Cambridge Assessment International Education

Teaching Pack

Investigating Stationary Waves

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.

↓

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.

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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: Standing waves

This *Teaching Pack* focuses on standing, or stationary, waves on a string or wire.

A string which is plucked and then allowed to vibrate will show resonance at certain frequencies. This means the amplitude of vibration is large. In stringed instruments the frequency of the vibration is heard as the pitch of the note being played.

By using a string held under tension and a vibration generator which can provide a range of frequencies, we can create measurable standing wave patterns in the laboratory.

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

- 7.1 Progressive waves
- 8.1 Stationary waves

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.

- 7.2 Transverse and longitudinal waves
- 7.1 Progressive waves

Briefing lesson: Superposition and standing waves

Resources	• A set of ***sterilised*** bottles or boiling tubes, filled to different levels with coloured water • Sterilising wipes • Large springs – 'slinkies' • Worksheet A

Learning objectives	By the end of the lesson: • ***all*** learners should be able to state the principle of superposition. • ***most*** learners should be able to describe the formation of nodes and antinodes. • ***some*** learners will be able to sketch the standing waves for fundamental frequencies.

Timings	Activity
10 min	**Starter / Introduction** Arrange on the benches a set of ***sterilised*** bottles or boiling tubes containing coloured water at different heights. Your learners are probably already familiar with the idea of blowing across the top of a bottle to make a musical note. Invite them to use the tubes containing water to create notes with different pitches. They should use the sterilising wipes so they can pass the bottles or tubes around. Ask your learners what is making the sound? Can they explain why the pitch is different in each one? If you are musical or have a learner who could help, you can actually tune the bottles by adding or removing water to produce a scale.
20 min 20 min	**Main lesson** Your learners will have already met the concept of superposition when talking about interference. Using the large spring, demonstrate the reflection of a pulse. To do this, one end of the spring needs to remain fixed. Then show learners how the superposition of two waves from coherent sources travelling in opposite directions can form a stationary wave. There are many examples of standing waves which can be seen online and these include waves produced in a tank. Some examples of videos you could show are: https://youtu.be/NpEevfOU4Z8 (a standing wave in water) https://youtu.be/9L9AOPxhZwY (wave on a guitar string) Introduce the idea of the standing wave including the fact that these can be produced on a string or in a column of air. Explain to your learners how these are formed. They will need to be familiar with the vocabulary of nodes and antinodes to move forward. Now start your learners off on the process of constructing standing wave patterns for themselves. Using Worksheet A they can start to develop their knowledge of standing waves on a string. The first two diagrams are drawn for them and they must complete the others. They should also complete the measurement of wavelength in terms of length of the string and find the value of frequency for each harmonic. At the end they are asked to deduce the mathematical relationship between f_n, v and L.
10 min	**Plenary** Ask your learners to share their deductions for the mathematical relationship between f_n, v and L. They should work together to identify any misconceptions and with your support ensure that they have the correct relationship.

Planning lesson: Standing waves

Resources	• *Standing waves* video • Mini whiteboards or equivalent

Learning objectives	By the end of the lesson: • ***all*** learners should be able to describe a simple demonstration of standing waves. • ***most*** learners should be able to predict changes to the wave shape. • ***some*** learners will be able to explain in terms of harmonics the points on the waves where nodes and antinodes appear.

Timings	Activity
5 min	**Starter / Introduction** Using mini-whiteboards do a fast review of the key vocabulary; frequency, amplitude, wavelength, node, antinode, standing wave, interference, harmonics.
20 min 10 min 15 min	**Main lesson** This experiment is called Melde's Experiment and your learners can research it online. In particular explain to them that this demonstration depends on the reflection of a wave, followed by superposition onto another wave with which it might be in phase, or antiphase. Tell your learners what equipment will be available to them, and ask them to start by sketching how they would set up the equipment to generate and investigate standing waves. Once your learners have the set-up on paper they should identify what measurements they will take. They should be able to infer that different frequencies from the signal generator – through the vibrator – will produce different wave patterns. Encourage your learners to mark onto their diagrams the measurements they will make and exactly the points they will measure between. Now they can go on to infer how to change the frequency of vibration to produce at least the first four harmonics (although often many more can be seen). They should now be ready to write a brief method. Your learners should also plan their table of results and predict the relationship they expect to see. They should also think about their experiment design and: • what factors will they keep the same throughout? • how will they ensure safety and reduce risk? Show your learners the *Standing waves* video. After watching it, they will be evaluating each other's plans. Learners should exchange books and evaluate each other's work. The success criteria they are looking for include a clearly labelled diagram, a brief method, an organised table of results and a prediction backed up by theory.
10 min	**Plenary** Learners return to their own work and make any corrections; encourage them to share ideas as they do this.

Lab lesson: Standing waves

Resources	• Equipment as outlined in the Teacher notes • Stroboscope if you have one (not essential) • *Teacher walkthrough* video

Learning objectives	By the end of the lesson: • ***all*** learners should be able to perform a simple demonstration of standing waves (Melde's Experiment). • ***most*** learners should be able to describe the standing wave forms seen. • ***some*** learners will be able to predict frequencies that will produce a standing wave.

Timings	Activity
5 min	**Starter / Introduction** Ask your learners the following questions: • How is a standing wave formed? • How does it differ from a progressive wave?
10 min 30 min	**Main lesson** Distribute the equipment to your learners and ensure they have plenty of space to set up. Depending on previous experience within the group you will probably need to demonstrate the correct usage of the signal generator as this can be confusing to connect. The vibration generator should be connected to the low-impedance sine wave output and the cord should be around 1 m long. Once you are sure your learners are comfortable with the equipment, let them set up their experiment. Ask them to alter the frequency until they find the first harmonic of their cord. Once your learners have the first harmonic they should note the frequency and take time to observe what they are seeing. The nodes are not immediately obvious, since they are the connecting points of the cord. The antinode creates an optical illusion which is likely to be new to them. If you have a stroboscope it is worth observing the effect in 'freeze frame'. If not then simply putting the end of a pencil into the 'hole' in the standing wave is often surprising, and worth doing. Discuss with learners that the reflected wave meets the outward wave in phase and so an area of maximum displacement is formed. Now learners should adjust the frequency until they find the second harmonic and note this frequency. This second standing wave is more unusual at first sight since there is a node in the centre. Again encourage learners to stop and observe carefully their standing wave. They can use either the stroboscope or pencil test again to test the 'hole' in between the antinodes, and the firmness of the central node. The node is caused by reflected waves from the pulley being in antiphase with the wave coming from the vibrator. From here ask learners to predict the next frequency rather than hunting for it, and to test their prediction by going straight to it. They should do this up to the fourth or fifth harmonic. Once the table of results is completed, ask them to check their numbers against the theory predicted in the last lesson. Can they now find the speed of their standing waves? **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.

Timings	Activity
	**Plenary** Learners seeing long chains of nodes and antinodes for the first time are often delighted by them and your group will enjoy presenting their findings to their peers. This is a good chance for them to look again at the wave in terms of it being a reflection which may be in phase or antiphase.
	Learners can dismantle their equipment and clear away.

Teacher notes

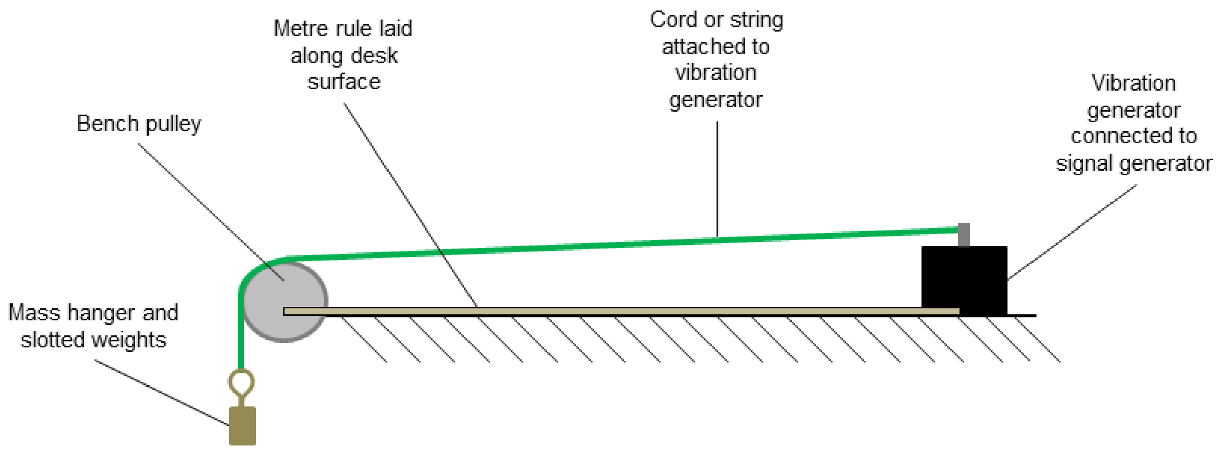
Watch the *Teacher walkthrough* video and read these notes.

Each group will require:
- Elastic cord
- Bench pulley
- Mass hanger
- Slotted masses 10 × 10 g
- Vibration generator
- Signal generator
- Leads
- Metre rule
- Dark coloured background

Safety
- Wear a lab coat and eye protection.
- No eating or drinking in the lab.
- Check the electrical equipment before use.

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
- the amount of space required as each set-up may occupy up to two metres of desk space.

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. They will need about 1m of cord.	
3. Make sure your learners can switch on the equipment they are using and can use the vibrator and signal generator	*Demonstrate setting these up if they find it difficult.*
4. Your learners should follow their methods and collect the necessary data relating to the formation of standing waves.	

Clean-up

After the experiment learners should:

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

Debriefing lesson: Standing waves in practice

Resources	• graph paper • Worksheet B and Worksheet C

Learning objectives	By the end of the lesson: • ***all*** learners should be able to use a graphical method to explain stationary waves. • ***most*** learners should be able to produce patterns of odd harmonics in a closed tube of air. • ***some*** learners will be able to describe how the speed of sound can be measured using stationary waves.

Timings	Activity
5 min	**Starter / Introduction** Ask your learners to name some musical instruments which use standing waves to produce notes.
15 min 15 min 15 min	**Main lesson** Your learners should produce on graph paper a set of diagrams to explain, the superposition of waves in phase and antiphase. Your learners should appreciate that the patterns their graphs predict match those they saw in the investigation. The investigation looked at standing waves on strings, but standing waves are also produced in a column of air (as seen with the demonstration in the briefing lesson). The stationary wave in the air can't be seen, but it can be demonstrated. Show your learners this video, https://youtu.be/qUiB_zd9M0k, where a Kundt tube containing small spheres of polystyrene is used to visualise the wave. Your learners should work on constructing a set of diagrams showing the harmonics in a column of air, using Worksheet B as their guide. The frequencies and predictable wavelengths of stationary waves can be used to measure the speed of sound in air. This investigation is illustrated in Worksheet C. You can talk to your learners about this, or you may wish to demonstrate it or show them the video at https://youtu.be/lEq-ShFTAbY Using the diagram on the worksheet and following the video link or demonstration, ask your learners to predict the positions of resonance for tuning forks of different frequencies, for example, 512 Hz (C), 488Hz (A), 433 Hz (B).
10 min	**Plenary** A game of hot seat. Every learner must write down three questions with the correct answers for each. Choose a learner to start off in the hot seat. They are asked a question from the selection your learners have prepared. A correct answer means they are asked another question. A wrong answer means the person asking the question then takes up the hot seat, and they are asked a new question. Three correct answers in a row wins a reward. Great for reinforcing learning of new vocabulary.

Worksheets and answers

	Worksheet	Answers
For use in *Briefing lesson*:		
A: Standing waves on strings	**14**	**17**
For use in *Debriefing lesson:*		
B: Standing waves in air	**15**	**18**
C: Finding the speed of sound in air	**16**	

Worksheet A: Standing waves on strings

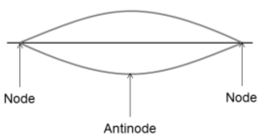
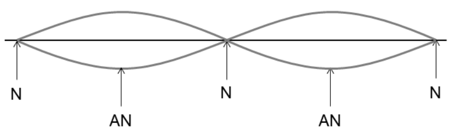
Standing waves are produced between two fixed points. At certain frequencies, sometimes called natural frequencies, a distinct waveform will appear with **nodes** (areas of **no** disturbance) and **antinodes** (areas with maximum disturbance of amplitude). You are going to sketch these frequencies, which are also called **harmonics** and complete the calculations for wavelength and frequency.

The Fundamental Frequency

The fundamental frequency is annotated as f_0, and is also called the first harmonic. Within the length, L, between the nodes, there is one half of a wavelength.

Therefore for this frequency we can say that $\lambda = 2L$. Using the wave equation, $v = f\lambda$, that means we can now say that $f_0 = \frac{v}{2L}$.

Complete the table below with the missing diagrams and information.

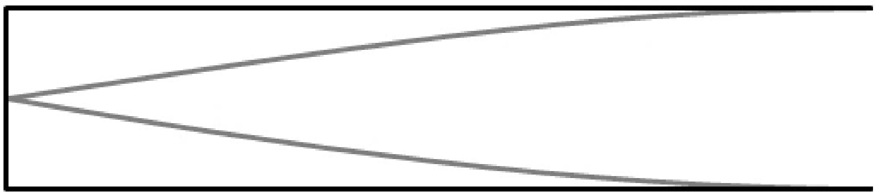
Diagram	Characteristics
	Fundamental frequency / First harmonic $\lambda = 2L$ $f_1 = \frac{v}{2L}$
	First overtone / Second harmonic $\lambda = L$ $f_2 =$ …………….
	Second overtone / Third harmonic $\lambda =$ ……………. $f_3 =$ ……………
	Third overtone / Fourth harmonic $\lambda =$ ……………. $f_4 =$ ……………

A mathematical relationship is building up which relates f_n, the frequency of the nth ***harmonic*** with v and L. Can you work out what it is?

Worksheet B: Standing waves in air

Use the spaces provided to construct diagrams to show how harmonics in a column of air form.

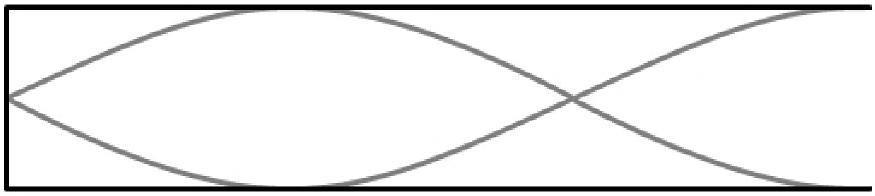
Note, there is always a **node** at the closed end, and an **antinode** at the open end of the column.



Fundamental: first harmonic

$$L = \frac{1}{4}\lambda$$

$$f_0 = \frac{v_{air}}{4L}$$



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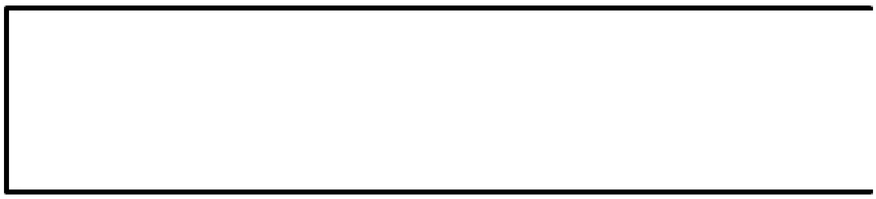
$$L = \frac{3}{4}\lambda$$

$$3f_1 =$$

Continue to construct the harmonics in a column of air.



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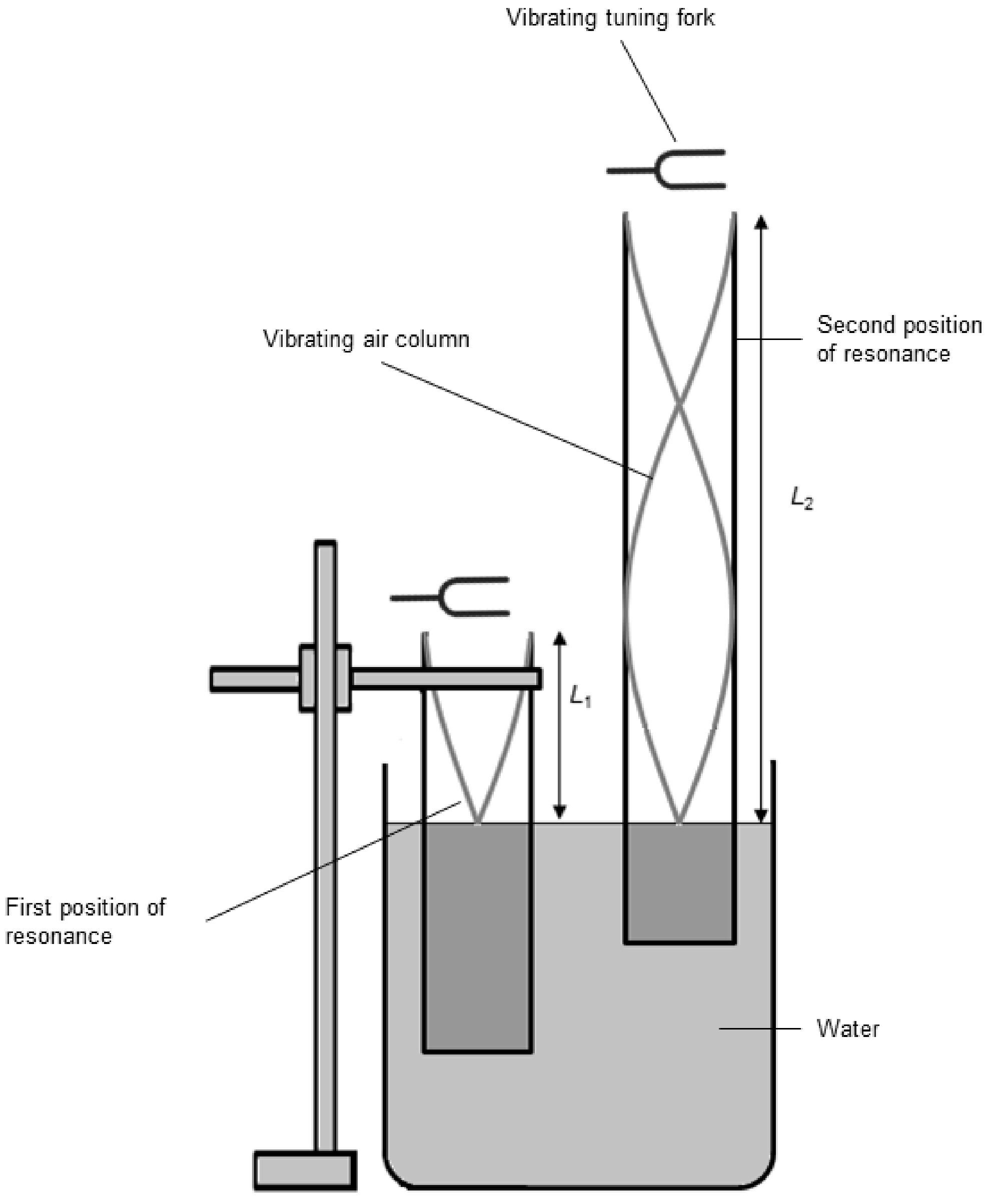
Why are there no even numbered harmonics?

Worksheet C: Finding the speed of sound in air

The equipment set-up shown demonstrates how you might use the position of resonance to calculate the speed of sound in air.



Worksheet A: Answers

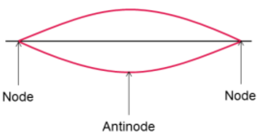
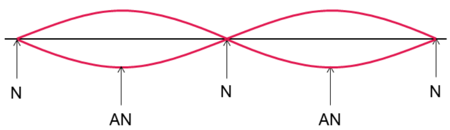
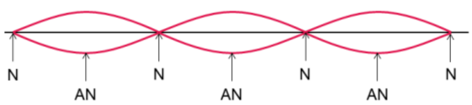
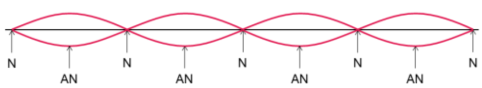
Standing waves are produced between two fixed points. At certain frequencies, sometimes called natural frequencies, a distinct waveform will appear with **nodes** (areas of **no** disturbance) and **antinodes** (areas with maximum disturbance of amplitude). You are going to sketch these frequencies, which are also called **harmonics** and complete the calculations for wavelength and frequency.

The Fundamental Frequency

The fundamental frequency is annotated as f_0, and is also called the first harmonic. Within the length, L, between the nodes, there is one half of a wavelength.

Therefore for this frequency we can say that $\lambda = 2L$. Using the wave equation, $v = f\lambda$, that means we can now say that $f_0 = \frac{v}{2L}$.

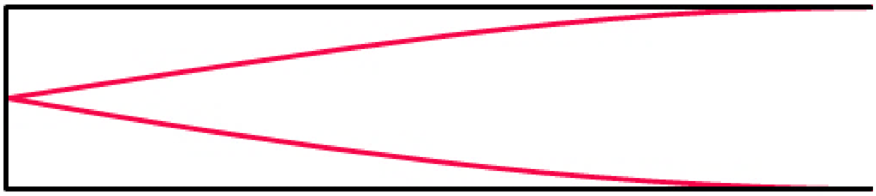
Complete the table below with the missing diagrams and information.

Diagram	Characteristics
	Fundamental frequency / First harmonic $\lambda = 2L$ $f_1 = \frac{v}{2L}$
	First overtone / Second harmonic $\lambda = L$ $f_2 = \frac{v}{L}$
	Second overtone / Third harmonic $\lambda = \frac{2L}{3}$ $f_3 = \frac{3v}{2L}$
	Third overtone / Fourth harmonic $\lambda = \frac{L}{2}$ $f_4 = \frac{2v}{L}$

A mathematical relationship is building up which relates f_n, the frequency of the nth ***harmonic*** with v and L. Can you work out what it is? $\boldsymbol{f_n = \frac{nv}{2L}}$

Worksheet B: Answers

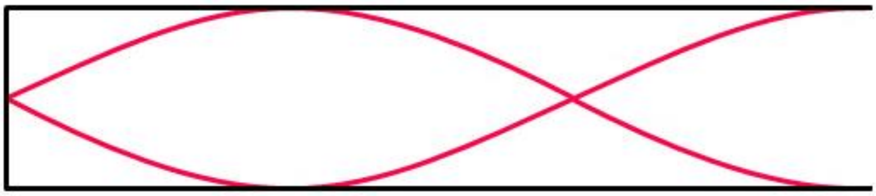
Note, there is always a **node** at the closed end, and an **antinode** at the open end of the column.



Fundamental: first harmonic

$$L = \frac{1}{4}\lambda$$

$$f_0 = \frac{v_{air}}{4L}$$

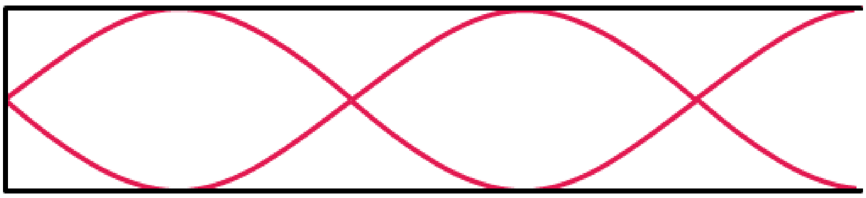


Third harmonic

$$L = \frac{3}{4}\lambda$$

$$3f_0 = \frac{3v}{4L}$$

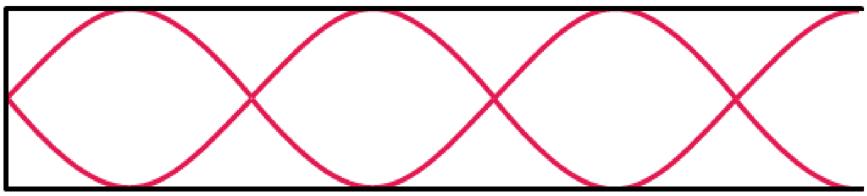
Continue to construct the harmonics in a column of air.



Fifth harmonic

$$L = \frac{5}{4}\lambda$$

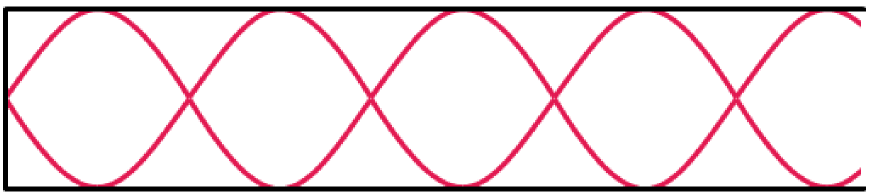
$$5f_0 = \frac{5v}{4L}$$



Seventh harmonic

$$L = \frac{7}{4}\lambda$$

$$7f_0 = \frac{7v}{4L}$$



Ninth harmonic

$$L = \frac{9}{4}\lambda$$

$$9f_0 = \frac{9v}{4L}$$

Why are there no even numbered harmonics?

The closed end forces a node at one end of the wave, while the open end must be a antinode. This means waves must always be multiples of one quarter wavelength

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