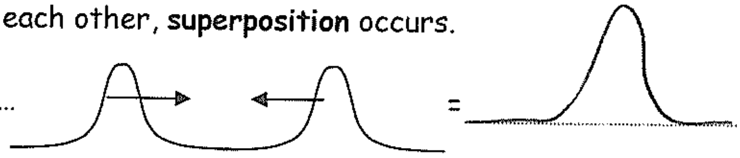
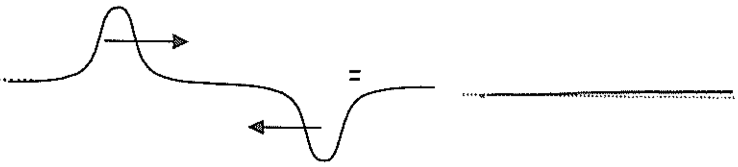
# Standing Waves

When two waves pass through each other, **superposition** occurs.

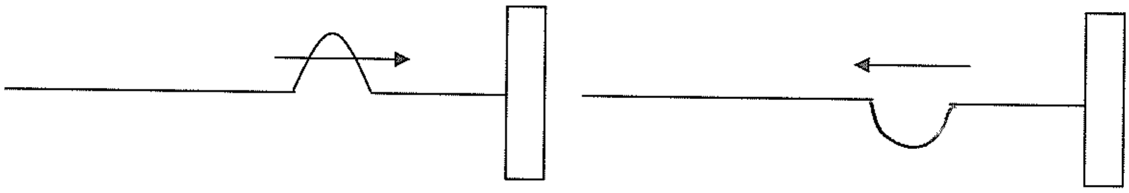
Crest + Crest = big crest



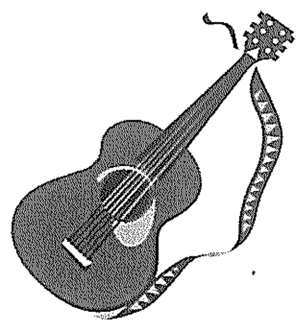
Crest + Trough = zero



When a wave reflects off a solid boundary it comes back inverted

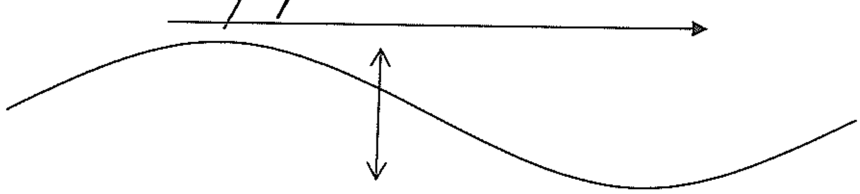


## Transverse Standing Waves

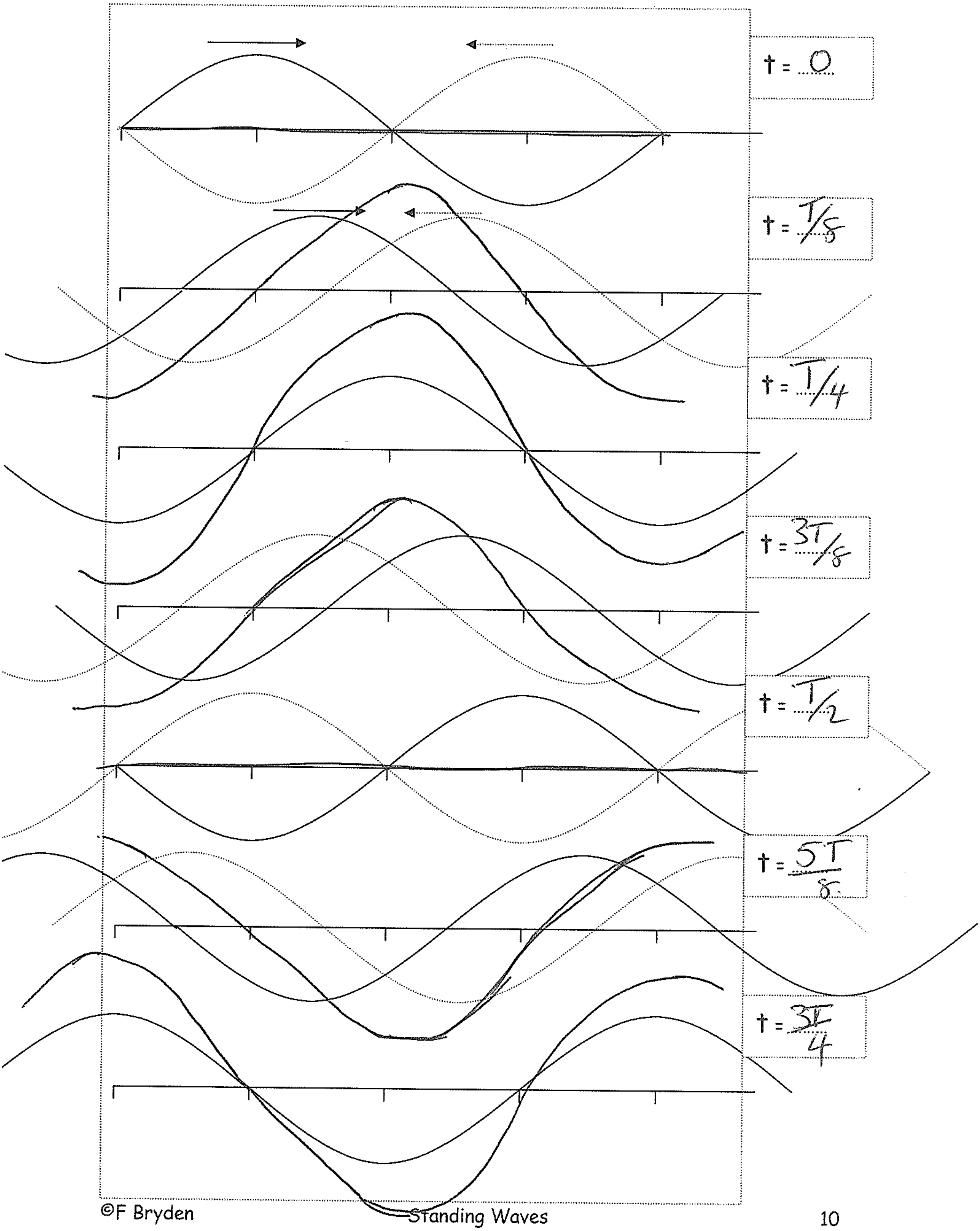


Both these effects occur in a string instrument to produce a **standing wave.**
If a sting is plucked, two positive pulses travel in opposite directions, reflect inverted (negative pulse), and superimpose in the middle to form a large negative amplitude. They keep going, reflect inverted (positive pulse) and superimpose to form a large positive amplitude.

This is called a standing or stationary wave. It is formed by two travelling waves, but looks as if the wave is not moving. The standing wave is transverse because the string vibrates perpendicular to the direction the wave is travelling.



Draw the resultant of the two waves travelling in opposite directions.

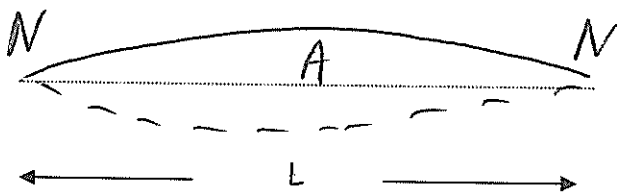


There are places where the amplitude is always zero, called ..nodes.......... and places where the amplitude is always maximum called ..antinodes......... (or not nodes).

(n.b. we are talking **amplitude** , not **displacement**. The displacement is sometimes zero at an antinode.)

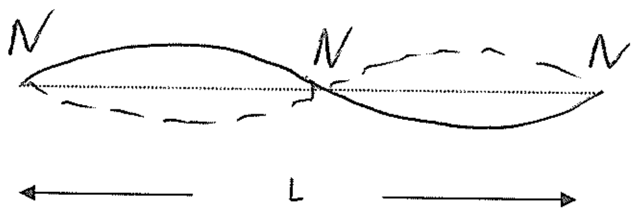
You can see the same thing when you wiggle the end of a spring. If you send a wave along just as the previous one arrives back, they add to give a ..standing...... wave.

There are different possible modes of vibration:
The lowest frequency standing wave is called the ..fundamental.. or 1st ..harmonic..
(Draw the standing waves, label nodes and antinodes.)



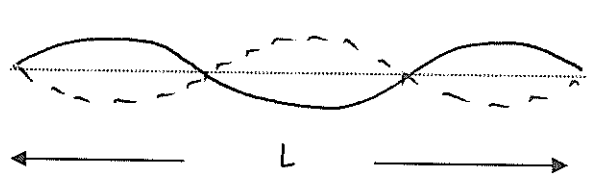

wavelength = ..2.. x L

frequency = $f_1$




wavelength = ..1.. x L

frequency = ..2.. x $f_1$




wavelength = ..1.5.. x L

frequency = ..3.. x $f_1$

nb in a string instrument, both ends must be fixed (closed/closed) to keep it under t..ension.... The ends are therefore always ..nodes........

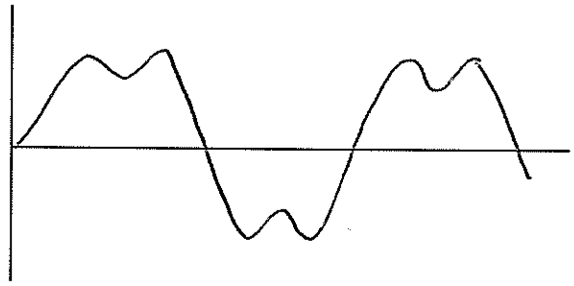
Experiment Note. Use a stretched string between two people. Then use a signal generator and a speaker or vibrator attached to a 1m elastic.

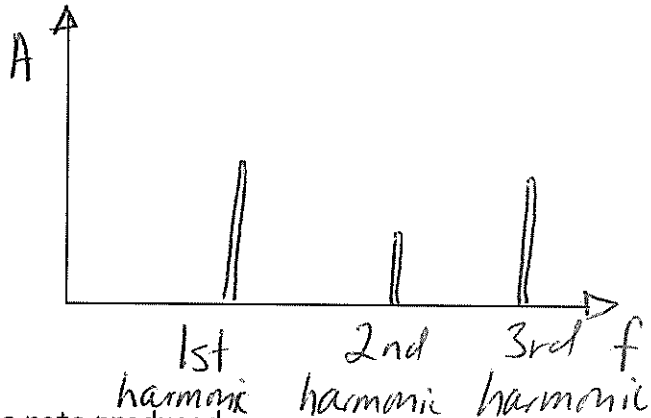
## Harmonics

How can you tell the difference between a guitar playing "C" and a piano playing "C"?

If you analyse the frequencies produced by an instrument you find the complex note is a mixture of different sine waves added together. When you pluck a guitar string, it doesn't just vibrate in the fundamental mode, but also vibrates at many different harmonics. The sounding box will amplify some of these harmonics more than others, and the characteristic sound produced is the total of all the different harmonics added together.

Sketch a graph of the sound wave from a guitar, and a bar graph showing the loudness of the harmonics.






## Frequency of a Vibrating String.

A guitarist and the manufacturer can alter the note produced.

*What determines the frequency of vibration of a string?*

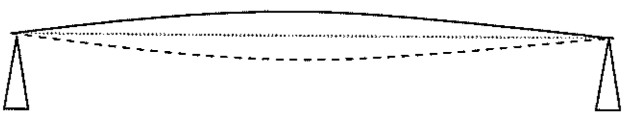
The frequency of vibration depends on three things.

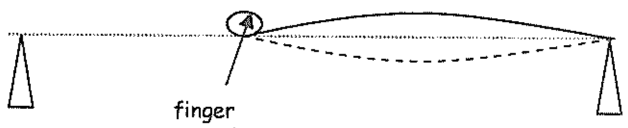
1) mass/length Set by the manufacturer
2) tension Set by the guitarist before playing (or varied while playing)
3) length Adjusted during playing

The frequency of vibration depends on how fast a wave travels to the end and back. The less time it takes, the ...higher... the frequency. *(t= d/v)*

The time it takes depends on the distance (string ...length...) and the ...speed

The guitarist changes the distance travelled by the wave by putting their fingers on the frets.






Experiment Note. Various sound analysis programs or Vernier "Logger Pro" can be used to analyse sound waves

The speed of a wave on a string is given by:

$$v = \sqrt{\frac{T}{\rho}}$$

T = tension Waves travel faster on a ....tight.... string

ρ = mass per metre Waves travel faster on a ....light.... string

*Explain how the sound of a guitar would change if it warmed up while playing.*

metal string expands, tension reduces, speed of wave reduces, frequency reduces

The frequency of the 1st harmonic is given by:

$$f = \frac{v}{\lambda} \qquad v = \sqrt{\frac{T}{\rho}} \qquad \lambda = 2L$$

$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{\rho}}$$

Explain how this equation supports your prediction about the three factors on the previous page.

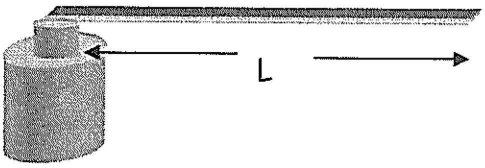
f increases as T increases
f decreases as L increases
f decreases as ρ increases

Summary: The frequency can be increased by:

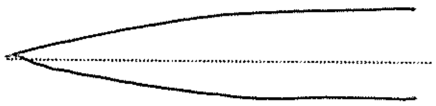
decreasing...... the length
decreasing...... the linear density (mass per metre)
increasing...... the tension

We said before that all string instruments were closed/closed. We can produce closed/open transverse waves. The wave travels to the end, reflects off the open end and travels back. If the closed end is vibrated with a period equal to the travelling time for the wave, a standing wave is set up.

Experiment Note: Wave speed can be shown using two springs of different linear density. (Get a snaky and overstretch it to make a light spring). Then two identical springs with different tension.



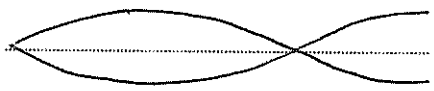

Draw the first mode of vibration:



frequency = .............. = f1 (1st harmonic)

wavelength = 4 L

Draw the next mode of vibration:



frequency = .............. = 3 x f1(3rd harmonic)

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

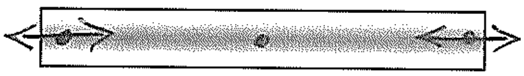
nb in a closed open standing wave, you can't get a 2nd harmonic (or any even harmonics)

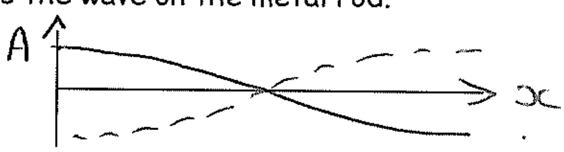
## Longitudinal Travelling Waves

The waves on a string instrument are transverse because the string moves perpendicula to the length of the string.

If you stroke a metal rod, you can set up a longitudinal standing wave, the metal vibrates in Same direction as the wave on the metal rod.

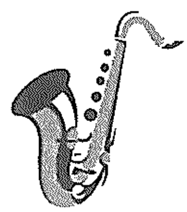
e.g.






## Wind Instruments

A similar thing happens in an air column. If you blow across the end of pipe, it causes a wave to travel down to the end and reflect back. This combines with the next wave to create a Standing wave. The air in the tube will resonate at certain frequencies. The air particles vibrate in the same direction as the wave travels, so this is a longitudinal standing wave



There are two types of wind instrument.

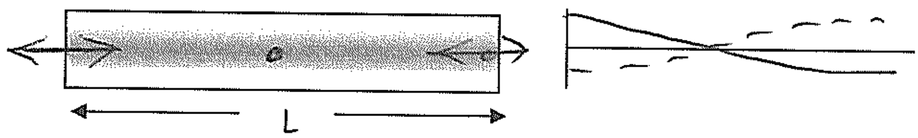
Open /closed eg flute (pan)

and open / open eg recorder

Experiment Note – use an aluminium bar from a retort stand. Rub it with rosin (see music dept). Hold it in the middle & stroke towards one end.

## Open/open tube

A standing wave can be set up in a tube like this. Draw the first diagram showing the vibration of the air particles and the second showing the amplitude at different positions.

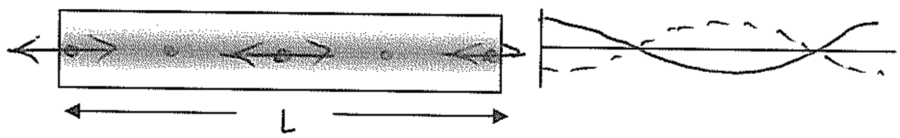



1st harmonic

frequency = ........= f1

wavelength = 2L

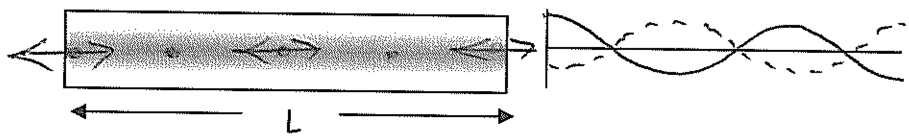
Just like a string, the air column at have different frequency standing waves or harmonics.




2nd harmonic

frequency = ........= ...... x f1

wavelength = L




........... harmonic

frequency = ........= ...... x f1

wavelength =..............

nb we draw arrows to show the motion of the air particles in the tube.

nb for simplicity we draw a displacement/position graph for the standing wave, but it's important to realise that the standing wave in the tube is longitudinal.

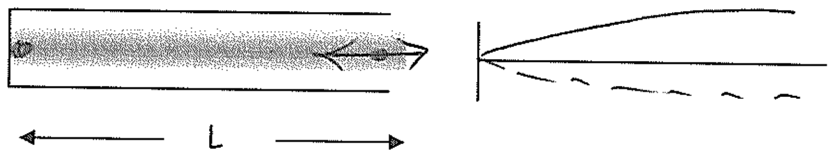
nb in a open/open tube, all harmonics are present.

Experiment note

See the Experiment book teachers guide for details of air resonance tube

## Open/Closed Tube

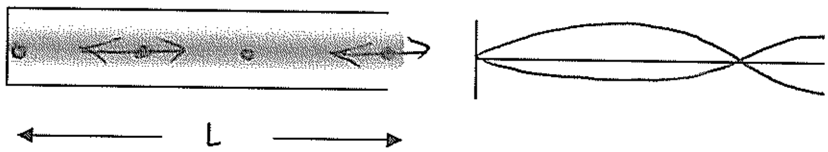
The same thing can happen in an open/closed tube.




1st harmonic

frequency = 1 = 1 x f1

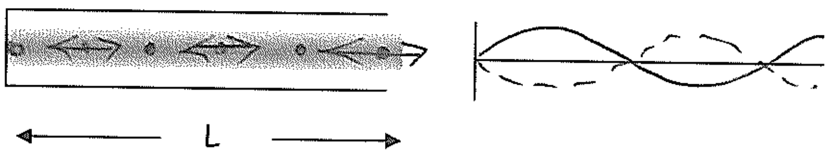
wavelength = 4L




3rd harmonic

frequency = 3 = 3 x f1

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




5th harmonic

frequency = ......... = 5 x f1

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

nb in an open/closed only Odd numbered harmonics are present.

*Explain way a flute playing "C" sounds different to a clarinet.*

They produce the same frequency harmonics but the harmonics have different loudness, when these are combined, the instruments sound different.

## Frequency of Wind Instruments

Just like for a string instrument, the frequency produced depends on the time it takes for the wave to travel down and back a tube. *(t = d/v)*

This depends on two things:

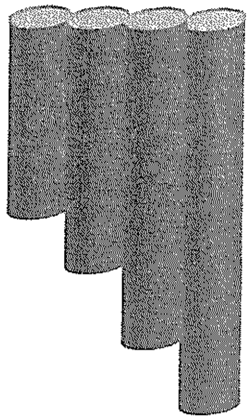
1) tube length

2) wave speed

The speed of the wave depends on the temperature. The musician can't control this.

The effective length of a wind instrument can be changed in different ways.

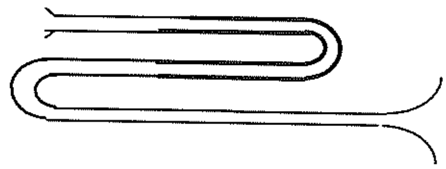
(1) Different length pipes:



e.g pan flute

organ

(2) One pipe with a slide to change the length.

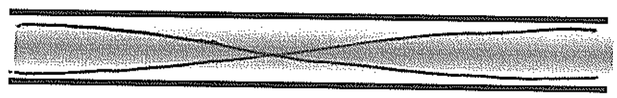


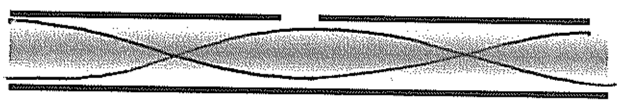
e.g trombone

(3) One pipe with holes.

e.g. recorder

Draw the standing wave for the pipes. Explain what happens to the note.





opening a hole creates an antinode there.

*Extension:*

*The standing waves we have looked at have been all one dimensional. You can also get two dimensional standing waves, e.g.* drum skin*, and three dimensional standing waves e.g.* microwave oven*. They are much more complex, but follow the basic rule that nodes are* ½ a wavelength *apart.*

*We can use this to calculate the speed of light (or microwaves)*

*Explain what we did*