Examples.

(1) A guitar string has a wave speed of 300ms^{-1} and produces a 1st harmonic of 220Hz.

(i) How long is it?

$l = 0.68\ m$

(ii) What length would it need to be to produce a note of 400Hz?

$l = 0.375\ m$

(iii) Explain why a thicker string of the same length and tension produces a different note.

linear density is higher ∴ mass is greater ∴ acceleration is smaller ∴ frequency is lower

(iv) Explain how a guitarist can produce a variation in frequency from a fixed length string.

Change length. This increases time for wave to travel down & back. This changes frequency.

(2) A 0.25m open closed tube produces a fundamental frequency of 340~~ms^{-1}~~. Hz
Calculate the speed of sound in the tube.

$V = 340\ ms^{-1}$

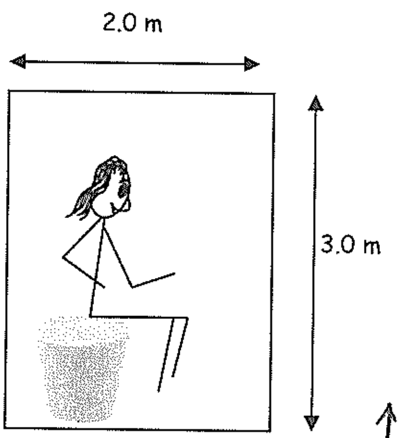
(ii) The end is removed, what is the new fundamental frequency?

680 Hz

(iii) The antinode is actually slightly outside the tube. How would this affect your calculated speed?

λ longer $V = f\lambda$ so V higher.

(3)



Jane is sitting in the toilet singing. She notices some notes are louder than others. 55hz is loud. Explain why, and calculate the next loud frequencies. (Vsound = 330ms^{-1})

↕ $f = \frac{330}{6} = 55Hz \sim 110Hz$

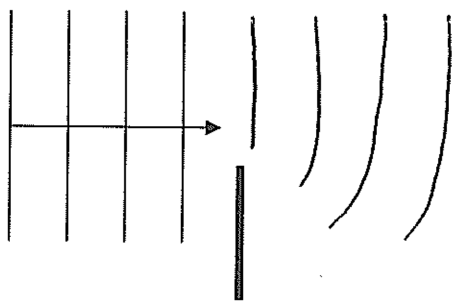
↕ ↔ $f = \frac{330}{4} = 83Hz \sim 165Hz$

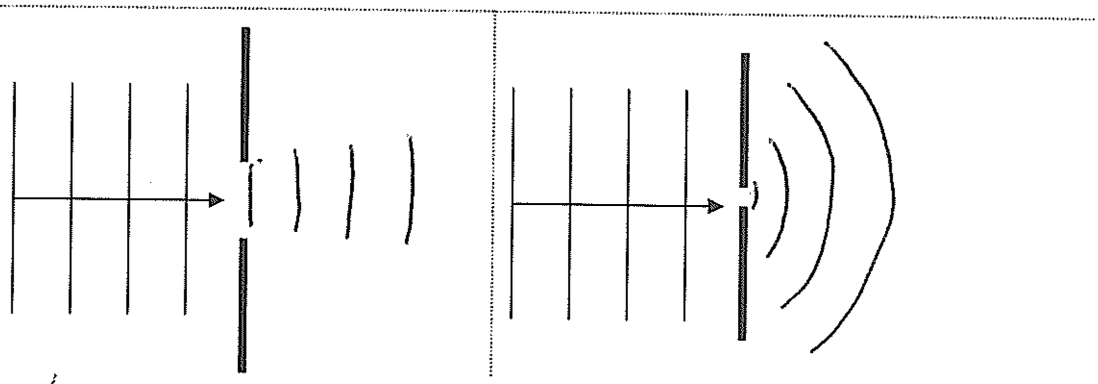
Diffraction and Interference

In this section we look at what happens to waves when they meet a barrier and then what happens when they meet and overlap.

Diffraction

Observe or recall waves in the ripple tank.

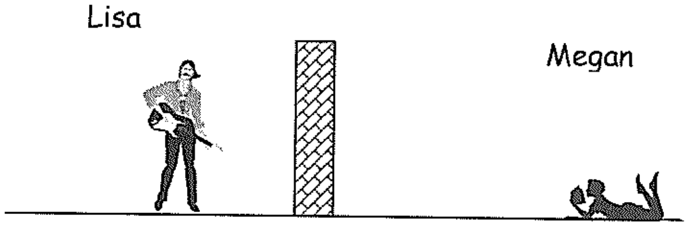




Waves ...bend... or ...diffract... after passing barriers. The amount of diffraction depends on the ...wavelength... Long wavelength waves diffract ...more... than short wavelengths. Diffraction through a gap also depends on ...gap... size. Smaller gaps produce ...more... diffraction. Diffraction only occurs when the gap width is a similar size or smaller than the wavelength

Does the same thing happen with light????

eg



Megan can hear the bass louder than the treble, and can't see Lisa. *Explain why*

bass – longer λ more diffraction

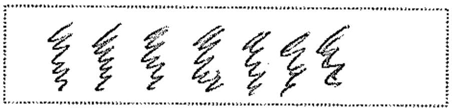
light – short λ – very little diffraction

Diffraction of Light

Shine light through a single narrow slit onto a screen. The light *spreads out*. This is called *diffraction*. As the slit gets narrower, the light *diffracts more*. The slit must be very *small* compared with the wavelength.

Double Slit Interference

Let's look at interference of light from two slits. *Try looking at a bright light through a double slit with a small separation.*

Observation: 

Now try shining a laser beam through a double slit onto a screen.

Observation: 

Because light produces an interference pattern it indicates it has *wave* properties.

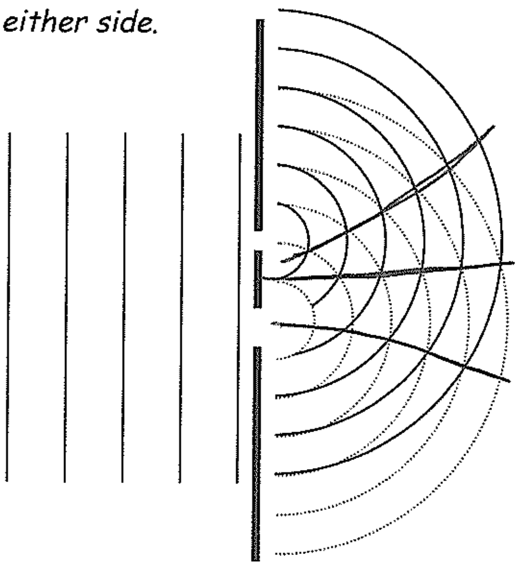
The weird thing, is that where you see no light between the bright fringes, it's actually *two* beams arriving from the two slits, but they are *out of phase* so they *cancel* and produce *darkness*.

Waves add **constructively** when they are *in* phase (crest plus *crest*) The point is called a *ntinode*.

Waves add **destructively** when they are *out of phase* (crest plus *trough*) The point is called a *node*.

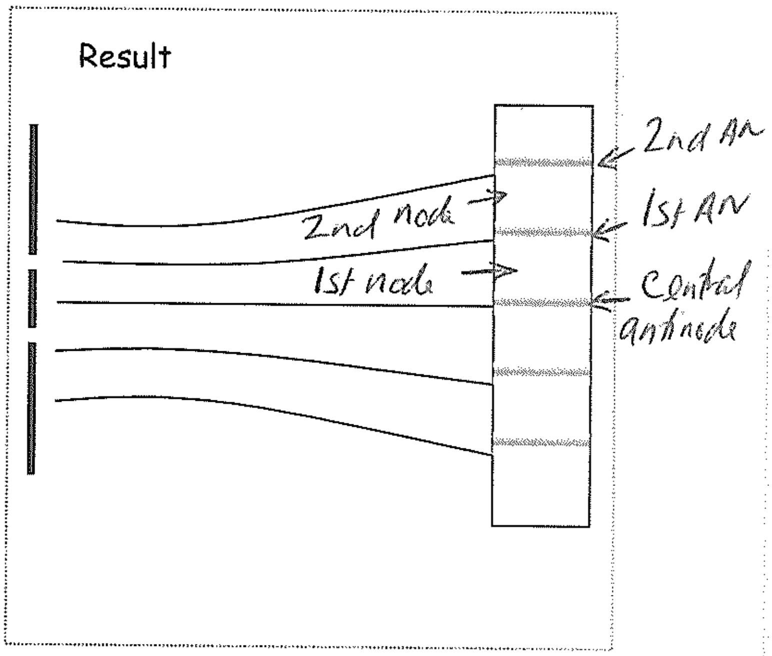
Draw lines showing the central antinode, and one antinode either side.

Experiment Note
Use a laser pointer and single/double slits



Inteference

Label the diagram:



As the waves pass through the gaps they ......diffract........, and then overlap.
Because of the extra distance waves travel from one gap compared with the other, (called ...path...... ...difference), the two waves arrive at a point...

in phase causing ...Constructive...... interference (...antinode...........) or

out of phase causing ...destructive........ interference (....node...................)

When the path difference is 0 or λ or 2λ or 3λ ...... you get antinodes...............

When the path difference is $\lambda/2$ or $3\lambda/2$ or $5\lambda/2$ ...... you get a ...node............

What happens to the pattern if:

The sources are moved closer?

pattern spreads out

The wavelength is decreased?

pattern gets closer

What would happen to the pattern if the sources were out of phase by 180^0?

pattern reverses

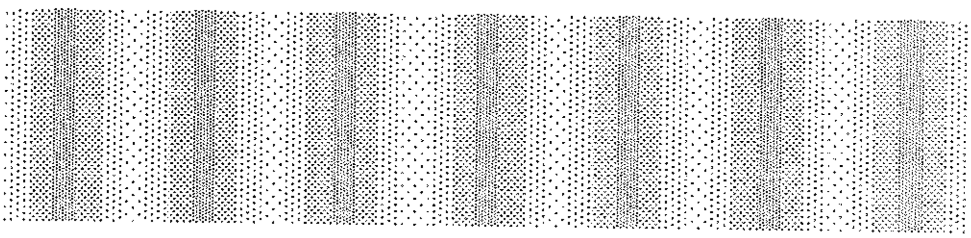
Write an equation for the path difference to the nth node and the nth antinode.

$pd = n\lambda$ $\qquad$ $pd = (n+\frac{1}{2})\lambda$ $\qquad$ $(n = 0, 1, 2 \ldots)$

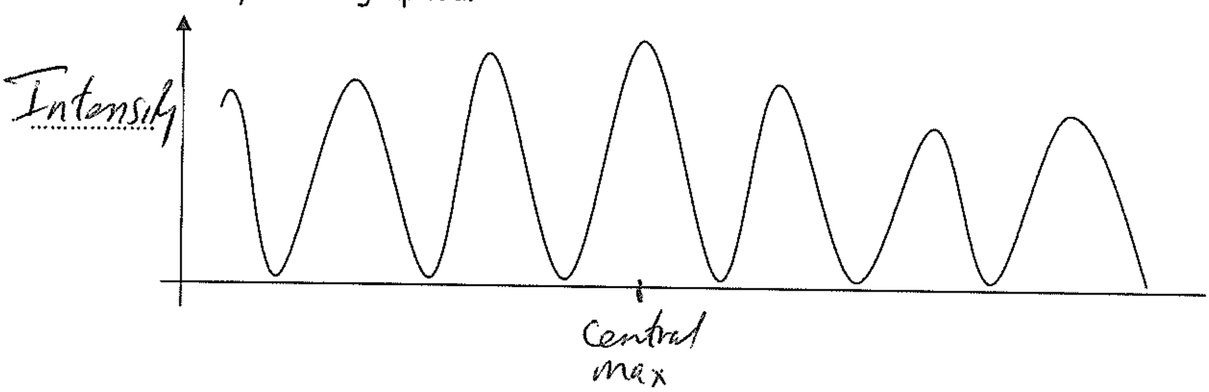
To get an interference pattern, the slit separation must be small compared with the wavelength, but not smaller than the wavelength. (In this case they act as one source). The waves must be coherent and have the same wavelength.

Interference Pattern Graphs.

An Interference Pattern formed by a double slit looks something like this:
Label bright and dark lines:

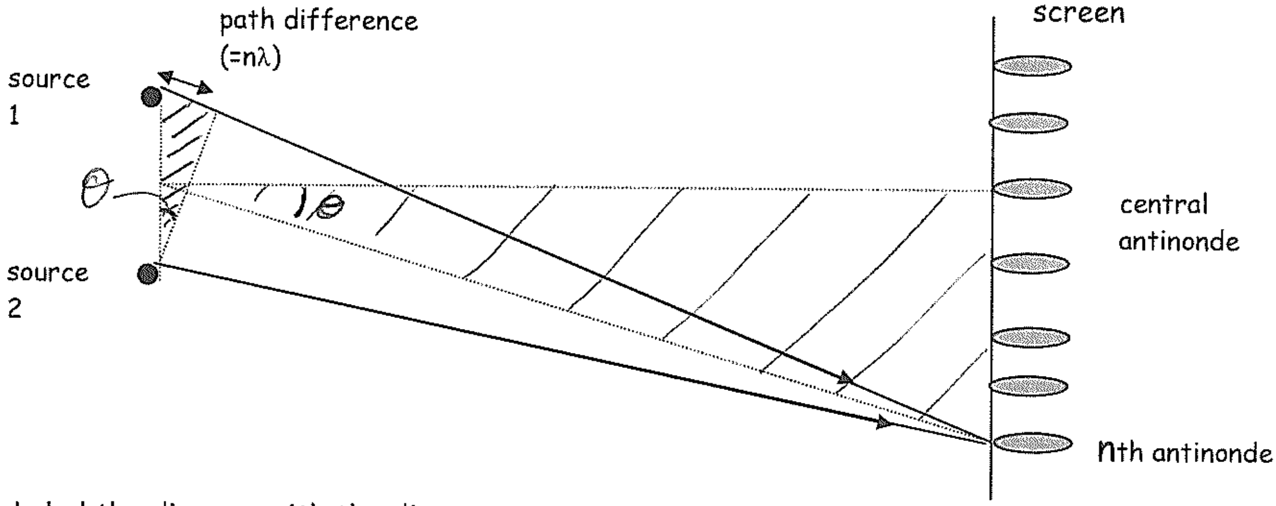


The intensity can be graphed.



Young's Equation

We will now work out an equation we can use to calculate the wavelength.



Label the diagram with the distances:
L = slits to screen
x = distance between antinodes
d = distance between centres of the slits.
θ = angle between central antinodal line and the nth antinodal line.

Shade the large right angle triangle.

$\tan\theta = \frac{nx}{L}$

for small angles, $\tan\theta = \sin\theta$

$\frac{nx}{L} = \frac{n\lambda}{d}$

Shade the small right angle triangle.

$\sin\theta = \frac{n\lambda}{d}$

so, $\lambda = \frac{dx}{L}$ $\quad n\lambda = \frac{dx}{L}$ for nth antinode

Both of these equations are useful, but the second one is only for when θ is small.

nb. n is the antinode number (1st, 2nd, 3rd......) or the ......order...... number.

Use the first equation to explain what happens to the interference pattern when the wavelength and slit separation is changed.

λ increases ∴ θ increases ∴ pattern spreads
d " ∴ θ decrease ∴ pattern compresses

Ex 1 A chemist wants to measure the wavelength of light produced by an incandescent gas. She passes the light through a double slit, (sepn, 0.10mm) and measures the angle between the central and first antinodes to be 15°. Calculate the wavelength.

Ex 2 A supermarket checkout operator wants to measure the wavelength of her bar code reader. She passes the light through a double slit (sepn, 0.15mm) and sees an interference pattern on the wall 2.0m away. The bright fringes are 5.0mm apart.
Calculate the laser's wavelength.

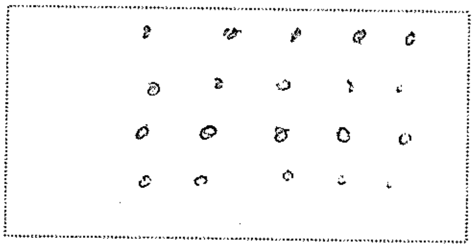
$\lambda = 750\,nm = 7.5 \times 10^{-7}\,m$

Extension: a student shines two lasers (450nm and 650nm) through a double slit. She notices the first antinode for the short wavelength light is at an angle of 5.0°. At what angle is the second antinode for the long wavelength?

$\theta = 14.6°$

Explain what you would see if you shine a laser through a ***fine gauze.***

Actual Result



Explain:

Gauze has a two dimensional array of holes. This produces a two dimensional interference pattern.

Diffraction Gratings

The double slit has three problems.
The fringes produced are not very ....bright.... or ....well defined.... or ....spread out....

Diffraction gratings can overcome these. A diffraction grating comprises heaps of ....slits...., really ....close.... ....together....

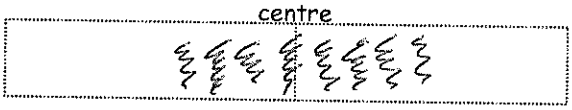
A typical diffraction grating might have 600 lines/mm!! or ....600 000.... lines/m

Shine the laser through a double slit then through two different gratings.

Observations:

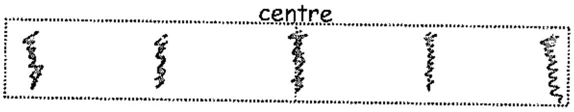
double slit

centre



100 lines/mm

centre



300 lines/mm

centre

Experiment Note Diffraction gratings are available with different numbers of slits/mm

First of all, we notice that with the diffraction grating, the pattern is

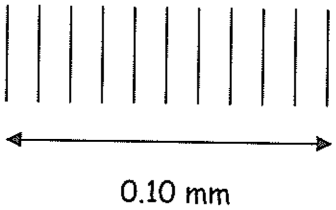
brighter .... because .... more slits = more light

more spread .... because .... slits are closer ($\sin\theta = \frac{n\lambda}{d}$)

more defined .... because .... more slits

The previous equations can still be used for diffraction gratings. The only tricky bit is that the **slit separation** isn't given, you are given the **number of lines per mm** or per m.

This diagram represents some of the slits in a diffraction grating



In this example, there are ....10.... slit spaces in 1mm, so t he slits are $\frac{1}{10}$ mm apart.

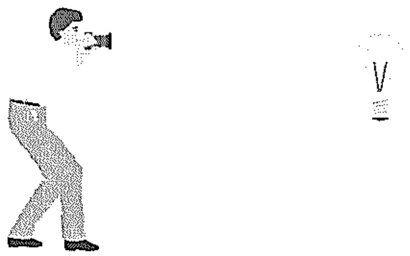
i.e the slit separation is x= $\frac{1}{N}$

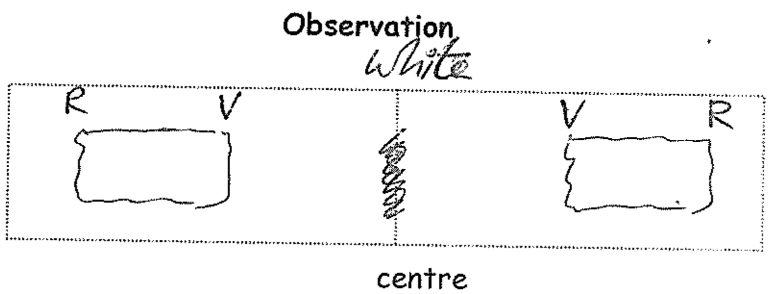
e.g Red light (λ= 650nm) strikes a diffraction grating with 500 lines/mm. Calculate the angle of the first antinode and the first node (from the centre.)

1st antinode $\theta = 19°$

White Light and Diffraction Gratings.

Now for a really beautiful experiment. Look at a white lamp through a diffraction grating.





You can see that the central antinode is ....White.... because all the colours (or ....wavelengths....) have their central antinode there.

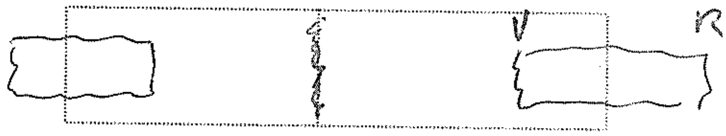
Explain why a spread out spectrum is produced at each antinode. (hint sinθ = $\frac{n\lambda}{d}$ *)*

different colours have different wavelengths + thus have their 1st antinode at different angles

What would you expect to see if a grating with a larger number of lines/mm were used?

Prediction

Actual Result



Explain why.

$\sin\theta = \frac{n\lambda}{d}$ so as d decreases θ will increase

Ex White light shines through a grating. The red light(700nm) forms an antinode at 18⁰.
(i) Calculate the grating spacing and the no. of lines/mm.

$d = 2.3 \times 10^{-6}$ m   442 lines/mm

(ii) At what angle does blue light (450nm) have its 1st and 2nd antinode?

1st ~ 11.3°
2nd ~ 23°

(iii) At what angle do all the colours have an antinode?

$\theta = 0°$

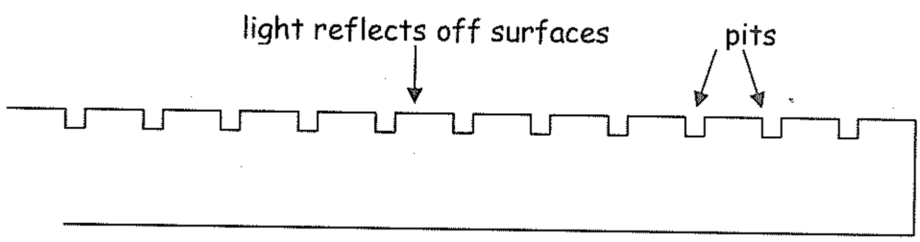
Extension. Design a system of radio transmitting towers to guide planes down the middle of a 50m wide runway. Think how you could sharpen the antinodes, and what sort of separation you would need. (assume a wavelength of 1m)

Have lots of towers in a line perpendicular to the runway. Central antinode in middle of runway.

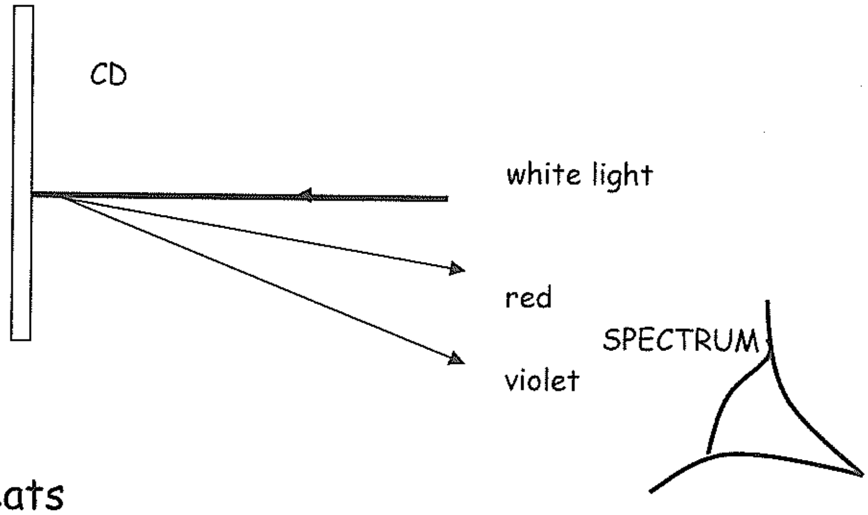
CDs and Diffraction

CDs are a reflection diffraction grating. They have a reflective surface with grooves or pits cut into it that don't reflect light. The pits are about 10^{-3} mm apart.

cross section view



When light hits the surface and reflects, the flat spots act like thousands of little ....sources.... of light. The light spreads out (..diffracts..) and produces an ....interference.... pattern.

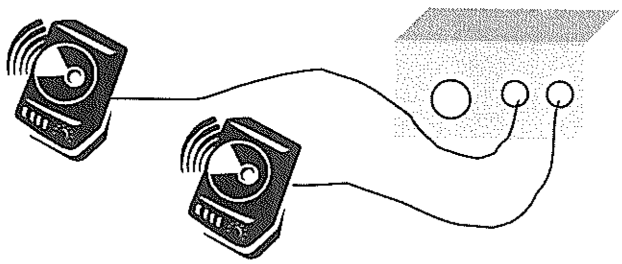


Colours are seen because different colours have different antinodes at different ...angles.... .

Beats

When two waves add together, they interfere. If the frequencies are the same, they can form a stationary interference pattern. Beats are produced when the *frequencies* are *different*.

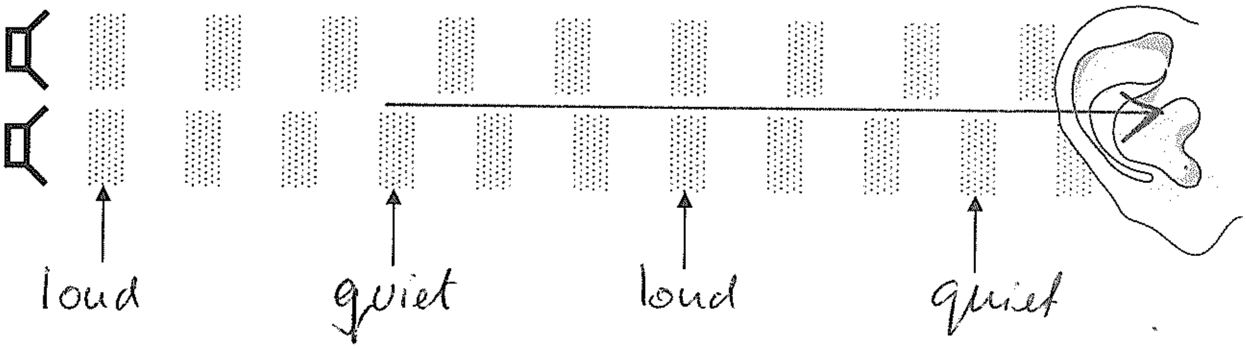
Experiment Note
Use two signal generators connected to two speakers.



This is most obvious with sound waves. *Describe the sound heard when two speakers produce slightly different frequencies.*

sound intensity (loudness) varies over time

This is why. Label the regions that are loud and quiet.



Two waves coming to your ear have different frequencies, so sometimes they are out of ...phase... and ...cancel... out. A short time later, they are in phase and ...add together... . This means the resultant sound is quiet then loud then quiet. This produces the waaaaawwwwaaaaaawwwwaaaaaa sound.

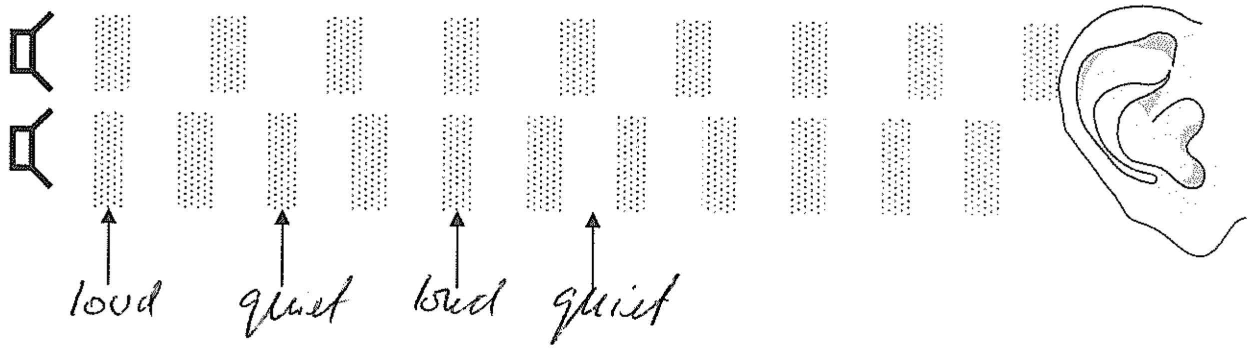
This variation in amplitude is called ...beats... .

What happens to the "beat frequency" when the difference in frequencies increases?

beat frequency increases

What happens to the "beat frequency" when the difference decreases?

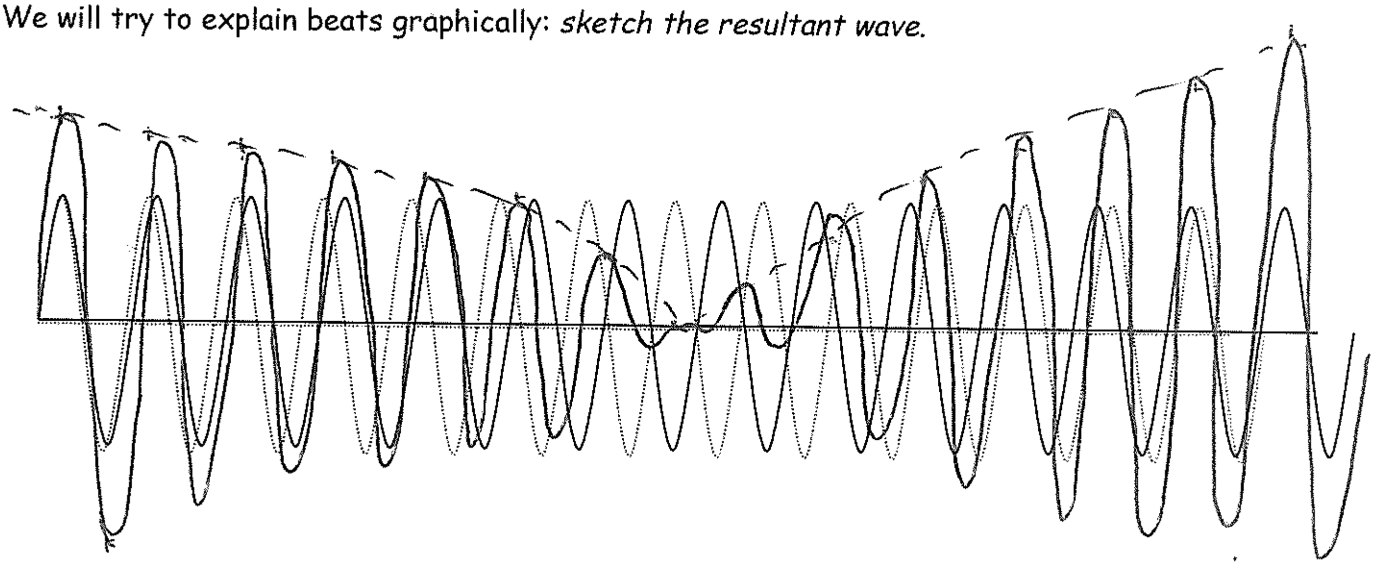
beat frequency decreases



These waves have a larger difference in frequency than before, and the beat frequency is higher because they go in and out of phase ...more... ...often...

This produces a wwaawwaawwaawwaawwaa sound

We will try to explain beats graphically: *sketch the resultant wave.*



The two waves above have different ...frequencies... At some times, they are ...in phase and add together ...constructively... . At other times they are ...out of... phase and add together ...destructively

The beat frequency is the frequency of the variation in amplitude. It can be calculated from the difference in the two frequencies.

$$f_B = |f_1 - f_2|$$

n.b. The frequency of the sound produced is the average of the two frequencies. $\frac{f_1 + f_2}{2}$