Cambridge Assessment International Education

Teaching Pack

Investigating Electromagnetic Induction

Cambridge International AS & A Level

Physics 9702

Version 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: Investigating electromagnetic induction

This *Teaching Pack* focuses on an investigation into electromagnetic induction.

An electromotive force can be induced by a magnetic field. This is called electromagnetic induction. This can be demonstrated by using a galvanometer which can detect very small currents, the presence of which shows that an electromotive force has been induced.

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

- 20.5 Electromagnetic induction

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.

- 20.1 Concept of magnetic field
- 20.2 Force on a current-carrying conductor
- 20.3 Force on a moving charge
- 20.4 Magnetic fields due to currents

Briefing lesson: Generated e.m.f.

Resources	• Access to the internet and relevant text books • Worksheet A
Learning objectives	By the end of the lesson: • ***all*** learners should be able to recall the uses of the three 'hand' rules. • ***most*** learners should be able to describe uses of solenoids. • ***some*** learners will be able to state both Faraday's Law and Lenz's Law.

Timings	Activity
5 min	**Starter / Introduction** Ask your learners to work in pairs to mind map some uses of electromagnetism and share with the group.
5 min	**Main lesson** Direct your learners to recall the pattern of magnetic field lines, and the uses of the Right and Left Hand Rules and the Solenoid (or Grip) Rule. They will have met these concepts at IGCSE level.
20 min	Distribute the materials required for your learners to make a poster. Worksheet A offers guidance for suggested content. Your learners should complete main parts of the poster, filling in sections on magnetic field lines, the use of the Right Hand, Left Hand and Solenoid rules and uses of solenoids. This task will refresh their knowledge of key information from IGCSE. They may use any resources you have available for this. The sections for Faraday's Law and Lenz's Law can either be left blank at this point or given as extension tasks for more able learners.
10 min	Introduce Faraday's Law. Your learners should note: 'the magnitude of the electromotive force (e.m.f.) induced in a conductor is proportional to the rate of change of magnetic flux linkage, or the rate at which the conductor cuts a magnetic flux'. Learners need to understand that the 'flux lines' are the field lines that they have already drawn in their diagrams. Demonstrate this concept using your fingers of two hands spread out, one set of fingers represent flux lines and the other the conductor. Show that when the fingers are parallel there is no 'cutting' but when they are at right angles the conductor will cut through the flux lines. Your learners should add a note to their posters.
10 min	Introduce your learners to Lenz's Law. Demonstrate this if you have the apparatus or have your learners watch the following clip (1'39") https://youtu.be/N7tIi71-AjA Elicit from learners that the motion of the induced magnetic field will follow the Right Hand Rule since the motion of the falling magnet is being used to generate an e.m.f. in the copper pipe. Your learners should add a note to their posters to include the law which states that 'the direction of an induced current is always such as to oppose the change in the magnetic field that produced it.'
10 min	**Plenary** Learners finish by peer-marking each other's posters. Ask them to look for clarity in diagrams, good labelling and correct wording and use of vocabulary in notes. They should finish by making two comments on what their peer has done well and one suggestion about what they can improve.

Planning lesson: Electromagnetic induction

Resources	• *Investigating electromagnetic induction* video

Learning objectives	By the end of the lesson: • ***all*** learners should be able to describe an experiment to show induced e.m.f. • ***most*** learners should be able to predict the outcomes of this experiment. • ***some*** learners will be able to explain the expected outcomes in terms of Faraday's and Lenz's Laws.

Timings	Activity
10 min	**Starter / Introduction** If you have mini whiteboards use those, otherwise using no-hands questioning, review the key points from the last lesson. For example: what do the fingers represent in the Left Hand and Right Hand rules? What is Faraday's Law? What is Lenz's Law?
30 min 10 min	**Main lesson** Watch the *Investigating electromagnetic induction* video. Explain what the galvanometer is, as some learners may not have used these before. Point out that the needle can move in both directions and that direction is significant. Learners should plan how they will conduct this experiment, writing their plans in detail. Encourage learners to plan in subtitled steps, with diagrams. They should include: • equipment list (including the reason for the use of the moving coil centre-zero galvanometer rather than a standard laboratory voltmeter) • a diagram to show the equipment set up • numbered steps describing the different tests they will undertake • predictions for the likely readings on the galvanometer, making reference to the relevant hand rules and laws. Learners should make two plans, one for the simple wire in a magnetic field, and another for the magnetic field moving within a solenoid. When finished ask your learners to exchange books and evaluate each other's plans. They should use the above bulleted list as success criteria to evaluate against. Ask them to read each other's work not just for detail but for clarity (how well can they understand the instructions, or read the diagrams). After making notes on their partner's work, they should pass the books back.
10 min	**Plenary** Your learners should look at their peer-assessed work and make any changes that have been suggested.

Lab lesson: Investigating electromagnetic induction

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

Learning objectives	By the end of the lesson: • ***all*** learners should state that a changing magnetic flux can induce an e.m.f. in a circuit and describe the factors affecting the magnitude of the induced e.m.f. • ***most*** learners should be able to describe and distinguish between two experimental demonstrations of Faraday and Lenz's Laws. • ***some*** learners will be able to the direction of an induced current is always such as to oppose the change in the magnetic field that produced it.

Timings	Activity
10 min	**Starter / Introduction** Ask learners to state Faraday's and Lenz's Laws, and state the meaning of magnetic flux lines and use their fingers to demonstrate cutting of flux lines by a perpendicular current and non-cutting by a parallel one. This was given as a teacher demonstration in the previous lesson.
20 min	**Main lesson** Distribute equipment from List 1. The first experiment focuses on two key facts: an e.m.f. is only produced when the wire is moving across the magnetic field – the faster the movement, the more e.m.f. is produced; and the e.m.f. is directional depending on the direction of motion. Learners are to move their wires through their magnetic fields, noting the direction and size of deflection on the galvanometer. They should investigate how first changing the speed of motion and second changing the direction affects their result. Finally ask learners to write a short paragraph or set of bullet points describing their findings. They should include in their description these key words: flux, flux cutting, induced e.m.f. and Faraday's Law. Extension activity: Learners can try to move their wires parallel to the lines of flux so there is no cutting (this is tricky to do) or try moving their wire at an angle. They should note their findings. **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.
20 min	Distribute equipment from List 2. Your learners should wrap their wire around the cardboard tube, taking care to keep coils as tight and neat as possible. They should make about 20 coils, neatly lined up against each other. The wire needs to be wrapped so that the ends are long enough to be connected to the galvanometer. They should note the direction and size of deflection on the galvanometer. Learners should investigate: changing the speed of motion, changing the direction (pushing in or pulling out), and how changing the pole of the magnet they introduce into the coil affects their result. Ask your learners to put the magnet inside the coil but not move it – what do they see?

Timings	Activity
	Your learners should add a further 10–15 coils and note the new result on the galvanometer. They should then add a further 10-15 coils and again note the new result. **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. Extension activity: Ask your learners to move the magnet into the coil very gently while concentrating on their fingers. They should be able to feel a ‘push’ back against them as the induced field inside the coil resists the movement. When complete, learners can write a short paragraph or set of bullet points describing their findings. They should include in their description these key words: flux, flux cutting, induced e.m.f., solenoid, Faraday’s Law (extension: Lenz’s Law).
	**Plenary** The groups should share their findings with the class and relate their experimental results to Faraday’s Law, and Lenz’s Law where extension work has been done.

Teacher notes

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

Each group will require:

List 1

- Moving coil centre-zero galvanometer
- Insulated copper wire (with bare ends)
- Magnadur magnets × 2
- Steel yoke

List 2

- Bar magnet
- Cardboard tube
- Insulated copper wire, bare ends, long enough to make up to 50 turns around the cardboard tube.

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.

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 number of large enough magnets you can provide
- the number of galvanometers you can provide

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. Learners need to set up their circuits according to their planned methods.	
4. Learners are to move their wires through their magnetic fields, noting the direction and size of deflection on the galvanometer. They should investigate how first changing the speed of motion and second changing the direction affects their result.	
5. Your learners should wrap their wire around the cardboard tube, taking care to keep coils as tight and neat as possible. They should make about 20 coils, neatly lined up against each other.	*When wrapping the coils learners must take care to keep them tight, neat and close up against each other. 'Sloppy' or messy coils give much poorer results.*
6. Learners should investigate: changing the speed of motion, changing the direction (pushing in or pulling out), and how changing the pole of the magnet they introduce into the coil affects their result.	

Clean-up

After the experiment learners should:
- break down circuits
- tidy up wires making sure none are coiled or knotted
- tidy up their work space
- return all equipment to the front of the room

Debriefing lesson: Induced e.m.f.

Resources	• Worksheet B

Learning objectives	By the end of the lesson: • ***all*** learners should recall methods of demonstrating induced e.m.f. • ***most*** learners should be able to apply knowledge in an exam situation. • ***some*** learners will be able to give a detailed description of experimental procedure.

Timings	Activity
5 min	**Starter / Introduction** Learners should produce a quick sketch of the experimental set up they used in the practical lesson.
40 min	**Main lesson** In pairs your learners should now work on the past paper question given in Worksheet B. Encourage them to use their reference materials and discuss their ideas.
15 min	**Plenary** Learners should exchange papers and continue to work in pairs, and mark each other's responses before returning the papers to the original pair.

Worksheets and answers

	Worksheet	Answers
For use in *Briefing lesson*:		
A: Poster template	**15**	
For use in *Debriefing lesson*:		
B: Past paper practice questions	**16**	**17–18**

Worksheet A: Poster template

This worksheet outlines what information should be on your posters. How you lay this work out is up to you, so draw out a plan first to decide how to use the space on your page.

A labelled diagram showing the magnetic field lines around a large horseshoe magnet. Make sure you include:

- labelled poles
- arrows on lines of flux
- the direction a negative charge would be moved in
- a note giving a definition of ‘lines of flux’.

A labelled diagram depicting the Left Hand Rule (LHR) including:

- a **clear title** explaining the situation where the LHR would be used
- what each finger (or thumb) is indicating
- a note reminding the reader that conventional current moves in the opposite direction to the electron flow
- what if the LHR was applied to an Electron Deflector or a particle accelerator – how would its use be changed?

A labelled diagram depicting the Right Hand Rule (RHR) including:

- a **clear title** explaining the situation where the RHR would be used
- what each finger (or thumb) is indicating
- a note reminding the reader that conventional current moves in the opposite direction to the electron flow.

Brief notes on Faraday’s Law.

Brief notes on Lenz’s Law.

A labelled diagram explaining the use of the Solenoid (or Right Hand Grip) Rule, showing information on the grip and poles.

Brief notes about the use of solenoids, and, if you are able, some uses of solenoids.

Worksheet B: Past paper practice questions

1. Which row shows an SI base quantity with its correct unit?

	SI Base quantity	unit
A	charge	coulomb
B	current	ampere
C	potential difference	volt
D	temperature	degree Celsius

2. Which of the following correctly expresses the volt in terms of SI base units?
    a. AΩ
    b. WA^{-1}
    c. $kg\ m^2\ s^{-1}\ A^{-1}$
    d. $kg\ m^2\ s^{-3}\ A^{-1}$

3. A thin card is inserted between two separate iron cores. A coil is wound around one core as shown in Fig. 1.1.

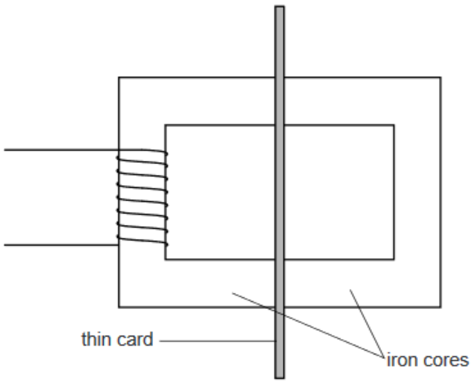

Fig. 1.1

A current in the coil may induce an e.m.f. in another coil wound on the other core. The induced e.m.f. *V* depends on the thickness *t* of the card.

A student suggests that

$V = V_0 e^{-\sigma t}$

Where V_0 is the induced e.m.f. without card between the cores and σ is a constant.

4. Design a laboratory experiment to test the relationship between *V* and *t* and determine the value of σ. You should draw a diagram, showing the relationship of the equipment. In your account you should pay particular attention to:
    a. the procedure to be followed
    b. the measurements to be taken
    c. the control of variables
    d. the analysis of the data
    e. the safety precautions to be taken.[15]

Worksheet B: Answers

1. Which row shows an SI base quantity with its correct unit?

	SI Base quantity	unit
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2. Which of the following correctly expresses the volt in terms of SI base units?
   a. AΩ
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   c. kg m^2 s^{-1} A^{-1}
   d. kg m^2 s^{-3} A^{-1}

3. A thin card is inserted between two separate iron cores. A coil is wound around one core as shown in Fig. 1.1.

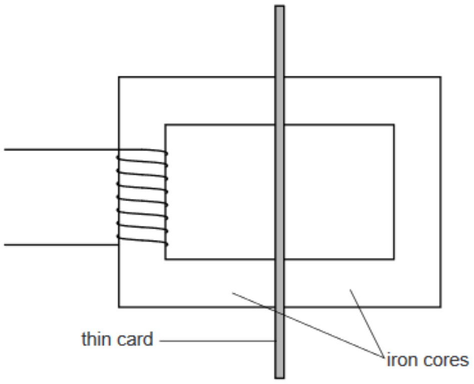

Fig. 1.1

A current in the coil may induce an e.m.f. in another coil wound on the other core. The induced e.m.f. *V* depends on the thickness *t* of the card.

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Worksheet B: Answers, continued

Defining the problem (3 marks)	
t is the independent variable or vary t	1
V is the dependent variable or measure V.	1
Keep the current (in the primary coil) **constant**.	1

Method of data collection (5 marks)	
Diagram showing **two** independent **labelled** coils wound on iron cores.	1
AC power supply / signal generator connected to one coil.	1
Voltmeter / oscilloscope connected to other coil in a workable circuit.	1
Measure thickness of card using micrometer / vernier callipers / digital callipers.	1
Method to keep current constant – rheostat (or variable power supply) **and** ammeter correctly positioned in primary circuit and explained. Diagram and text required.	1

Method of analysis (2 marks)	
Plot a graph of ln V against t (allow lg V against t) or ln V / V_0 against t	1
$\sigma = -$ gradient	1

Safety considerations (1 mark)	
Precaution linked to **hot coil(s)** e.g. switch off when not in use / do not touch / wear gloves.	1

Additional detail (4 marks)	
Relevant points might include Use large current (in primary coil) / large number of turns **on the secondary** to achieve measurable V (allow more turns on secondary than primary). Keep frequency of power supply **constant** or keep the number of turns on each coil **constant**. Use laminated cored or use insulated wire for turns. Repeat measurements of t and average. Measurement of V_0 stating that no card is present. Logarithmic equation: ln V = ln $V_0 - \sigma t$ Relationship is valid if the graph is a straight line with y-intercept = ln V_0 Discussion of compression of card / measure t when secured. Do not allow vague computer methods.	4

Total: 15 marks

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