11. Superposition

Definitions

Principle of Superposition: When two waves of the same kind meet at the same point, the resultant displacement at that point is given by the vector sum of the displacements of the individual waves at that point.

Stationary waves: A stationary wave is the result of interference between two waves of equal frequency, wavelength and amplitude, travelling along the same line with the same speed but in opposite directions.

Diffraction: The spreading of waves into regions where it would not be seen if it moves only in a straight line after passing through a narrow slit or pass an edge.

Coherence: Sources are said to be coherent if they have a **constant phase difference**. This implies that the sources must have the same frequency or wavelength. Velocities of the waves are assumed to be identical.

Interference: Interference is the superposition of two or more coherent waves to give a resultant wave whose resultant amplitude is given by the principle of superposition. (in phase = constructive and anti-phase = destructive)

NOTE

- In a stationary wave:
  - ➢ Disturbance does not propagate across space
  - ➢ Does not transport energy
  - ➢ Within 2 consecutive nodes, every particle oscillates in phase, i.e. reaches maxima and minima and eqm positions at the same time.
  - ➢ Particles in neighbouring loops vibrate 180 degrees out of phase with each other (antiphase)
- Antinode at the open ends of pipes are actually located slightly outside the pipe and thus a small end correction has to be included in calculations of the wavelength.
- Diffraction is pronounced when the wavelength of the wave is the same order of magnitude as the width of the aperture/obstacle.
- Intensity of higher order maxima will be lower due to the effects of diffraction.
- The formula x=lamdaD/a where D is the distance between the slit and the screen and a is the slit separation, can only be applied if a<<D (assumed that rays are parallel) and if theta is less than 10 degrees (assume that sintheta = tantheta)
- Typical values: slid width = 0.2 mm, slid separation = 0.5mm, D = 1m and wavelength of light = 500nm
- The purpose of the **single slid** is to ensure existing waves from the double slits are coherent
- Microphone peak signal is at the nodes as the pressure there is maximum.
- For the formula x = nlamdaD/a, if finding distance from central order maximum to n order dark fringe, then the n value used should be half less than the order.
- If 2 waves of different frequency meet, the resultant frequency is equal to the lower frequency

- Slit separation refers to separation between the two centres of the slits
- Note that amplitude is proportional to 1/r (to explain why destructive does not completely cancel out: distance from _ to _ and _ is significantly different, therefore amplitudes at that point will be different too, hence no complete destructive interference)
- **For observable interference pattern, must be unpolarised or polarised in the same direction! Otherwise no maxima or minima observed!**

Questions

1. Explain why the length of the string or the frequency of the vibrator has to be adjusted in order to obtain observable stationary waves on the string.
Ans: Since the tension of the string is fixed, the velocity of the wave on the string is fixed. Stationary waves will only be formed when the length of the string is equal to **certain integral multiples of half wavelength of the wave**. Hence it is necessary to adjust the length of the string to fit multiples of half-wavelength or adjust the frequency of the vibrator to fit the length of the string.

2. State the effects of (i) increasing the intensity of the red light incident on the double slit, (ii) increasing the distance between the double slit and the screen and (iii) reducing the intensity of light incident on one of the double slit.
Ans: (i) The contrast is improved because the bright fringes become brighter, (ii) the fringe separation increases and (iii) the contrast decreases as the dark fringes are not completely dark.

3. What happens when the slit width is decreased and the slit separation is kept constant.
Ans: Less light passes through and the fringes become dimmer, contrast decreases. On the other hand, light that passes through are diffracted more and extra fringes become visible (although very dim). Fringe separation remains unchanged.

4. What happens when the slit width of only one of the double slits is decreased and the slit separation is kept constant.
Ans: Since slit separation is maintained, the fringe separation remains unchanged. However, as one slit is made narrower, the fringes are less distinct and the contrast is lowered. The amplitude of light emerging from the narrowed slit will be less than that from the other slit. The amplitudes are not the same and hence the regions of maxima will be dimmer and at locations of destructive interference, there is no complete cancellation of waves and thus there will not be completely dark regions.

5. What happens when a transparent sheet of plastic is inserted between the single slit A and one of the double slits B?
Ans: This introduces extra optical path length to AB and the fringes will shift upwards. When **light travels through the plastic, its wavelength decreases due to a higher refractive index of plastic**. This means that at O', the optical path difference of the two light waves is no longer zero and the central order maximum is no longer at O'. Hence, in order for the light through B and C to travel equal number of "wavelengths", the path taken by the light through B should be shorter. Hence the central order maximum shifts up. Note: optical path length = refractive index × geometric length of light through the plastic medium.