Chap. 16

Superposition

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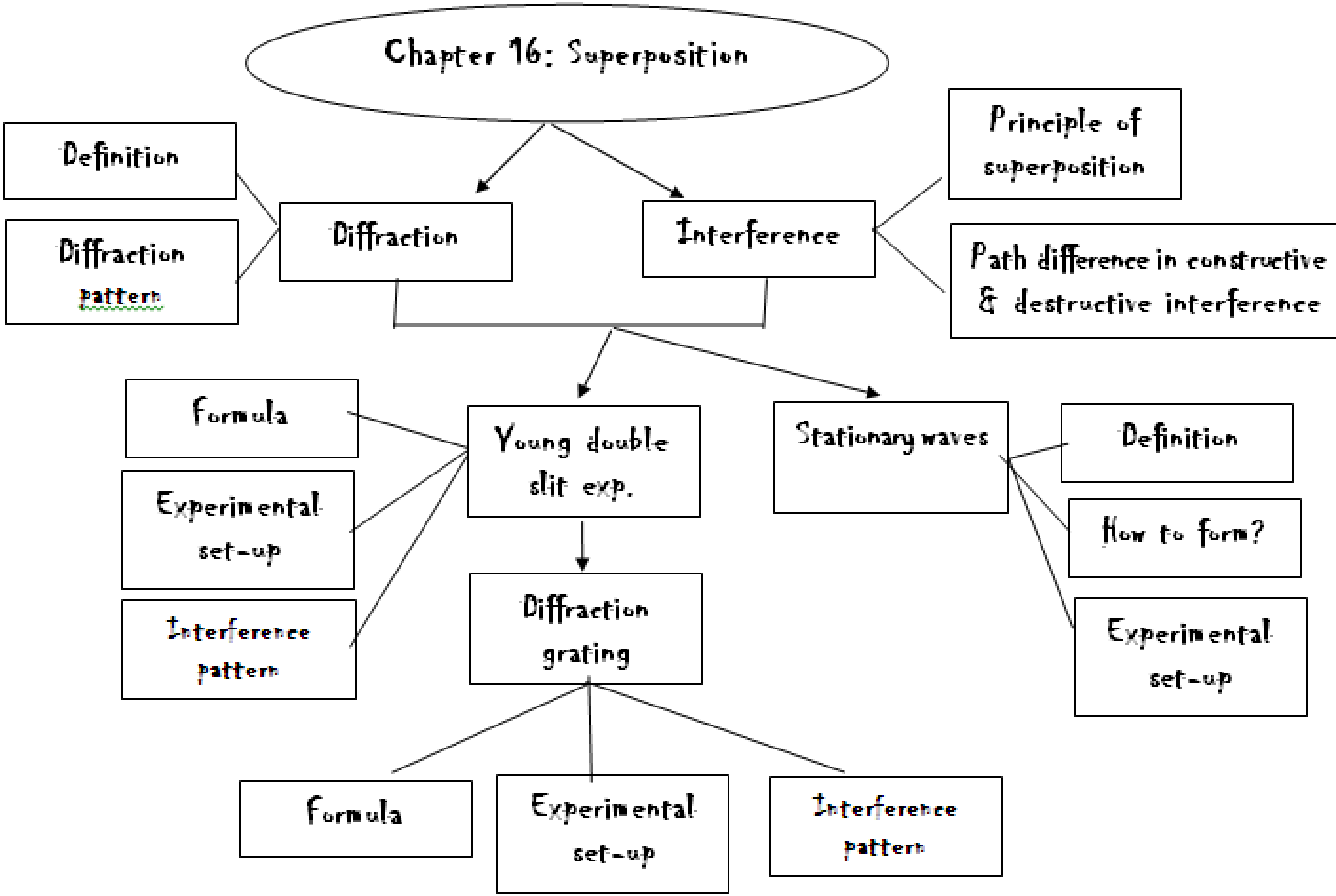
2012


Chapter 16: Superposition
Definition
Diffraction pattern
Diffraction
Interference
Principle of superposition
Path difference in constructive & destructive interference
Formula
Experimental set-up
Interference pattern
Young double slit exp.
Stationary waves
Definition
How to form?
Experimental set-up
Diffraction grating
Formula
Experimental set-up
Interference pattern

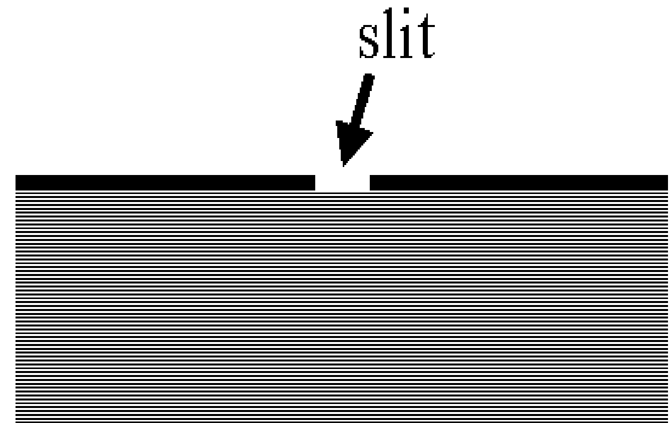
Learning Outcomes

(d) explain the meaning of the term diffraction

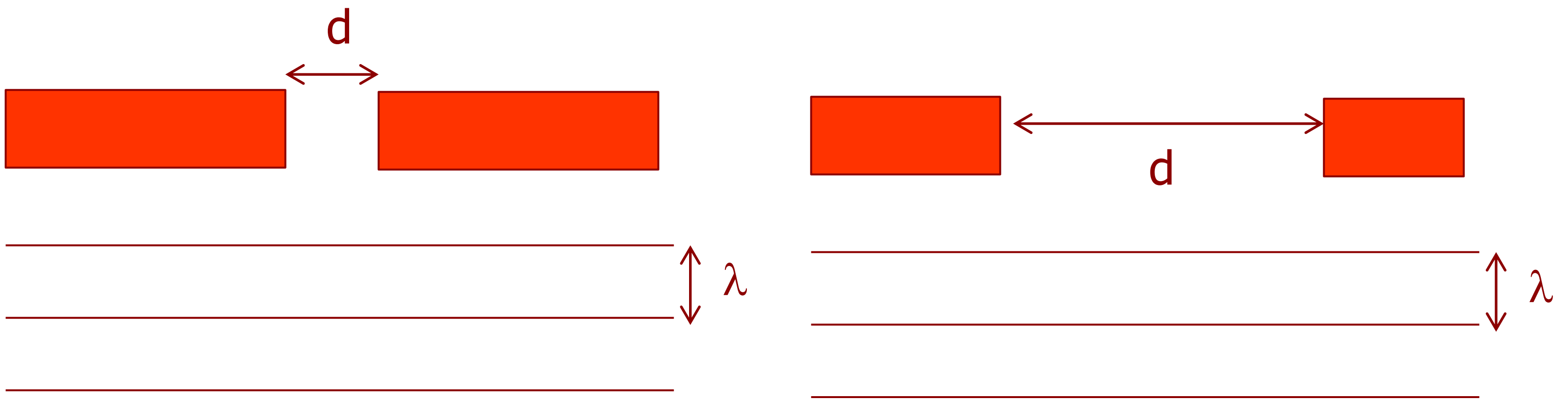
(e) show an understanding of experiments that demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap

Diffraction

- is the spreading out of waves around an obstacle or through an opening which size is comparable to the wave's wavelength.



diffraction of water waves in a ripple tank



Observation of spreading waves

$d >> \lambda$	the wavefronts passing through the gap almost straight except for some bending at the edges.
$d \sim \lambda$	the wavefronts passing through the gap are nearly circular and seem to originate from a point source situated in the gap.
$d << \lambda$	Waves cannot even pass through the gap intensity is too low for any diffraction pattern to be observed.

Single-slit light diffraction

the experimental set-up

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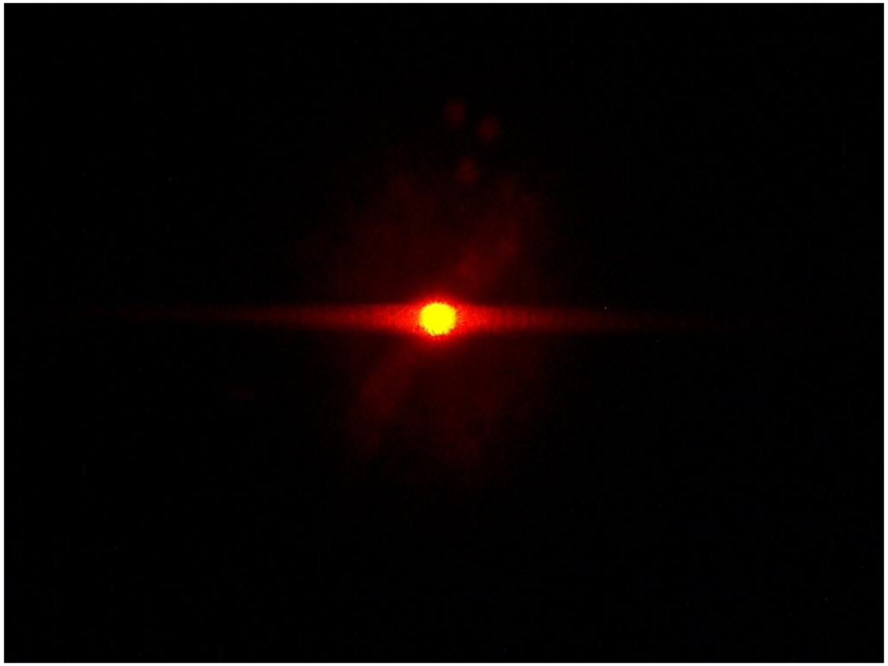
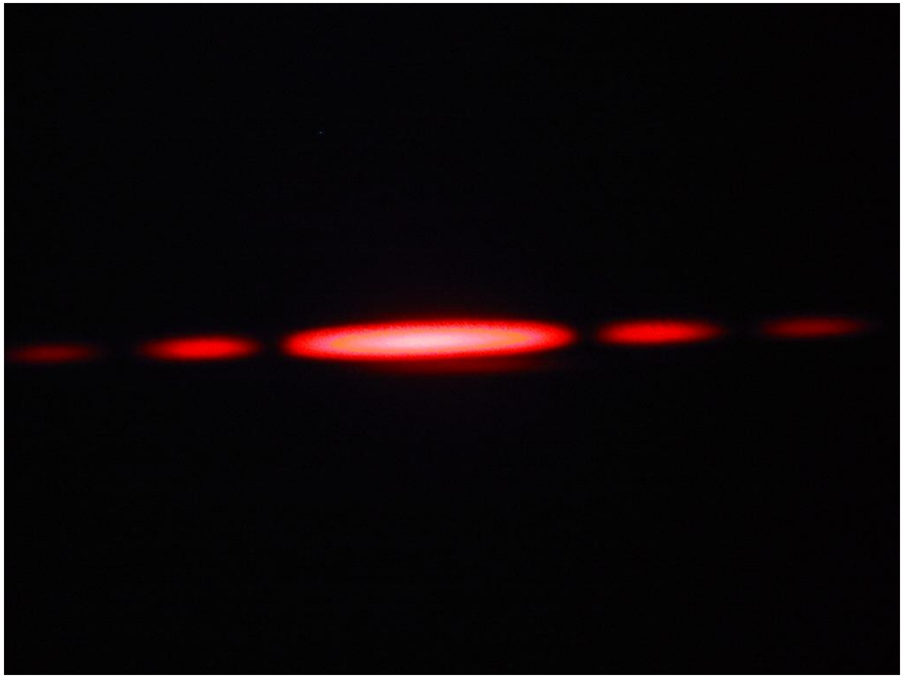
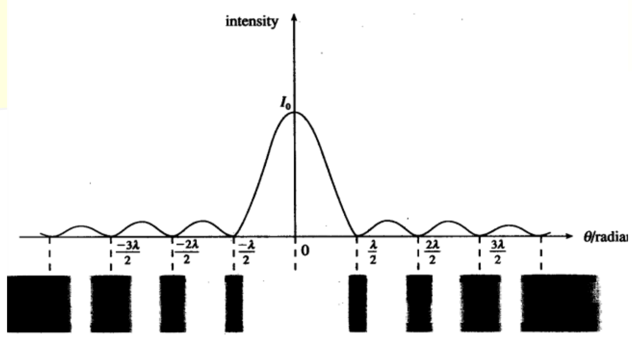
Single-slit light diffraction



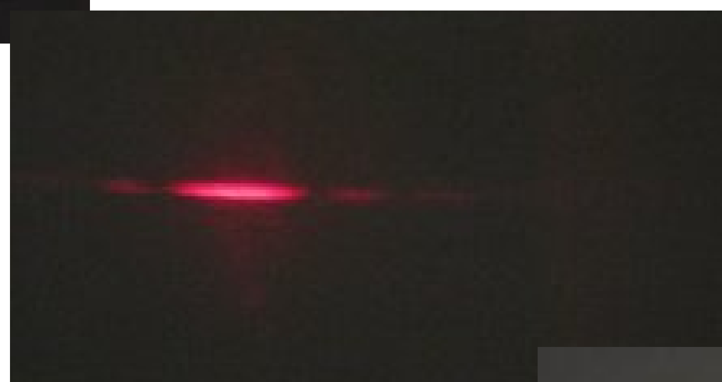


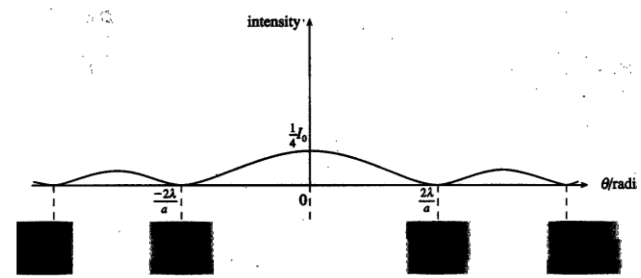
Diffraction patterns

Single-slit light diffraction

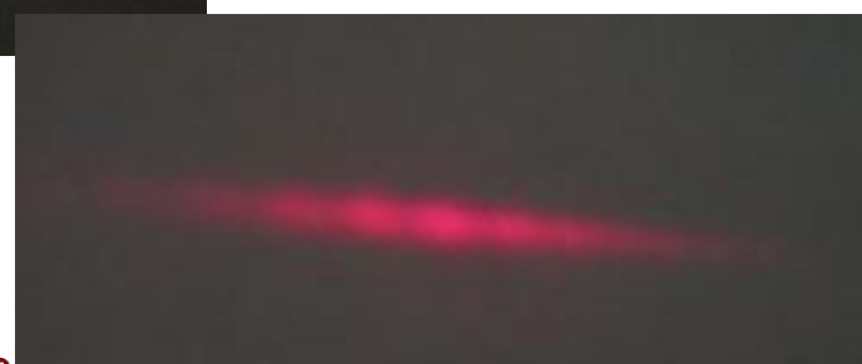


a) wide slit





b) narrow slit

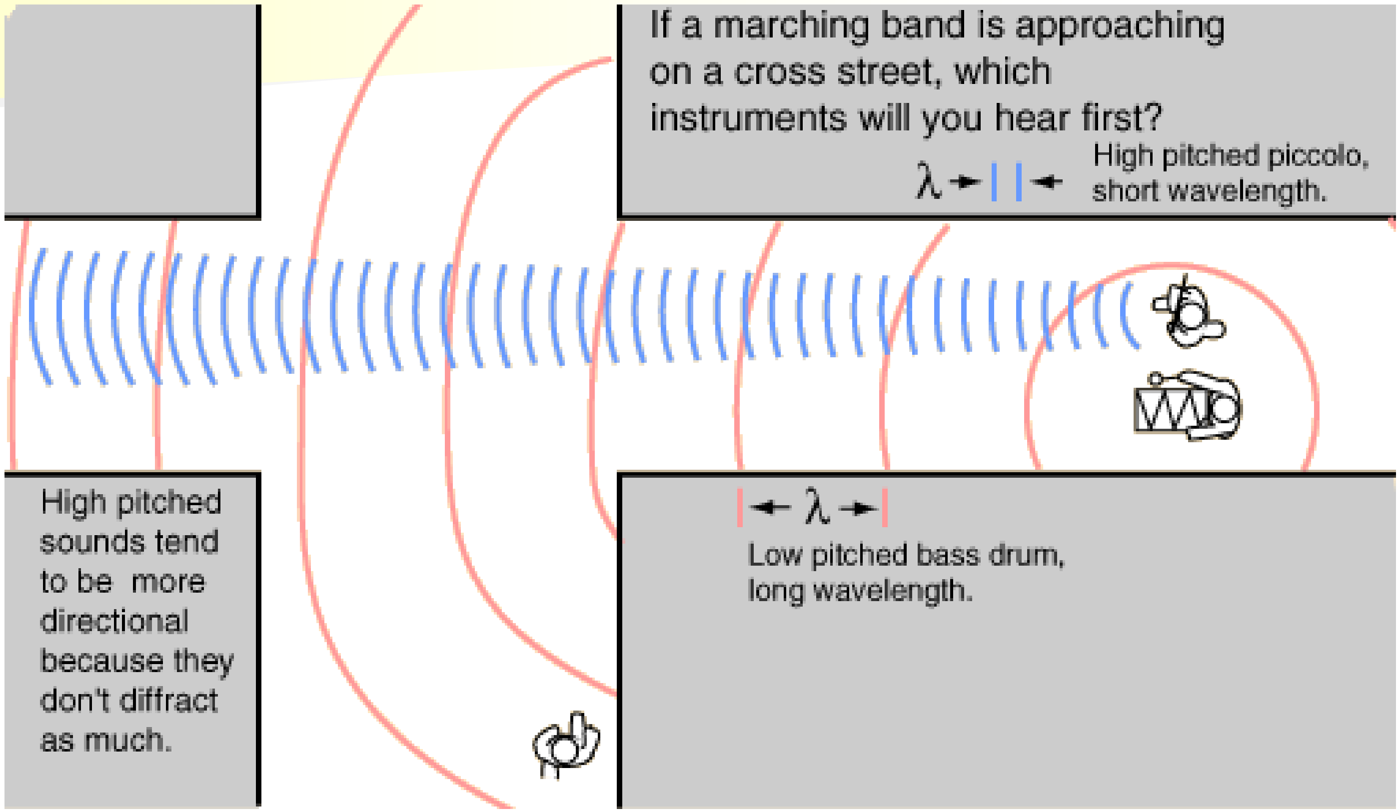


As the diffraction slit gets narrower ….

Diffraction: light & sound

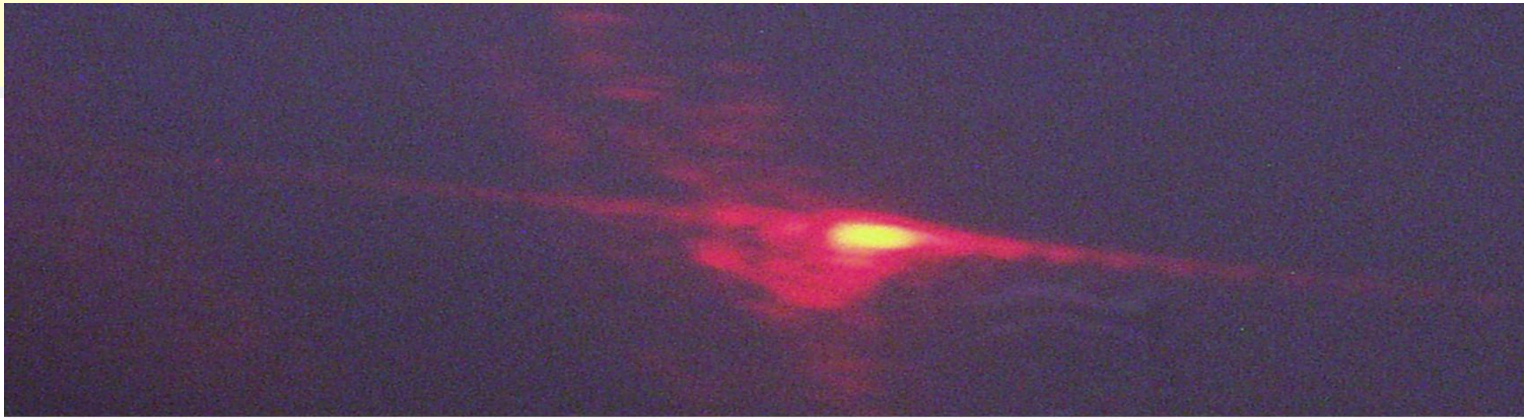
- Light waves propagate in a straight line.
- It cannot hardly be diffracted by door way as the wavelength is small to the size of the gap.
- Sound waves can be easily diffracted by door way as the wavelength is comparable to the size of the gap.

Diffraction: High & low frequency

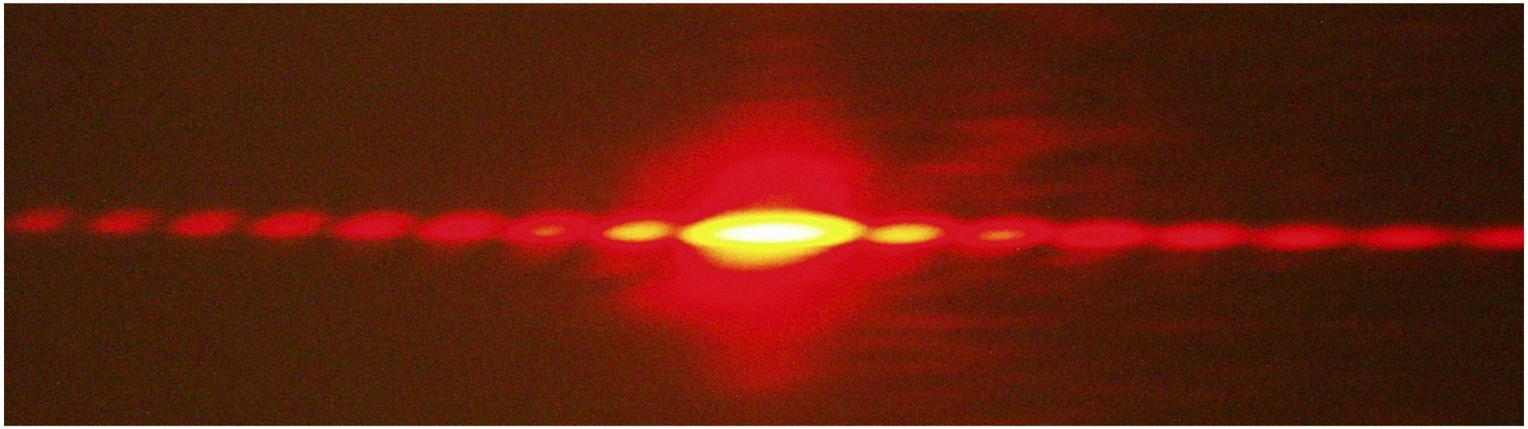


Why low notes of an orchestra playing in a hall can be heard through a doorway better than the high notes by a listener outside the hall?

Comparison: Single-slit & double-slit



Pattern produced from a single slit.



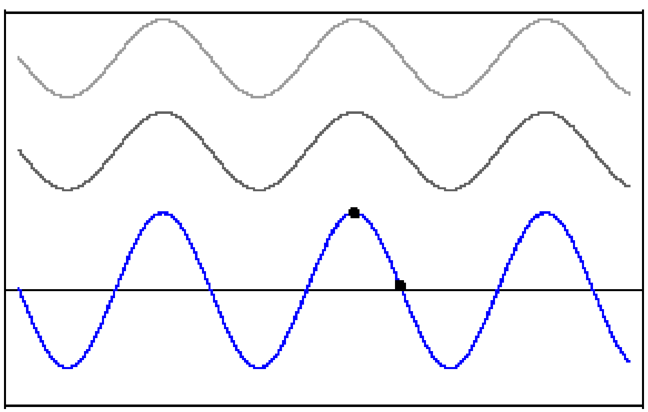
Pattern produced from a double slit.

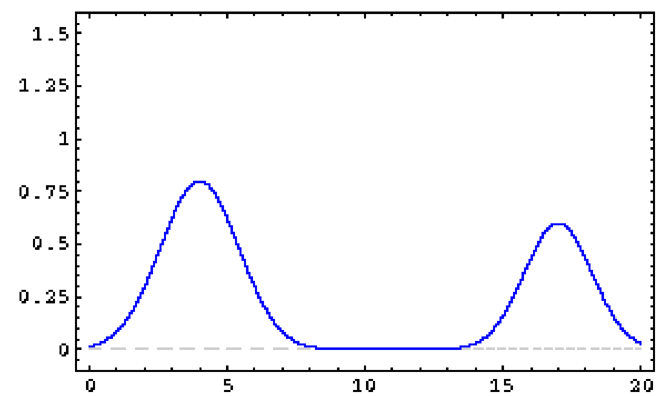
constructive and destructive Interference

	Constructive interference	destructive interference
Resultant amplitude	when two waves superimpose in phase, their amplitudes reinforce each other, building a wave of even **greater** amplitude	their amplitudes oppose each other (meet antiphase), resulting in waves of **zero/minimum** amplitude.
Path difference	$n\lambda$; n = 1,2,3,…	$(n-\frac{1}{2})\lambda$; n = 1,2,3,…
Phase difference	**2π, 4π, 6π, …**	**π, 3π, 5π…**

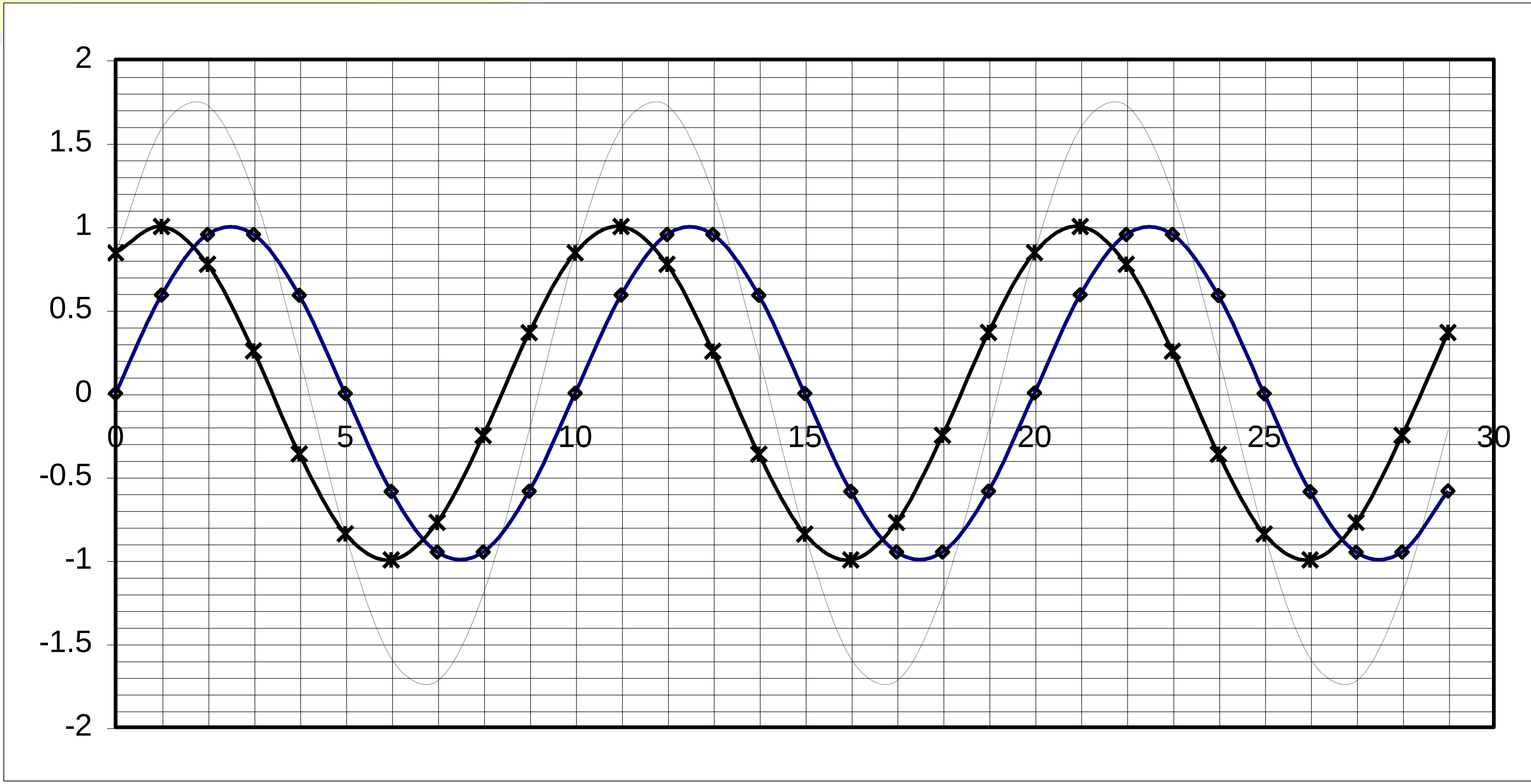
Principle of superposition

- When two or more waves meet at one point at the same time, the resultant displacement at the point is equal to the vector sum of the individual displacement of the waves.





superposition



Questions (1)

1. What does it mean by "two coherent sources"?

<u>Two waves with constant phase difference (not varying with time)</u>

2. Why coherent sources are needed?

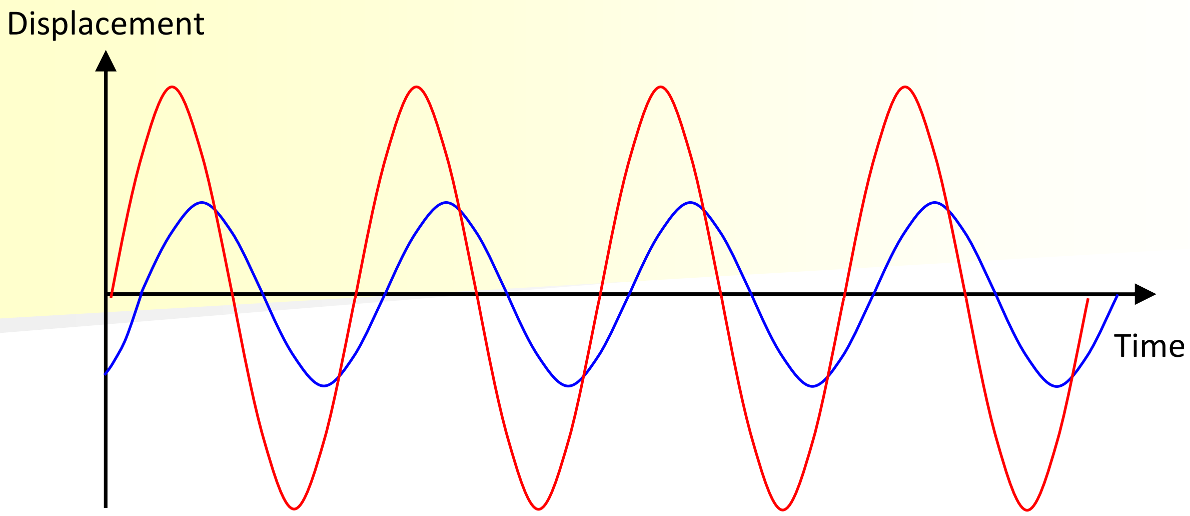
   <u>To produce a steady interference pattern, i.e. max intensity and minimum intensity regions are not changing with time</u>

3. How to produce coherent sources?

   <u>Use sources of same frequency</u>

   <u>And a light source with a narrow slit to get the emission of light from an electron at one time.</u>

   <u>Followed by a double-slit to get two coherent sources</u>



32 The graph shows two waves.

Which statement is correct?

A The waves are coherent and in phase.

B The waves are coherent but out of phase.

C The waves are incoherent and out phase.

D The waves are incoherent but in phase.

Questions (2)

1. What does it mean by "monochromatic source"? <u>single frequency</u>

2. Conditions for two waves to interfere

   <u>1. two waves meet at the same point, same time</u>

   <u>2. two waves are of same type</u>

   <u>3. unpolarised or polarised on the same plane</u>

3. Conditions to obtain an observable interference pattern

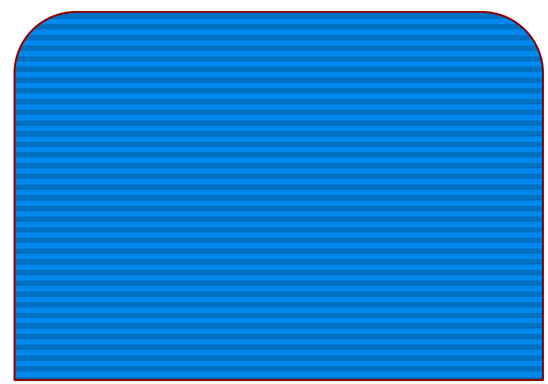
   <u>1. coherent sources (same frequency)</u>

   <u>2. same amplitude (for good contrast)</u>

   <u>3. large distance between the source and the screen (large spacing between fringes)</u>

A + A = 2A (bright)
A - A = 0
(total cancellation - completely dark)

2A + A = 3A
2A - A = A
(bright & not-so bright)



$2A + 2A = 4A$ (bright)
$2A - 2A = 0$

If intensity of both sources drops
$A + A = 2A$ (bright – brighter)
$A - A = 0$ (dark- remains dark)

If intensity of one of the sources drops
$2A + A = 3A$ (bright – less bright)
$2A - A = A$ (dark- brighter – NOT total cancellation)

Interference of sound

1.Qualitative description

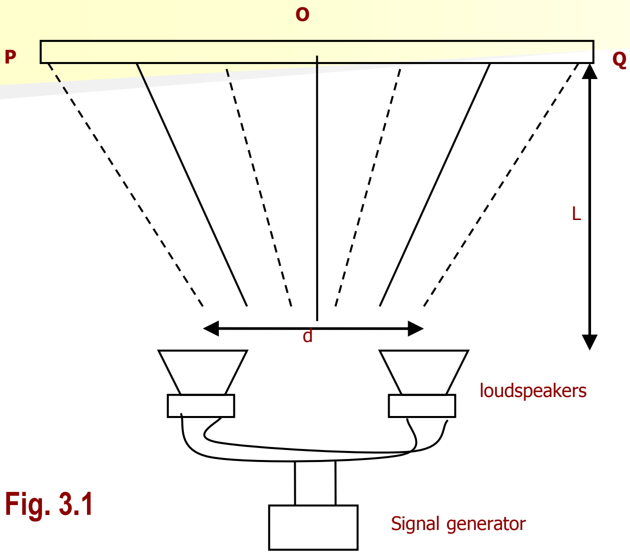


Fig. 3.1

	Spacing between two regions of loud sounds
1. Two speakers are further separated.	
2. The observer walks further from the speakers.	
3. Low-pitch sound is used.	

Calculation

Fig. 3.2 shows two loudspeakers with 1 m apart, are connected to the same oscillator so that both emit sound waves of frequency 1700 Hz. A sensitive detector is moved along line PQ, which is 2.40 m from the speakers. A loud sound is detected at the centre i.e. O and the next one at Y.
Calculate the speed of sound.

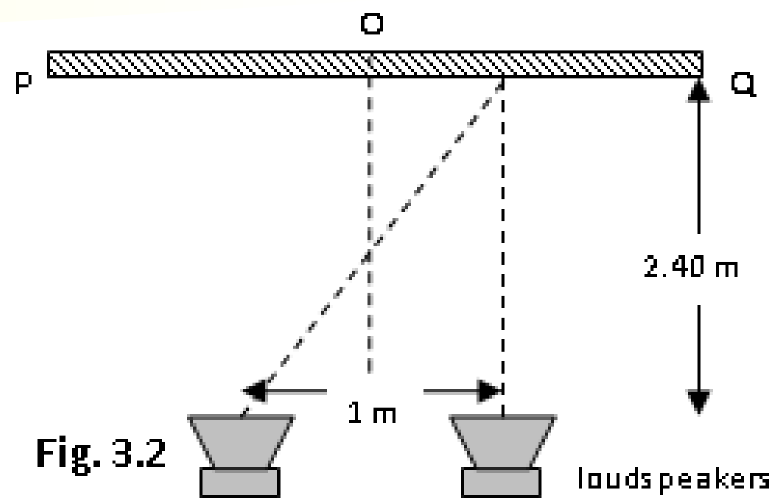
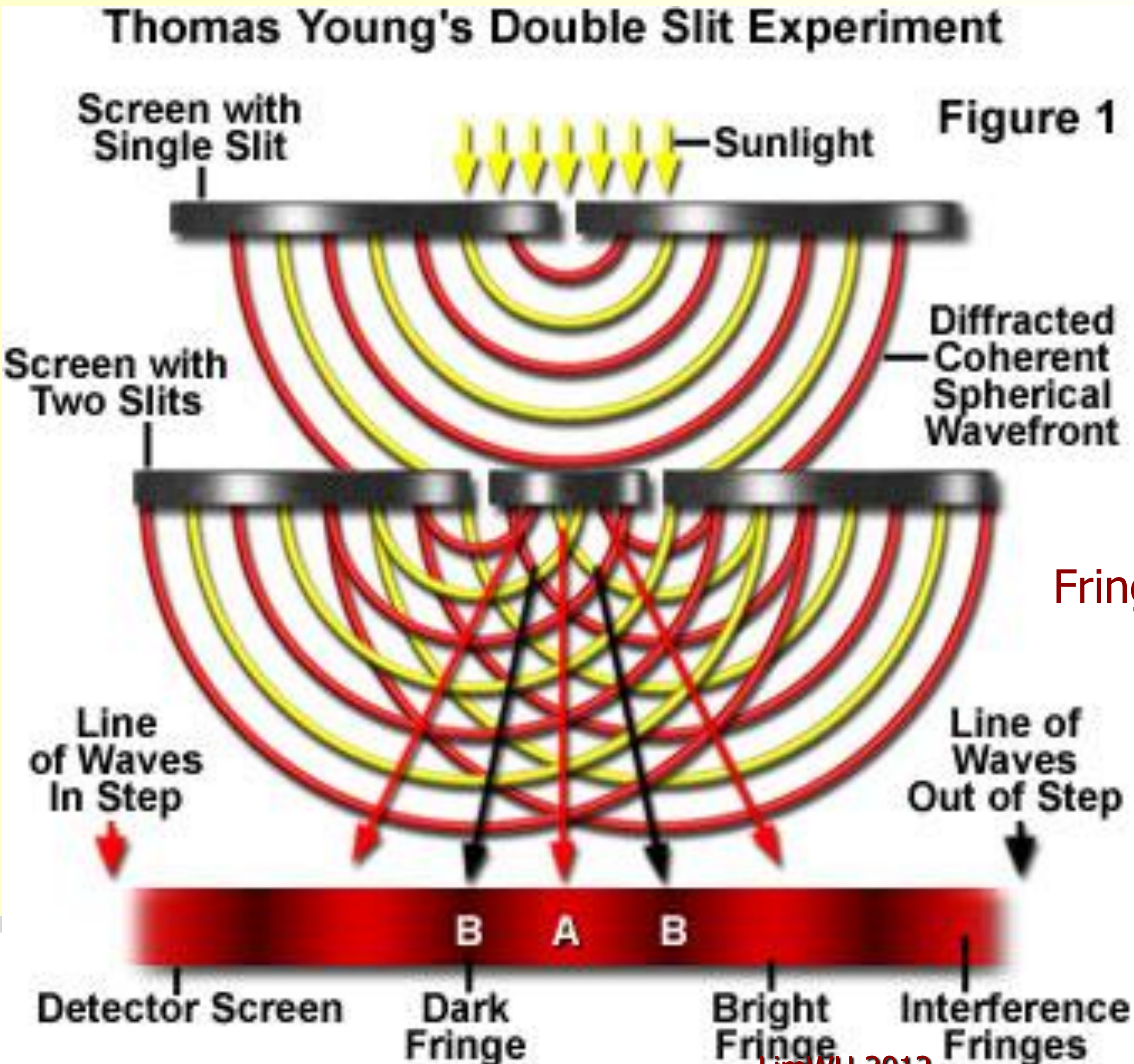


Fig. 3.2

Young double-slit Experiment (Light)



Distance btwn sources & screen

$$X = \frac{\lambda L}{d}$$

Fringe spacing

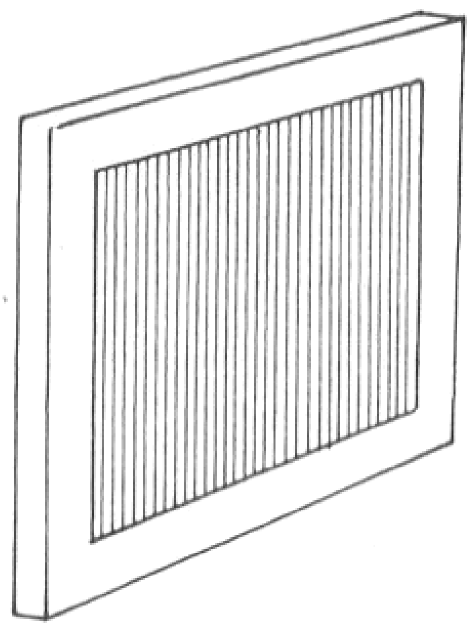
Slit spacing

Parameter	Interference pattern	Explanation
Distance, L increases		
Slit spacing, d increases		
λ increases (e.g. replace a blue light with a red light)		
The width of the slit increases		
Cover one of the slits		

diffraction grating

1. What is diffraction grating?

is a piece of glass or plastic with lines etched on it, normally 10 to 1000 lines per mm.



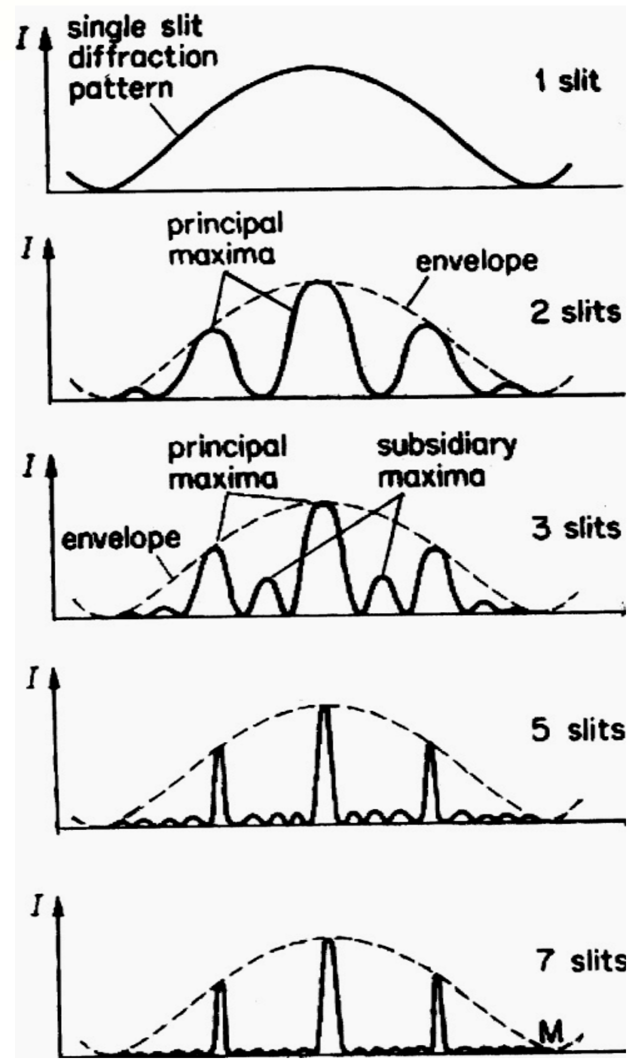
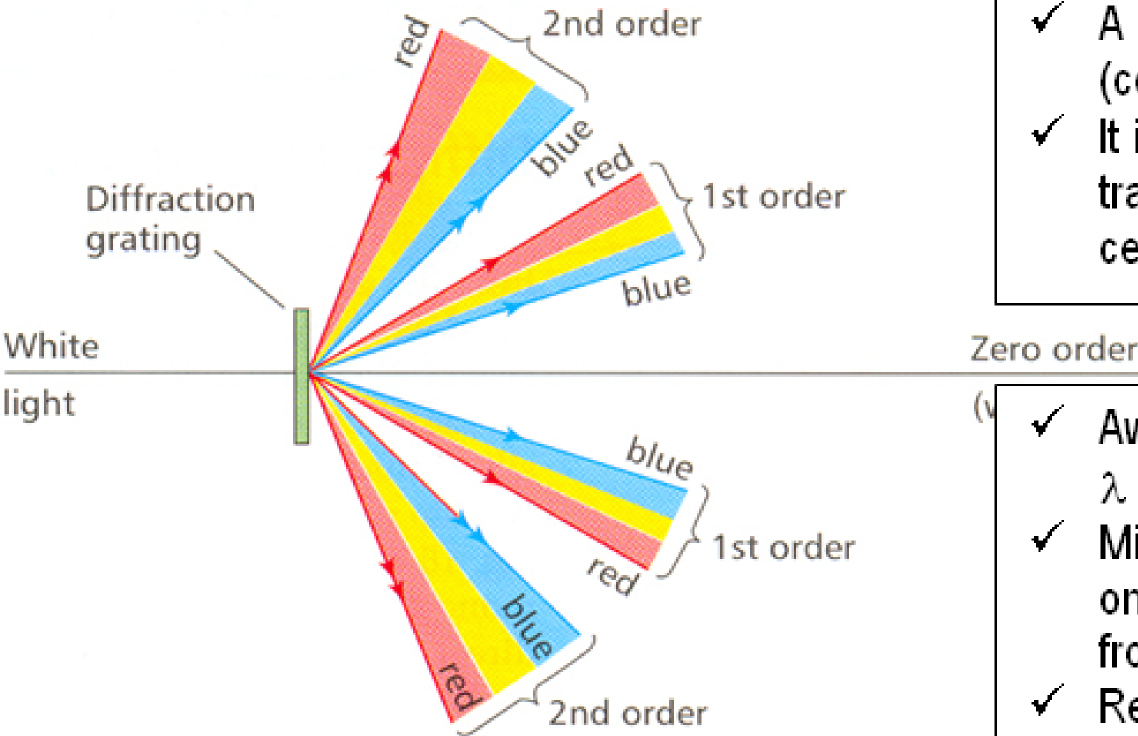


Fig. 9

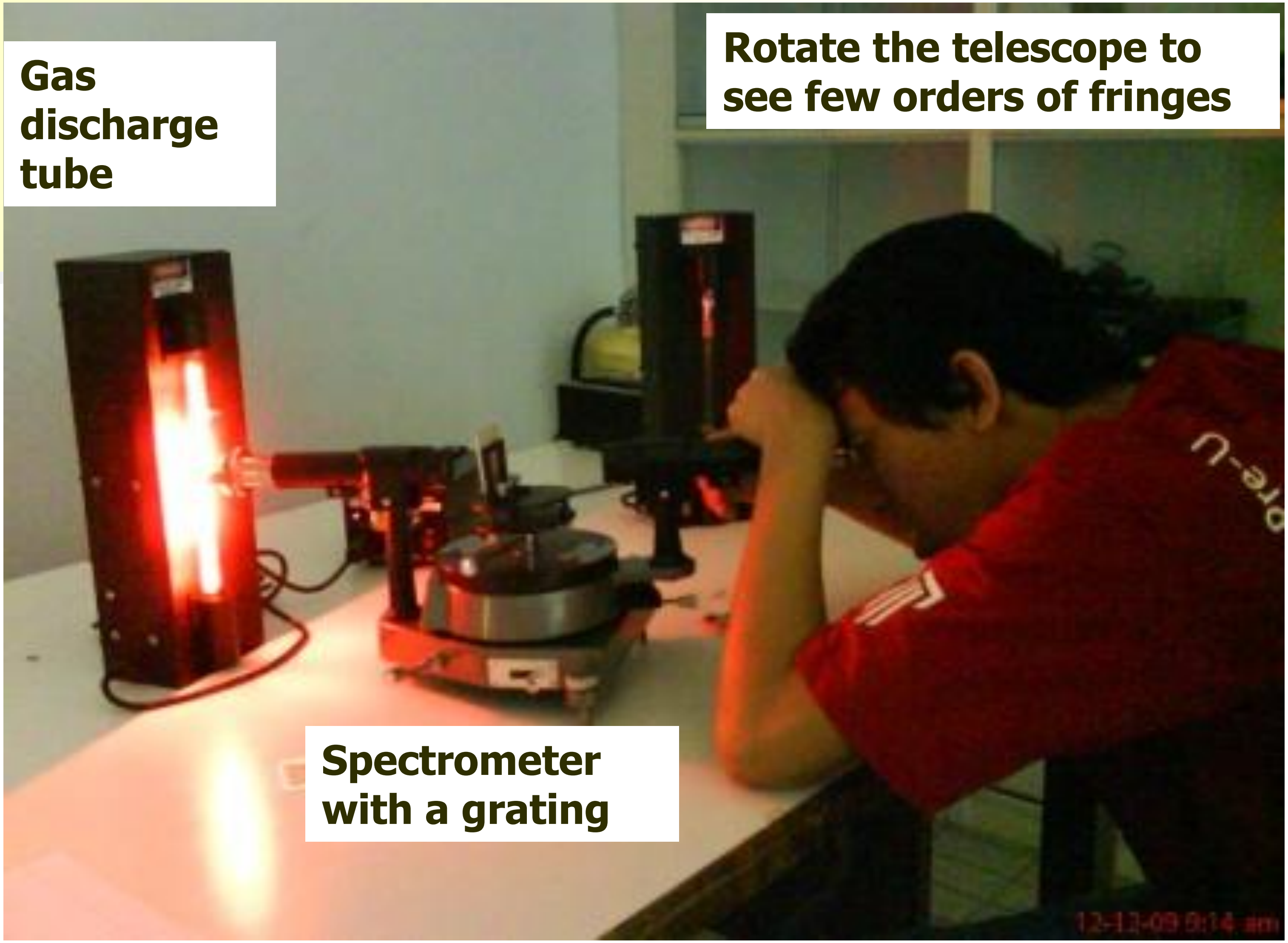
Monochromatic light

White light



- ✓ A white band is found at the centre (constructive interference).
- ✓ It is because all the colours of different λ travel from all slits arriving in phase at the centre, therefore no separation of colours.

- ✓ Away from the centre, colours of different λ are diffracted through different angles.
- ✓ Mini spectra are observed in other fringes on both sides with a range of colours, from red to violet.
- ✓ Red light is diffracted the most, violet light the least.


Gas discharge tube
Rotate the telescope to see few orders of fringes
Spectrometer with a grating

Diffraction Grating

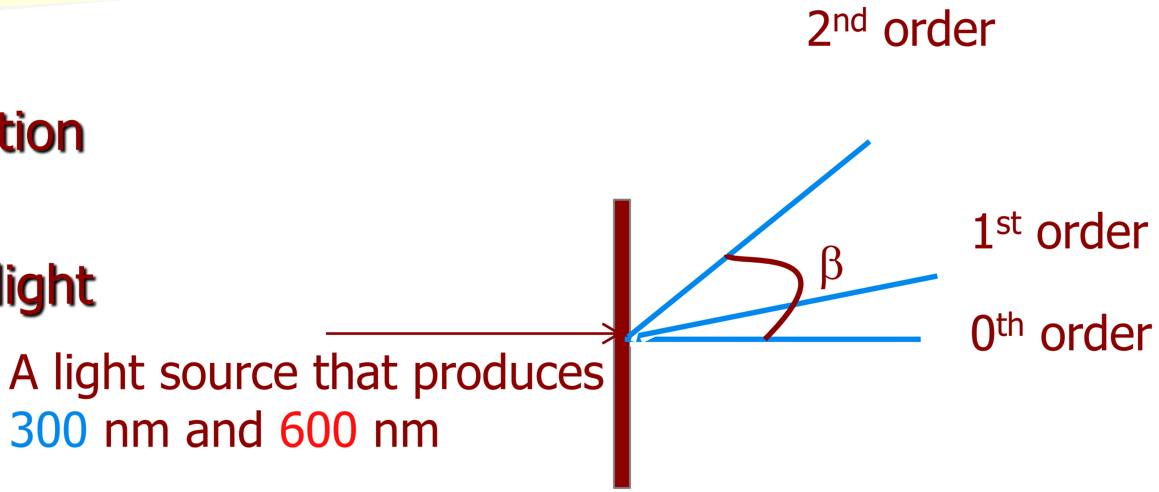
$d \sin \theta = n \lambda$

d : slit spacing

θ : angle of diffraction

n : no. of order

λ : wavelength of light



For example: there are 500 lines per mm on a grating, thus N = 500 lines per mm. d = 1/N = 1/500 mm per lines = 1/500 x 10^{-3} = ………… m per lines

$d \sin \theta = n \lambda$

e.g. to determine the shorter wavelength for n =2, θ is the corresponding angle of diffraction which is β.

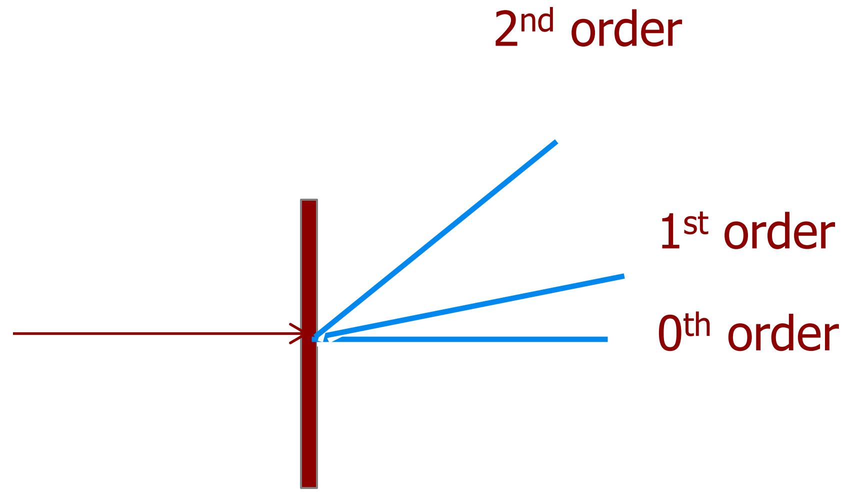
The highest order

Maximum angle of diffraction is 90º

$d \sin \theta = n \lambda$

$\sin \theta < n \lambda / d < 1$

$n < d / \lambda$



For example: there are 500 lines per mm on a grating, thus N = 500 lines per mm. d = 1/N = 1/500 mm = 1/500 x 10^{-3} = …………. m per lines

Determine the number of image for 600 nm.
$n_{max} < d/\lambda = (1/500 \times 10^{-3}) / 600$ n = …………….

Try this

Waves from a monochromatic source pass through a grating of 1000 lines per mm. The angle of the 1st order diffracted beam is measured as 36^o.

i) Determine the λ of the source.

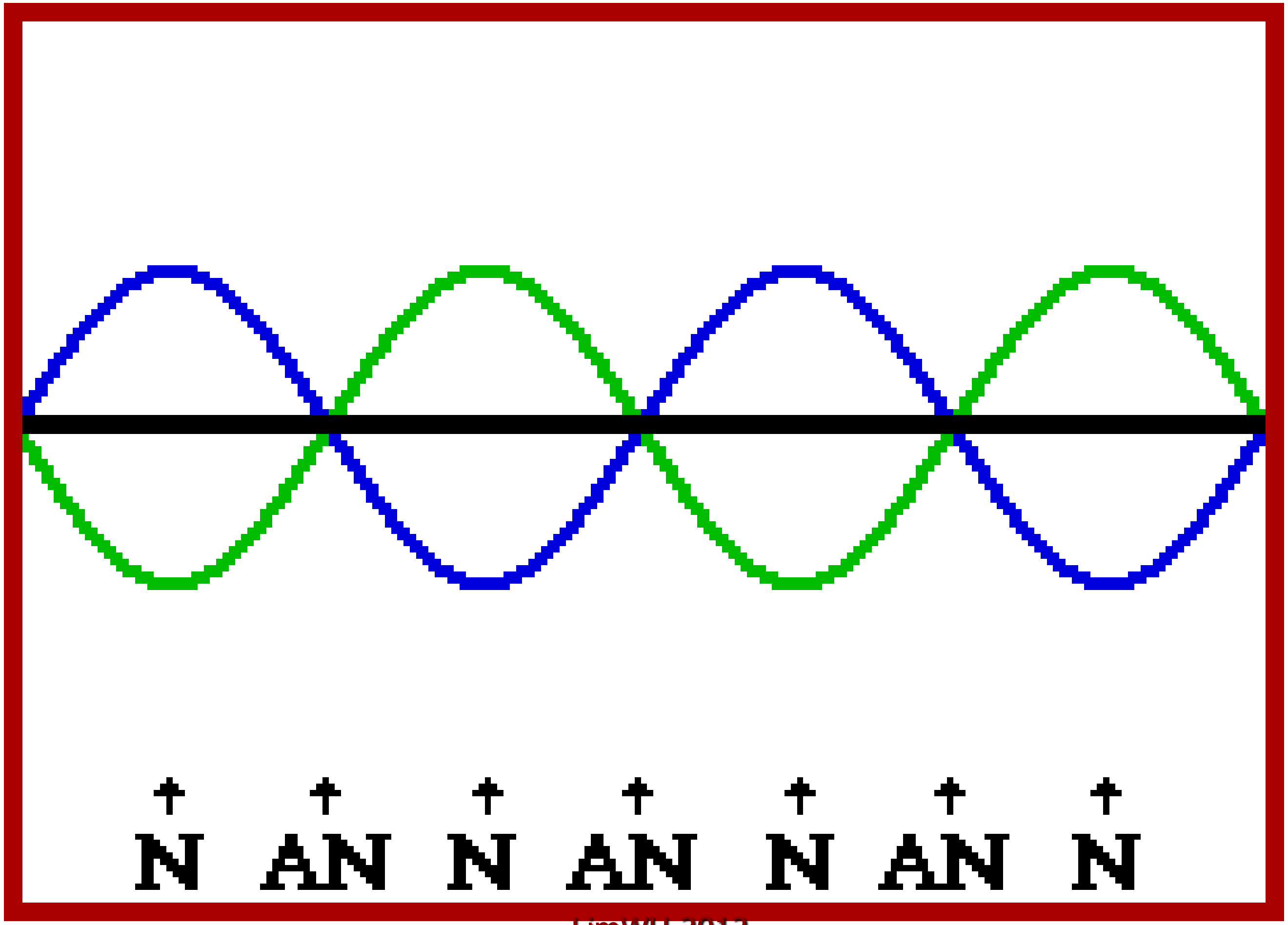
ii) Determine the maximum number of high-intensity fringes can be observed, include the central fringe. [588 nm, 3]

iii) Yellow light of wavelength 5.89×10^{-7} m passes through grating 5000 slits per cm. At what angles will the bright fringes be seen?

[0,17.1 ^{o}, 36.1^o, 62.1^o]

Stationary or standing waves

- Wave profile is not advancing



Stationary or standing waves

1. What is stationary wave?

   A wave which wave profile/waveform is NOT advancing.

   Energy is NOT transferred along the direction of wave but it is confined between two nodes

2. How is it formed?

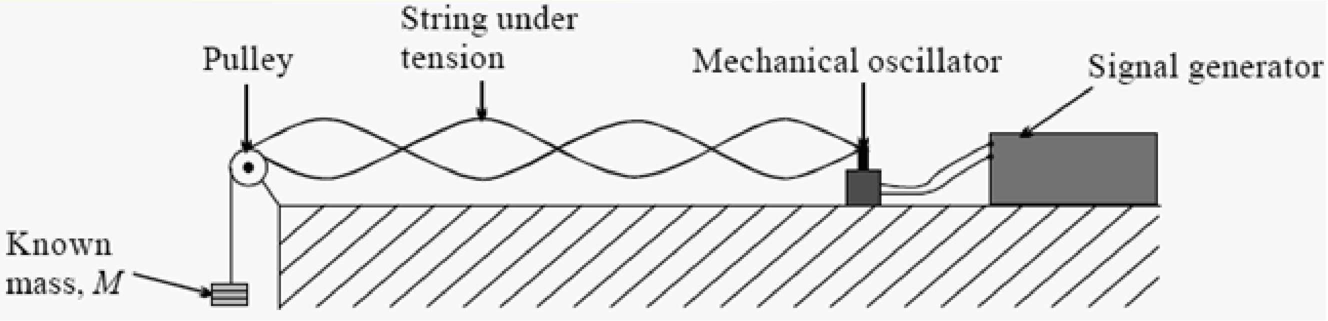
   It is a resultant wave formed from two progressive waves of the same amplitude, frequency and speed, travelling in opposite direction.

3. What are node and antinode on the waves?

   node- it is a point on a wave which amplitude is ALWAYS zero

   antinode- it is a point on a wave which amplitude is max

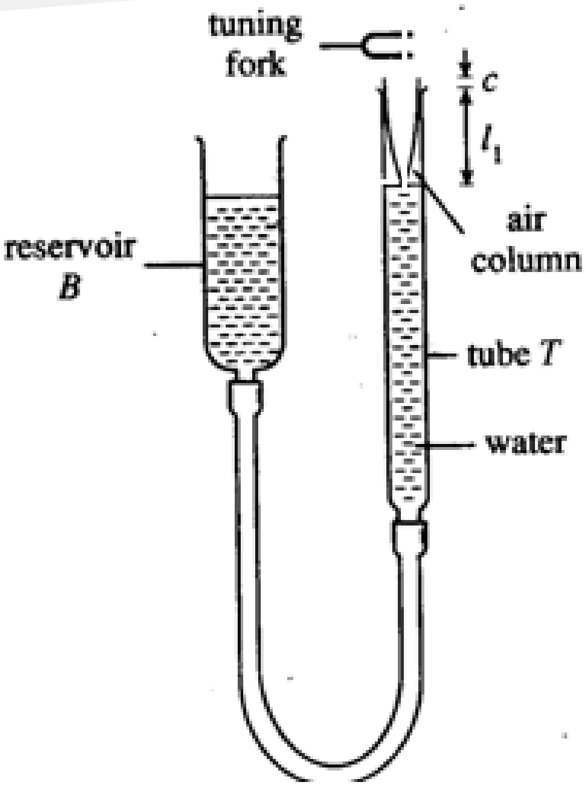
(1) Stretched string

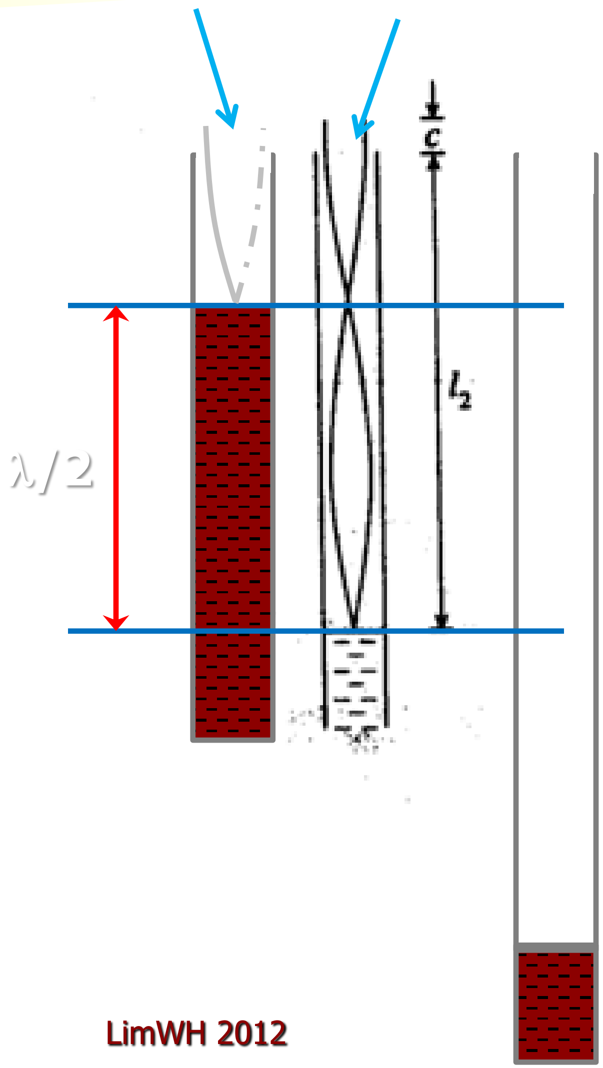


1. Why the point connecting to the vibrator is not exactly a node?
<u>It is connected to vibrator which has a small oscillation / vibration , displacement is not exactly zero</u>

2. Why the point connecting to the mass via the pulley is known as a node?
<u>It lies on the pulley therefore displacement is zero</u>

(2) Air column





$\lambda/2 = L$

$\lambda = 2L$

$v = f\lambda$

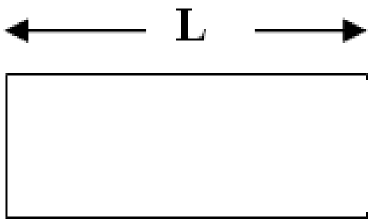
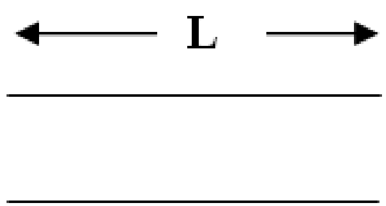
Graphical representation of standing waves

Displacement of air molecules

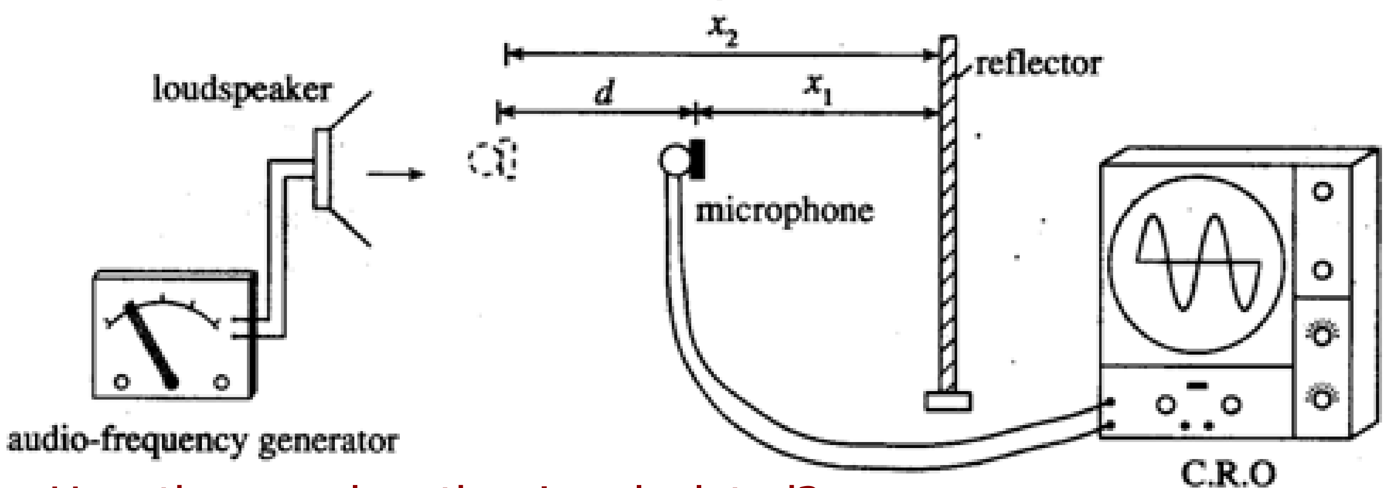
Distance along the air column

Actual movement of molecules

Wave profile in air columns

Pipe with a closed end	wavelength	freq	Pipe with both ends open	wavelength	freq
					
					
					

Stationary sound waves – to determine the speed of waves



1. How the wavelength λ is calculated?

2. How the speed of the sound in air v is determined?

3. To be more accurate, distance throughout which n nodes are detected is measured L. How to determine λ then?

4. Distance between two successive antinodes is also equal to $\lambda/2$. Suggest why nodes instead of antinodes are detected to determine the wavelength?

Progressive waves vs. stationary waves

	Progressive waves	Stationary waves
energy	Energy is transferred along the propagation of waves	Energy is NOT transferred along the propagation of waves, is confined between two nodes.
Wave profile	Advancing/moving	NOT Advancing/moving
Displacement	All points are displaced	There are some points which always have zero displacement – nodes.
Amplitude	All points have the same amplitude	Different amplitude
phase	All points are moving with different phase	All points between two successive nodes are moving in phase.