

Summary

The wave theory of light is strongly supported by observations that light exhibits **interference** and **diffraction**. Wave theory also explains the refraction of light and the fact that light travels more slowly in transparent solids and liquids than it does in air.

[*An aid to predicting wave behavior is **Huygens' principle**, which states that every point on a wave front can be considered as a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself. The new wave front is the envelope (the common tangent) of all the wavelets.]

The wavelength of light in a medium with index of refraction n is

$$\lambda_n = \frac{\lambda}{n}, \quad (24-1)$$

where λ is the wavelength in vacuum; the frequency is not changed.

Young's double-slit experiment demonstrated the interference of light. The observed bright spots of the interference pattern are explained as constructive interference between the beams coming through the two slits, where the beams differ in path length by an integral number of wavelengths. The dark areas in between are due to destructive interference when the path lengths differ by $\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, and so on. The angles θ at which **constructive interference** occurs are given by

$$\sin \theta = m \frac{\lambda}{d}, \quad (24-2a)$$

where λ is the wavelength of the light, d is the separation of the slits, and m is an integer (0, 1, 2, ...). **Destructive interference** occurs at angles θ given by

$$\sin \theta = \left(m + \frac{1}{2}\right) \frac{\lambda}{d}, \quad (24-2b)$$

where m is an integer (0, 1, 2, ...).

Two sources of light are perfectly **coherent** if the waves leaving them are of the same single frequency and maintain the same phase relationship at all times. If the light waves from the two sources have a random phase with respect to each other over time (as for two lightbulbs), the two sources are **incoherent**.

The frequency or wavelength of light determines its color. The **visible spectrum** in air extends from about 400 nm (violet) to about 750 nm (red).

Glass prisms spread white light into its constituent colors because the index of refraction varies with wavelength, a phenomenon known as **dispersion**.

The formula $\sin \theta = m\lambda/d$ for constructive interference also holds for a **diffraction grating**, which consists of many parallel slits or lines, separated from each other by a distance d .

The peaks of constructive interference are much brighter and sharper for a diffraction grating than for a two-slit apparatus.

A diffraction grating (or a prism) is used in a **spectrometer** to separate different colors and observe **line spectra**. For a given order m , θ depends on λ . Precise determination of wavelength can be done with a spectrometer by careful measurement of θ .

Diffraction refers to the fact that light, like other waves, bends around objects it passes, and spreads out after passing through narrow slits. This bending gives rise to a **diffraction pattern** due to interference between rays of light that travel different distances.

Light passing through a very narrow slit of width D (on the order of the wavelength λ) will produce a pattern with a bright central maximum of half-width θ given by

$$\sin \theta = \frac{\lambda}{D}, \quad (24-3a)$$

flanked by fainter lines to either side.

Light reflected from the front and rear surfaces of a thin film of transparent material can interfere constructively or destructively, depending on the path difference. A phase change of 180° or $\frac{1}{2}\lambda$ occurs when the light reflects at a surface where the index of refraction increases. Such **thin-film interference** has many practical applications, such as lens coatings and using Newton's rings to check uniformity of glass surfaces.

In **unpolarized light**, the electric field vectors oscillate in all transverse directions. If the electric vector oscillates only in one plane, the light is said to be **plane-polarized**. Light can also be partially polarized.

When an unpolarized light beam passes through a **Polaroid** sheet, the emerging beam is plane-polarized. When a light beam is polarized and passes through a Polaroid, the intensity varies as the Polaroid is rotated. Thus a Polaroid can act as a **polarizer** or as an **analyzer**.

The intensity I_0 of a plane-polarized light beam incident on a Polaroid is reduced to

$$I = I_0 \cos^2 \theta \quad (24-5)$$

where θ is the angle between the axis of the Polaroid and the initial plane of polarization.

Light can also be partially or fully **polarized by reflection**. If light traveling in air is reflected from a medium of index of refraction n , the reflected beam will be **completely** plane-polarized if the incident angle θ_p is given by

$$\tan \theta_p = n. \quad (24-6b)$$

The fact that light can be polarized shows that it must be a transverse wave.

Questions

1. Does Huygens' principle apply to sound waves? To water waves? Explain how Huygens' principle makes sense for water waves, where each point vibrates up and down.
2. Why is light sometimes described as rays and sometimes as waves?
3. We can hear sounds around corners but we cannot see around corners; yet both sound and light are waves. Explain the difference.
4. Two rays of light from the same source destructively interfere if their path lengths differ by how much?
5. Monochromatic red light is incident on a double slit, and the interference pattern is viewed on a screen some distance away. Explain how the fringe pattern would change if the red light source is replaced by a blue light source.
6. If Young's double-slit experiment were submerged in water, how would the fringe pattern be changed?