WAVE OPTICS

COHERENT AND INCOHERENT ADDITION OF WAVES

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Light sources can be categorized into two main types: coherent and incoherent. Coherent light waves are those that share the same frequency, whereas incoherent waves are characterized by variations in phase, resulting in a lack of consistent alignment among the waves.

Coherent Addition of Waves

Coherent waves exhibit the same wavelength, frequency, and a consistent phase difference. For instance, sound waves produced by two loudspeakers driven by the same audio oscillator result in coherent waves. Laser-produced light is another example of coherent waves.

To generate coherent sources, two methods are employed. The first method employs wave front division, which employs prisms, lenses, and mirrors to split the wave front into multiple components. As the optical wave traverses a wave front, either real or imagined, it maintains a constant phase.

The second approach involves dividing the wave's amplitude into two or more parts through partial reflection or refraction. These split components may follow different paths before recombining to create interference.

Characteristics of Coherent Sources

Coherent sources possess the following characteristics:

- The phase difference between the emitted waves remains constant.
- All waves have an identical frequency.
- The waves should exhibit uniform amplitudes.

Types of Coherence

Coherent sources are divided into different parts

1. Temporal Coherence

- Temporal coherence is a concept that characterizes the connection between the wave's characteristics and its ability to produce a time delay of T at any given time interval.
- Temporal coherence is employed to assess the degree of monochromaticity in a source.
- Coherence time represents the duration required for a noticeable alteration in phase or amplitude to occur.

2. Spatial Coherence

- In systems like optics or water waves, the wave's spatial extent can range from one to two dimensions.
- Spatial coherence refers to the capability of two points, denoted as x_1 and x_2, within the wave's region to exhibit interference.
- Put simply, it can be understood as the relationship between two points at any given moment within a wave.
- Perfect spatial coherence is observed when a single amplitude value extends continuously over an indefinite distance.

Examples of Coherent sources

Electrical signals are employed to generate sound waves from speakers with a consistent frequency. Coherent sources, such as lasers, utilize stimulated emission to generate extremely coherent light. Even though small sunlight sources exhibit some degree of coherence, this allows us to observe interference patterns on soap bubbles and appreciate the vibrant colors of butterfly wings.

Incoherent Sources of waves

If light waves lack a consistent phase difference, they are considered incoherent. These sources emit light with frequent and random phase shifts between photons. Common examples of incoherent light sources include standard fluorescent tubes and tungsten filament lamps. Incoherent wave sources do not produce interference patterns.

Let's consider two waves generated by two sources with different intensities, I_1 and I_2, but they have the same intensity. The total intensity, denoted as I, is the sum of I_1 and I_2.

In terms of coherence, coherent light waves are generally stronger compared to incoherent light waves, which are typically weaker. Coherent light waves have a single, well-defined direction, while incoherent light waves radiate in all directions.

Examples of Incoherent Sources

Incoherent sources are commonly generated using tungsten filament lamps, while standard fluorescent tubes emit incoherent light.

Scattering of Light Waves

When a light wave interacts with a substance, it scatters light in all directions except forward, which is known as scattering. Light scattering can be attributed to all molecules of matter and can exhibit both coherent and incoherent wave addition phenomena. To understand scattering, we analyze the phase delays of the scattered waves.

If the phase delay is consistent for all scattered waves, the scattering is coherent and results in constructive interference. If the phase delay varies uniformly from 0 to 2, it is also coherent but leads to destructive interference. In the case of random phase delay fluctuations, the scattering is incoherent. Coherent scattering occurs in one or a few specific directions, while coherent destructive scattering takes place in all other directions.

Note:

Here are some important points to keep in mind:

- There are two types of light sources: coherent and incoherent.
- Coherent waves have identical frequencies and no phase difference between them.
- Incoherent waves have varying frequencies and random phase differences between them.

Coherent Sources Characteristics:

The waves generated from coherent sources maintain a constant phase difference and share the same frequency. Coherent sources can be categorized into two types: temporal coherence and spatial coherence.

In contrast, incoherent light is produced by light sources where the phase difference between photons changes frequently and unpredictably. Conventional light sources, like incandescent light bulbs, are examples of such incoherent sources.

Coherent light waves are typically more intense when compared to the incoherent combination of light waves.

Conclusion

It is important to understand that coherent sources are light sources that emit waves with a constant phase difference of zero and share the same frequency. Conversely, incoherent addition of waves refers to light sources that emit waves with random frequencies and phase variations.

Non-coherent Waves

Waves are considered non-coherent when the phase difference between them continually changes. Examples of such non-coherent wave sources include light bulbs and study lamps, as they emit waves with varying phase differences.

Explanation

Let's now examine a scenario with two needles, denoted as S_1 and S_2, oscillating vertically on the surface of the water and directed towards a point P. In this context, the path difference is calculated as $S_1P - S_2P$. The displacements of these two needles, y_1 and y_2, are described by the following equations:

y_1 = A cos (ωt) ……………… (1)
y_2 = A cos (ωt) ……………... (2)

Here, A represents the amplitude of the oscillations, ω is the angular frequency, and t denotes time.

Hence, the combined displacement at point P is given by $y = y_1 + y_2$. When we substitute the values of y_1 and y_2 into this equation, we have:

y = A cos (ωt) + A cos (ωt)
y = 2A cos (ωt)……………….. (3)

Now, it is important to note that the intensity of the waves is directly proportional to the square of the amplitude. In mathematical terms, we can express this relationship as:

$I_0 \propto A^2$

Here, I_0 represents the initial intensity of the wave, and A^2 corresponds to the square of the amplitude. Considering equation 3, we can determine that A = 2A. Therefore, we can express the relationship as:

$I_0 \propto (2A)^2$ or $I_0 \propto 4A^2$

This implies that the intensity I is equal to 4 times the initial intensity I_0:

$I = 4 I_0$

When two needles, S_1 and S_2, are in phase, the potential difference between them can be expressed as:

$S_1P – S_2P = n\lambda$

Where n represents an integer, and λ denotes the wavelength.

When the two needles, S_1 and S_2, are in a state of destructive interference, the potential difference can be described as:

$S_1P – S_2P = (n + 1/2)\lambda$

Here, n is an integer, and λ represents the wavelength of the wave.

If the potential difference of the waves is denoted as Φ, the displacements of the two needles can be expressed as follows:

$y_1 = \alpha \cos wt$
$y_2 = \alpha \cos wt$

In these equations, α represents the amplitude of the wave, w is the angular frequency, and t is time.

When considering the individual intensities of each wave as I0, we can express the resultant displacement y as follows:

$y = y_1 + y_2$

$y = \alpha \cos wt + \alpha \cos (wt + \Phi)$

By adding these two displacements together, we get:

$y = 2 \alpha \cos (\Phi/2) \cos (wt + \Phi/2)$

In this equation, α represents the amplitude of the wave, w is the angular frequency, t is time, and Φ is the potential difference between the two waves.

Considering that intensity is proportional to the square of the amplitude ($I0 \propto A^2$), we can express the intensity as:

$I_0 \propto 4\alpha^2 \cos^2 (\Phi/2)$

This leads to the resultant intensity:

$I = 4 I_0 \cos^2 (\Phi/2)$

However, the time-averaged value of $\cos^2 (\Phi/2)$ is 1/2. Therefore, the intensity becomes:

$I = 2 I_0$ for all points.