Superposition

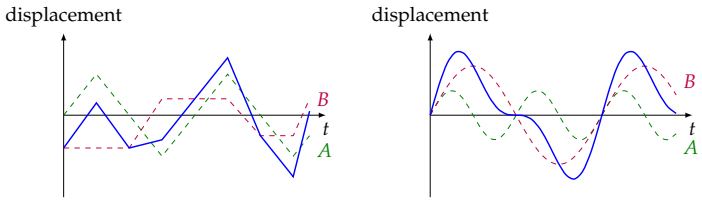
Name _____ Date _____

By the end of this topic I can…

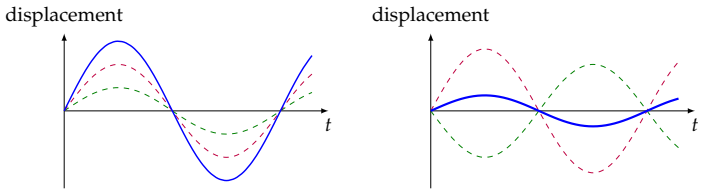
- state the principle of superposition and use path and phase difference
- explain interference and use the double-slit formula
- use the diffraction grating equation
- describe stationary waves, nodes and anti-nodes and find their wavelengths

Superposition of waves

The **principle of superposition**: when two or more waves meet, the resultant displacement is the _____ of the individual displacements.



- **constructive**: peak meets _____ (greatest amplitude)
- **destructive**: peak meets _____ (amplitudes cancel)



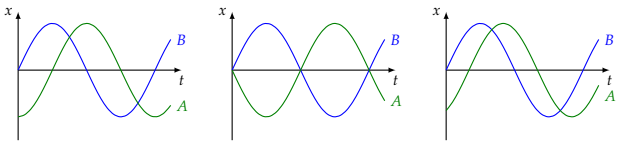
Path difference and phase difference

- **path difference** ΔL: the _____ travelled by two waves to reach a point

Constructive: $\Delta L =$ _____ Destructive: $\Delta L =$ _____

Example 10.1 Two loudspeakers are wired to produce identical sound signals in unison. The sound wave produced has a wavelength of 80 cm. Describe the volume you hear when you are at a distance of (a) 10 m from both speakers, (b) 10 m from one speaker and 12 m from the other?

- **phase difference** $\Delta\phi$: how far one wave is ahead of another, in _____
- in phase: $\Delta\phi =$ _____; anti-phase: $\Delta\phi =$ _____

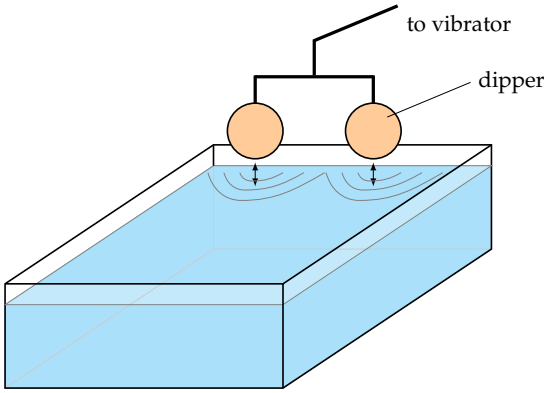


Example 10.2 Each diagram shows the displacement of a point in two waves A and B of wavelength 30 cm travelling in the same direction. The time shift between them is (a) $\frac{1}{4}T$, (b) $\frac{1}{2}T$, (c) $\frac{1}{6}T$. Find the phase difference and path difference in each case.

Interference

Interference is the formation of a stable pattern of _____ and _____ when waves of _____ (_____ waves) overlap.

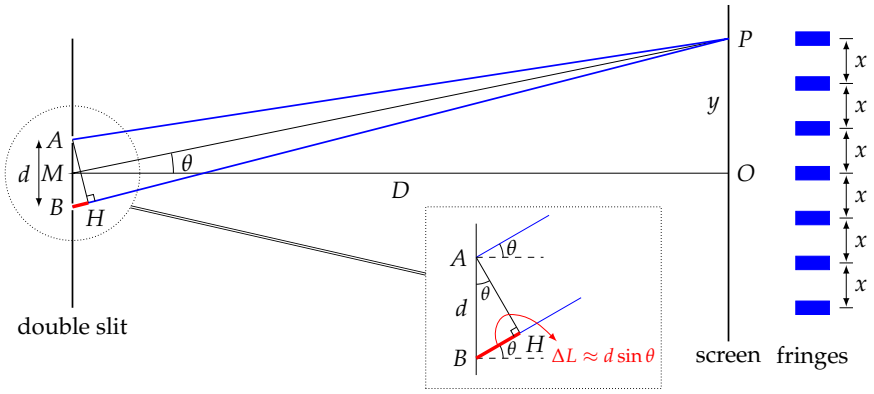
- _____ sources have a constant phase difference; the easiest way to get them is to use _____ (a laser through two slits, two speakers on one signal generator, dippers on one beam)
- maxima where $\Delta L = n\lambda$; minima where $\Delta L = (n + \frac{1}{2})\lambda$



Example 10.3 Two coherent waves meet in space, one of which has an amplitude of 0.30 cm and the other of 0.20 cm. How does the intensity of maxima compare with the intensity of minima?

Young's double-slit experiment

For slit separation d and slit-to-screen distance D ($D \gg d$), the _____ is



• bright fringes where $d \sin\theta = n\lambda$; for small angles $\sin\theta \approx \tan\theta = y/D$, so $y_n = n\lambda D/d$

• _____, larger D or smaller d gives _____

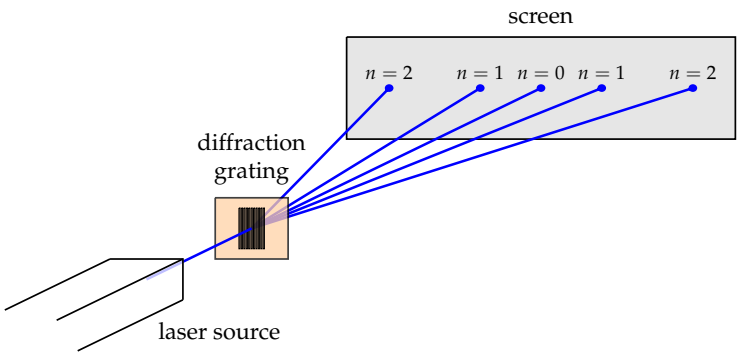
Example 10.4 A teacher demonstrates the double-slit experiment with a beam of red light produced from a helium-neon laser. The beam of wavelength of 632 nm is sent through a double-slit separated by 0.30 mm and passed onto a wall at about 2.0 m from the slits. (a) What is the fringe separation? (b) If the experiment is carried out using a green laser, what changes do you expect?

Example 10.5 Coherent light passes through a double slit. Initially, the light intensity from each slit is the same. State the change to the appearance of the fringes if (a) the separation between the slits is increased, (b) The width of one of the slits is reduced.

Diffraction gratings

A **diffraction grating** has hundreds of slits per mm, producing _____ maxima than a double slit:

where d is the _____ and n the _____; light is incident normally.



- the highest order: (round _____);

total maxima $= 2n_{\max} + 1$

- white light: the central maximum is _____; at higher orders a spectrum forms with _____ at the greater angle

Example 10.6 Light of 632 nm wavelength produces first-order maxima at 16° when passing through a diffraction grating at right angles. How many lines per millimetre are there in the diffraction grating?

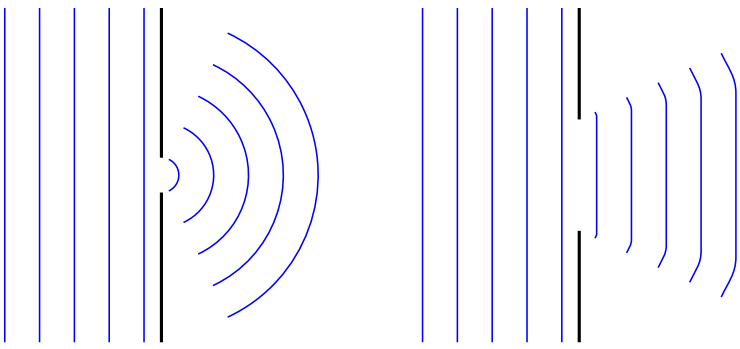
Example 10.7 Green light of 510 nm wavelength is incident normally on a diffraction grating with slit separation of 2.0 μm. (a) What is the highest order seen? (b) how many maxima are produced? (c) If blue light is used for the same diffraction grating experiment, suggest the effect on the diffraction pattern.

Example 10.8 Light of wavelength 630 nm produces a second-order maxima at angle of 60° when it is directed at a diffraction grating. If visible light of another wavelength can also give a maximum at the same angle, what is this wavelength?

Diffraction

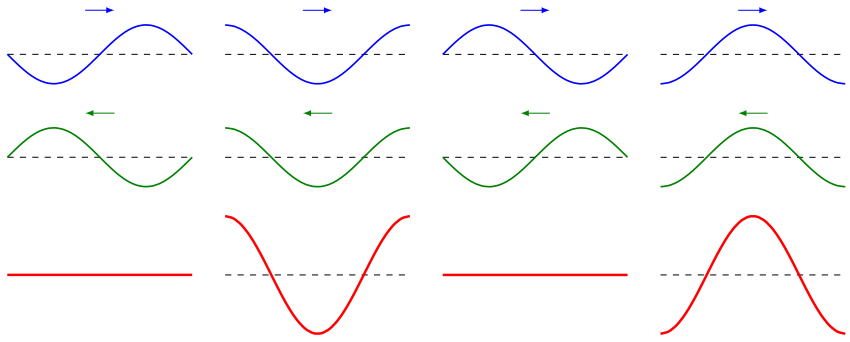
Diffraction is the _____ of a wave when it passes through a gap or around an obstacle.

- the effect is greatest when the gap width is _____



Stationary waves

A **stationary (standing) wave** forms when two waves of the _____ travelling in _____ superpose (often a wave and its reflection).

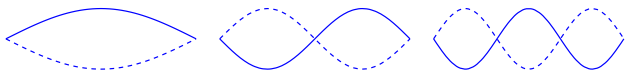


$t = 0$ $t = \frac{T}{4}$ $t = \frac{T}{2}$ $t = \frac{3T}{4}$

- **nodes**: points of _____; **anti-nodes**: points of _____
- the distance between adjacent nodes is _____, so

- a _____ end is a node; a _____ end is an anti-node

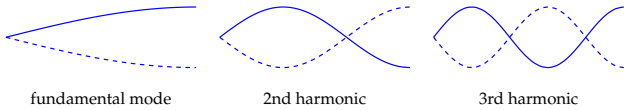
Both ends fixed



fundamental mode 2nd harmonic 3rd harmonic

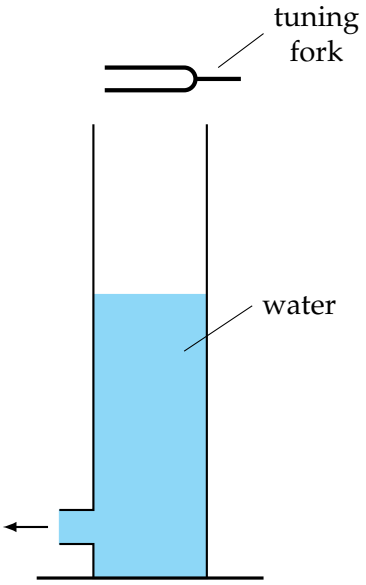
Example 10.9 In Melde's experiment a string of length 80 cm vibrates with five loops. (a) Find the wavelength. (b) How could a stationary wave of longer wavelength be produced?

One fixed (closed) end and one open end



Example 10.10 The graph shows a standing sound wave produced in an air column in a closed pipe of length 30 cm. The frequency of this sound wave is 825 Hz. (a) What is the wavelength of the sound wave? (b) Calculate the speed of sound. (c) What is the frequency of the fundamental mode for sound wave in this air column? (d) Describe the motion of an air molecule near the open end.

Example 10.11 A tuning fork is held above a tall cylinder which is initially filled with water. The water level, measured from the bottom of the cylinder, is lowered at a constant rate. A loud sound is first heard when the water level is at 60.0 cm, and the next loud sound is heard when the water level is at 26.8 cm. It is known that the speed of sound in air is 340 m s^{-1}. What is the frequency of the sound wave produced by the tuning fork?



Stationary and progressive waves

	Progressive wave	Stationary wave
energy	transferred along the wave	_____
amplitude	the same for all points	_____: zero at nodes, maximum at anti-nodes
phase difference	any value from 0 to 2π	_____ only

Practice questions

Question 10.1 A wave of frequency 10 Hz travels at 4.0 m s^{-1}. What is the phase difference between two points 0.50 m apart?

Question 10.2 Yellow light of wavelength 580 nm passes through slits 0.40 mm apart onto a screen 2.5 m away. What is the distance between a bright fringe and its nearest dark fringe?

Question 10.3 A red laser of wavelength 630 nm gives fringes 15 mm apart on a screen 4.0 m from a double slit. Find the slit separation.

Question 10.4 Light falls normally on two slits 2.00 mm apart. The screen is 2.5 m away and the 4th bright spot is 3.2 mm from the central maximum. Find the wavelength.

Question 10.5 Light is incident normally on a grating with 1000 lines per mm. The angle between the two first-order maxima is 60°. Find the wavelength.

Question 10.6 Light of wavelength 590 nm gives a first-order maximum at 20.0° from a grating. Find (a) the slit separation, (b) the angular separation of the first and second orders.

Question 10.7 Light of wavelength 480 nm is incident normally on a grating of slit separation 3.0 μm. How many maxima are observed?

Question 10.8 A stationary wave is three wavelengths long. How many nodes (including both ends) and anti-nodes are there?

Question 10.9 A rope of length 150 cm is fixed at both ends. At what wavelengths can stationary waves form?