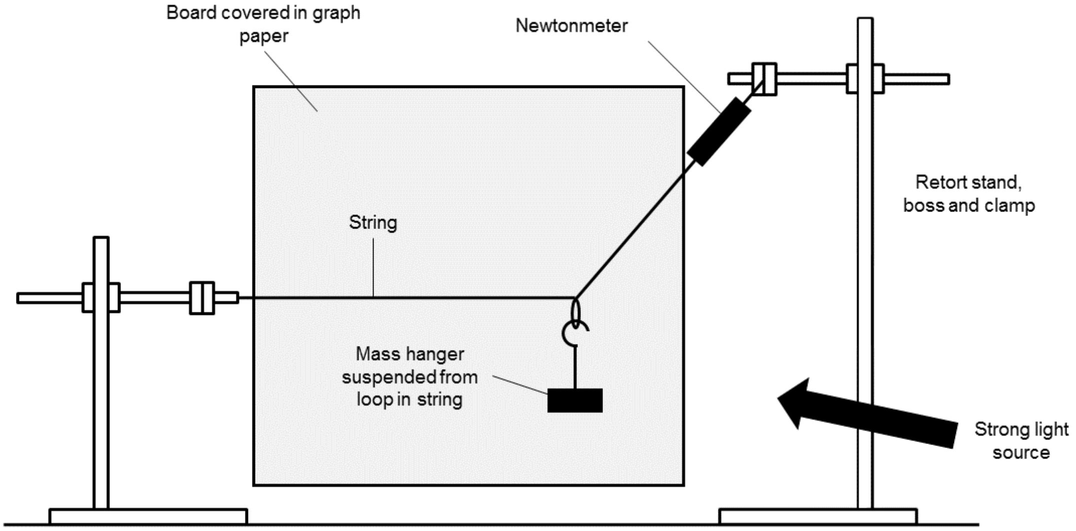
The information in the table below is a summary of the key points you should consider before undertaking this experiment with your learners.

- stands must be securely fixed to the bench using the G clamps
- protect bench and feet from falling masses.

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

Hazard	First aid
Masses falling onto feet.	Apply ice immediately after the injury. Ice the bruise for 10 minutes at a time.

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 2–3 learners)
- the amount of equipment required
- the amount of space required for each group to set up the experiment.

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.	*Learners may need to be reminded about safe handling of the mass hangers to avoid them falling onto feet.*
3. Learners should take readings of force, using the Newtonmeter, and angle, using a protractor.	
4. Mass should be added to the hanger.	
5. Steps 3 and 4 should be repeated until a minimum of 6 sets of data is collected.	*Learners should ensure that they do not exceed the maximum reading on the Newtonmeter. A Newtonmeter with a different scale may be used if necessary.*
6. Make sure your learners have recorded all of the relevant data before packing away.	

Clean-up

After the experiment learners should:

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

Debriefing lesson: Resolving forces

Resources	• The results from the lab lesson

Learning objectives	By the end of the lesson: • ***all*** learners should plot a graph and find the gradient. • ***most*** learners should be able to explain how the graph relates to the free body diagram for the experiment. • ***some*** learners will be able to explain how the sources of error for the experiment affect the results.

Timings	Activity
10 min	**Starter / Introduction** Ask your learners for sources of error and limitations of the experiment. Possible prompts: • What parts of the experiment were difficult to carry out? • What method was best for measuring the angle? • How precise are the Newtonmeter measurements? • Did the angle vary during the experiment? If so, why? • What was limiting about the experiment?
5 min	**Analysis** Learners should begin the analysis of the results from the lab lesson by calculating the weight on the mass hanger ($W = mg$).
15 min	**Interpretation** Using the results and calculations they have carried out of weight, learners should now plot a graph of weight on the y-axis against force on the x-axis. Learners should find the gradient of the graph using a large triangle and discuss what the value represents. They should compare the value of the gradient to the sine of the average angle. Learners should go on to consider: • What do the results suggest? • Are there any alternative interpretations? • What conclusions can be drawn?
10 min	**Evaluation** Learners should calculate the error in their measurements. They should consider the absolute error in each measurement, the percentage error in each measurement and any compound errors. Give learners Worksheet C if learners need support with the calculations.

Debriefing lesson: *continued*

Timings	Activity
10 min	**Quality of data** Ask learners to discuss, and subsequently make notes, on the quality of data. Learners 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? • Was there an expectation that the angle would change during the experiment? If so, how did this affect the results? • 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 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? • 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	Answers
For use in *Briefing lesson*:		
A: Identifying forces	**15**	**18**
For use in *Planning lesson*:		
B: Coplanar forces	**16**	**19**
For use in *Debriefing lesson*:		
C: Calculating the error in a measurement	**17**	**–**

Worksheet A: Identifying Forces

Activity 1:

(a) With a partner list as many of the measurable variables you have learnt about in Physics already e.g. time, wavelength, electric field strength.

(b) Sort your list of variables into two: scalar or vector.
Perhaps you think of a criteria or easy way to work out if a variable is a scalar or a vector.

Activity 2:

(a) With a partner, think of at least three varied everyday examples of equilibrium e.g. this piece of paper resting on the desk in front of you.

(b) Draw a rough sketch of your examples and label the forces. Try to be precise when estimating the approximate size and direction of each force.

Activity 3:
For the following examples, draw scale diagrams and use the diagram to find the missing information.

(a) A box is pulled with a force that is at an angle of 35° to the horizontal surface it travels along. How much force is applied if it moves at a constant speed and there is a frictional force of 200N?

(b) A car that weighs 15 000 N travels down a hill. The hill forms an angle of 10° to the horizontal. What is the magnitude and direction of the friction required to keep the car moving at a constant velocity?

(c) A rock climber has a weight of 600 N and hangs from a rope at 15° to the vertical cliff face with a tension of 450 N. What is the magnitude and direction of the force the climber exerts with their body to the wall?

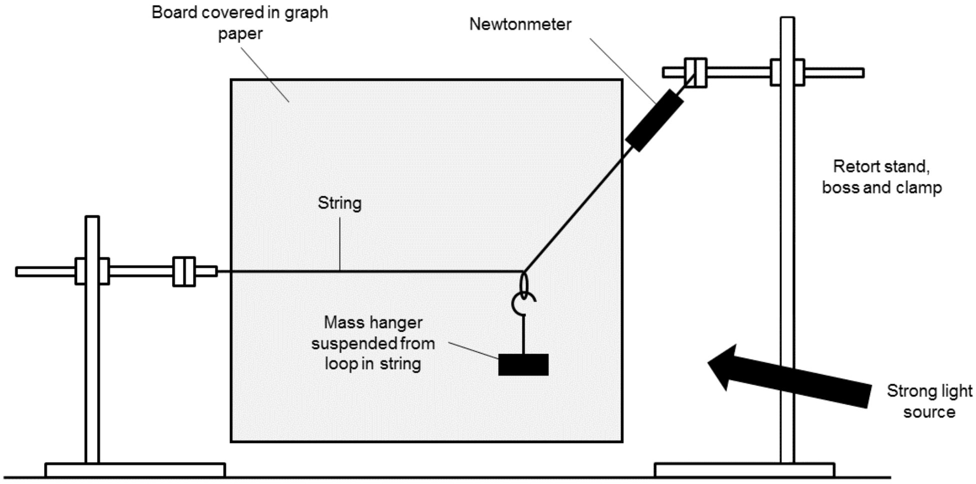
Activity 4:

(a) Using a mathematical approach, solve the questions from Activity 3.

(b) Which method do you think is more accurate? Explain why we might use both methods.

Worksheet B: Coplanar forces

Below is a diagram of the equipment used to investigate coplanar forces:

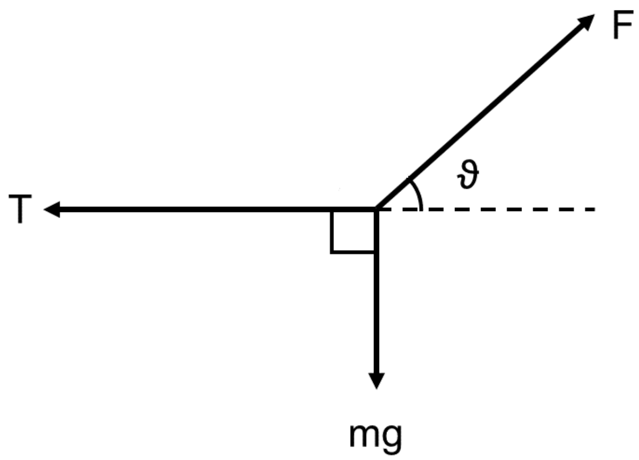


Activity 1: Identifying forces

(a) Identify and label the forces in the diagram above.
(b) Draw a simple free body force diagram of the forces in the above diagram.
(c) Considering the components of force carefully, write mathematical expressions to describe the horizontal and vertical forces separately.

Activity 2: Planning

(a) Identify the measurements that need to be taken to investigate the relationship between the vertical force and the diagonal force.
(b) Identify sources of error in this experiment and note down simple methods of reduction.
(c) Explain the benefit of taking repeat readings.
(d) Write a full method for the experiment bearing in mind the previous points.



Worksheet C: Calculating the error in a measurement

Absolute error is defined as the 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 $\pm$ 1 mm. If the error in the instrument is bigger than the 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 and 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: $A = BC$

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

Activity 1:

Scalar	Vector
charge	displacement
current	field strength
distance	force
energy	moment
frequency	momentum
mass	velocity
power	
pressure	
speed	
temperature	
time	
volume	

Activity 2:

More examples could include:

- *A person sitting on a chair.*
- *A car travelling at 70mph on the motorway.*
- *A bird gliding in the sky.*
- *The International Space Station orbiting the Earth.*

Rough sketches of the examples should have labelled forces and appropriately sized arrows pointing in the right direction.

Activity 3 and 4:

(a) *The pulling force is 244N.*

(b) *The friction is 2605N opposite to the direction of the car's movement. The angle would be 10° above the horizontal, parallel to the slope.*

(c) *The force is 202N away from the vertical wall at 55° above the horizontal.*

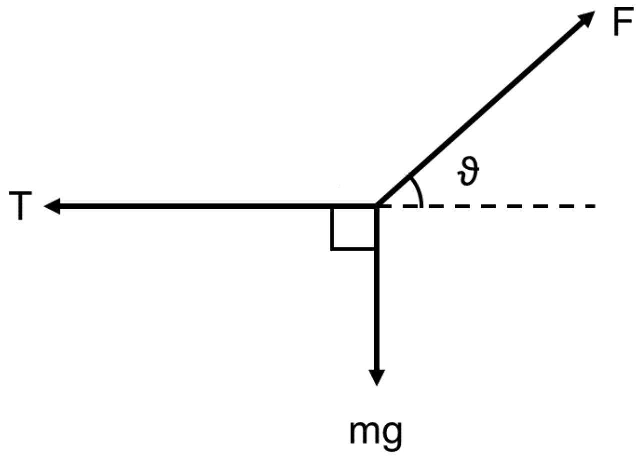
The mathematical method is more accurate, but the scale diagram can help us to understand the directions and give us good estimates of magnitudes.

Worksheet B: Answers

Activity 1: Identifying forces

(a) There is the vertical force of weight of the mass hanger, the horizontal force of tension in the spring and the diagonal force being measured by the Newtonmeter.

(b) Free body force diagram:



(c) Horizontal: $T = F\cos\vartheta$

Vertical: $mg = F\sin\vartheta$

Activity 2: Planning

(a) Measure the diagonal force, F, on the Newtonmeter, the angle, ϑ, and mass on the mass hanger, m.

(b) Sources of error in this experiment may include, but not be limited to, difficulty in measuring the angle, inaccuracy in the horizontal string being truly horizontal and inaccuracies in assumed mass on mass hanger. Learners may discuss alternative ways of measuring the angle, such as using a bright lamp to cast a shadow onto a screen. Learners may suggest using a combination of multiple metre rule measurements, set squares or a spirit level app in ensuring the horizontal string is truly horizontal. Learners may suggest finding the mass of each mass hanger increment using a top pan balance.

(c) Learners should be able to explain the benefit of taking repeat readings referring to eliminate random error and reduce percentage error.

(d) The learners’ methods can be compared to the master video of the experiment.

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