Chapter 24
Wave Optics

Diffraction
Interference
Polarization

The Lens Equation

\[ \frac{1}{d_0} + \frac{1}{d_1} = \frac{1}{f} \]

Geometrical and Physical Optics

Geometrical Optics: The study of optical phenomena in terms of rays

Physical Optics: The study of optical phenomena in terms of waves

Geometrical optics is an approximation of physical optics whose usefulness comes from its simplified view of light propagation.

The Nature of Light

Light have wave (Huygen’s view) and particle (Newton’s view) properties

One of the central problems of contemporary physics has been the resolution of this apparent paradox.

Light Diffraction Through Clouds

Diffraction: Waves are able to bend around the edge of an obstacle in their path.
The diffracted waves spread out as though they originated at narrow slits or gaps.
Conditions for wave diffraction to occur

- The size of an obstacle must be on the order of the wavelength of the wave.
- Diffraction phenomenon significantly depends on the ratio of the wavelength of the wave to the size of the obstacle.

Diffraction limits the useful magnification of an optical system.

Question: We can hear sounds around the corners, but we cannot see around corners; yet both sound and light are waves. Why?

Answer: Hearing sound around corners depends on diffraction. The wavelengths of sound waves are comparable to the size of obstacles, and thus can diffract around obstacles, which block light waves.

Audible sound: wavelengths are of cm to meters
Visible light: $4 \times 10^{-7}$ - $8 \times 10^{-7}$ m

Interference of Light

When light waves from one source are mixed with those from another source, the two waves trains are said to interfere.
We can easily observe interference in water waves, and hear beats, a result of interference in sound waves. But if we shine light from two flashlights on a screen, there is no evidence of interference. Why?

1. Light waves have extremely short wavelengths (400nm-750nm)
2. Natural light is incoherent (the phase relationship varies)

Complete the following sentence: The term coherence relates to

(a) the phase relationship between two waves.
(b) the amplitude of two waves.
(c) the polarization state of two waves
(d) the frequency of two waves.
(e) the diffraction of two waves.

Which one of the following statements best explains why interference patterns are not usually observed for light from two ordinary light bulbs?

(a) Diffraction effects predominate.
(b) The two sources are out of phase.
(c) The two sources are not coherent.
(d) The interference pattern is too small to observe.
(e) Light from ordinary light bulbs is not polarized.

Question: For two light beams to interfere, their sources must be

(a) coherent
(b) incoherent
(c) lasers
(d) slits

Answer: a

Question: An interference pattern is produced whenever

(a) reflection occurs
(b) refraction occurs
(c) diffraction occurs
(d) polarization occurs

Answer: c
1. A source of monochromatic light (light consisting of only a single wavelength)
2. Narrow slits

\[ \sin \theta = m \lambda / d \] or \[ d \sin \theta = m \lambda \]

\( m = 0, 1, 2, 3, \ldots \) Constructive inference
\( m = 1/2, 3/2, 5/2, \ldots \) Destructive inference

The figure shows the interference pattern obtained in a double-slit experiment using light of wavelength 600 nm.

1. Which fringe is the same distance from both slits?
   (a) A  (b) B  (c) C  (d) D  (e) E

2. Which fringe is the third order maximum?
   (a) A  (b) B  (c) C  (d) D  (e) E

3. Which fringe is 300 nm closer to one slit than to the other?
   (a) A  (b) B  (c) C  (d) D  (e) E

4. Which fringe results from a phase difference of \( 4 \pi \)?
   (a) A  (b) B  (c) C  (d) D  (e) E

Which one of the following phenomena would be observed if the wavelength of light were increased?
(a) The fringes would be brighter.
(b) More bright fringes would appear on the screen.
(c) The distance between dark fringes would decrease.
(d) Single-slit diffraction effects would become non-negligible.
(e) The angular separation between bright fringes would increase.

Which one of the following phenomena would be observed if the distance between the slits were increased?
(a) The fringes would become brighter.
(b) The central bright fringe would change position.
(c) The distance between dark fringes would increase.
(d) The distance between bright fringes would increase.
(e) The angular separation between the dark fringes would decrease.
Which one of the following statements provides the most convincing evidence that visible light is a form of electromagnetic radiation?

(a) Two light sources can be coherent.
(b) Light can be reflected from a surface.
(c) Light can be diffracted through an aperture.
X(d) Light can form a double-slit interference pattern.
(e) Light travels through vacuum at the same speed as X-rays.

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**Answer:** c

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**Question:** In a double-slit experiment, the maximum intensity of the first bright line on either side of the central one occurs on the screen at locations where the arriving waves differs in path length by

(a) $\lambda/4$  (b) $\lambda/2$  (c) $\lambda$  (d) $2\lambda$

**Answer:** c

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**Question:** Two rays of light from same sources destructively interfere if their path length differ by how much?

**Answer:** $l_2-l_1=(m+1/2)\lambda$.

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**Example:** In a double-slit experiment it is found that blue light of wavelength 460 nm gives a second-order maximum at a certain location on the screen. What wavelength of visible light would have a minimum at the same location?

**Answer:** For constructive interference

$d \sin \Theta = m \lambda = 2 \times 460 \text{ nm} = 920 \text{ nm}$

For destructive interference of the other light, we have

$d \sin \Theta = (m'+1/2) \lambda$.

When the two angle are equal, then

$920 \text{ nm} = (m'+1/2) \lambda$.

$\lambda = 1.84 \times 10^3 \text{ nm}$ for $m'=0$

$\lambda = 613 \text{ nm}$ for $m'=1$

$\lambda = 368 \text{ nm}$ for $m'=2$

The only wavelength here that is visible is 613 nm
When a light wave travels from one medium to another, its frequency does not change, but its wavelength does:
\[ \frac{\lambda_2}{\lambda_1} = \frac{v_2}{v_1} = \frac{n_1}{n_2} \quad (v = c/n) \]

\[ \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{\sin(r)}{\sin(i)} \]

The shorter \( \lambda_1 \), the larger refraction angle

Dispersion by drops of water. Red is bent the least so comes from droplets higher in the sky.