WAVES

AQA AS A LEVEL

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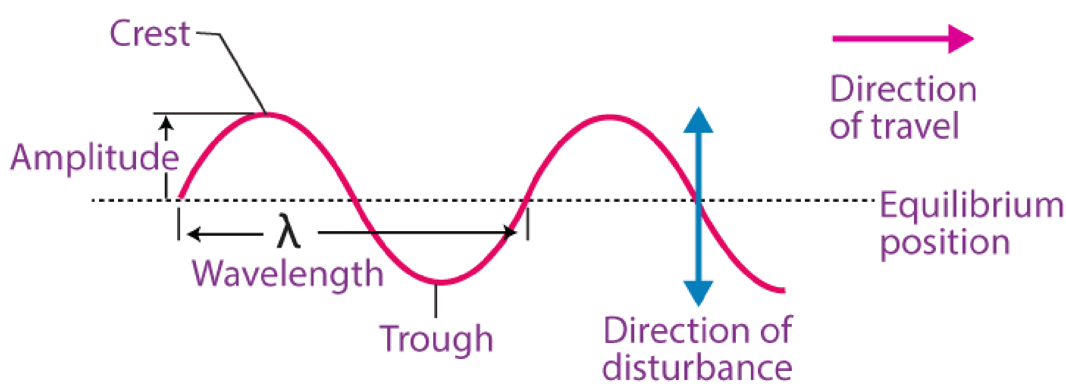
Progressive Waves:

- A progressive wave is a type of wave that transfers energy without transferring material.
- It is composed of particles of a medium (or field) oscillating, such as water waves where water particles move up and down.
- Key wave properties include:
    - **Amplitude:** The wave's maximum displacement from the equilibrium position (measured in meters, m).
    - **Frequency (f):** The number of complete oscillations passing through a point per second (measured in Hertz, Hz).
    - **Wavelength (λ):** The length of one complete oscillation, like the distance between successive peaks or troughs (measured in meters, m).
    - **Speed (c):** The distance traveled by the wave per unit time (measured in meters per second, m/s).
    - **Phase:** The position of a specific point on a wave cycle (measured in radians, degrees, or fractions of a cycle).
    - **Phase Difference:** Indicates how much one particle or wave lags behind another (measured in radians, degrees, or fractions of a cycle).
    - **Period (T):** The time taken for one full oscillation (measured in seconds, s).



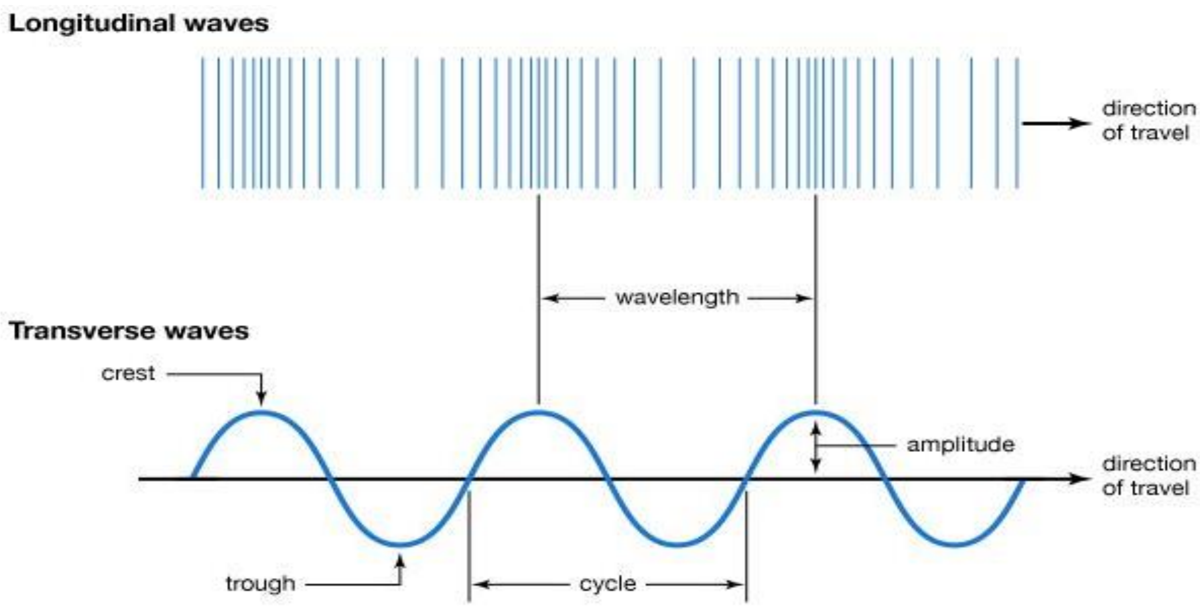
- Two points on a wave are "in phase" if they are at the same point in the wave cycle, sharing the same displacement and velocity, with their phase difference being a multiple of 360° (2π radians). They don't need the same amplitude, only the same frequency and wavelength.
- Two points are "completely out of phase" if they are an odd integer of half cycles apart, like being 5 half cycles apart (where one half cycle is 180° or π radians).
- The speed of a wave (c) is equal to the wave's frequency (f) multiplied by its wavelength (λ), expressed as $c = f\lambda$.
- The frequency of a wave (f) is equal to 1 divided by its period (T), so $f = 1/T$.

Longitudinal and Transverse Waves:

- **Transverse Waves:** In transverse waves, the oscillation of particles (or fields) occurs at right angles (perpendicular) to the direction of energy transfer.
- All electromagnetic (EM) waves, which include visible light, radio waves, and more, are examples of transverse waves. They travel at approximately 3 x 10^8 meters per second (m/s) in a vacuum.

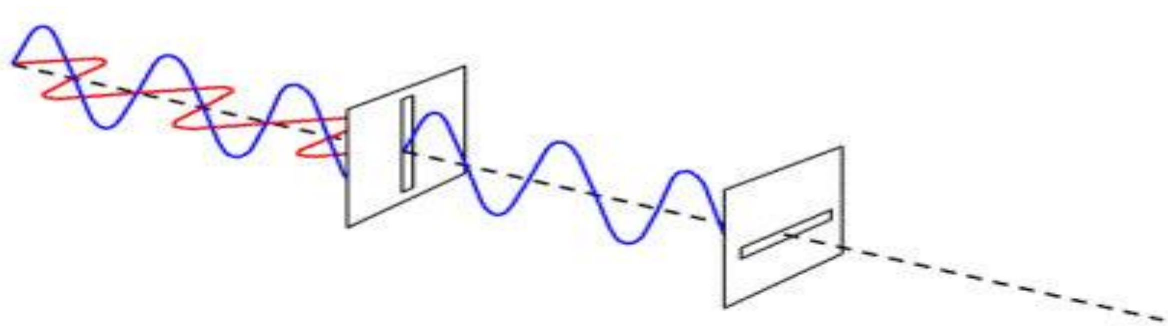
Longitudinal Waves:

- Longitudinal waves are characterized by oscillations of particles that are parallel to the direction of energy transfer.
- They consist of regions of compressions (particles close together) and rarefactions (particles spread apart).
- An example of a longitudinal wave is sound.
- You can demonstrate a longitudinal wave by pushing a slinky horizontally.



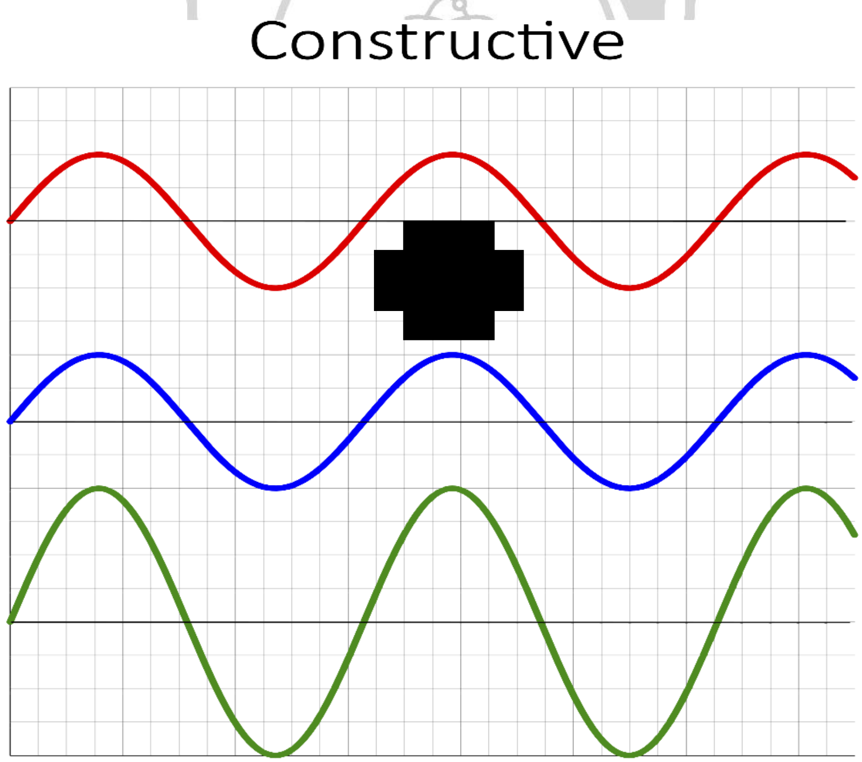
Polarized Waves:

- A polarized wave oscillates in only one plane (e.g., up and down).
- Only transverse waves can be polarized because polarization can only occur when wave oscillations are perpendicular to the wave's direction of travel (as they are in transverse waves).
- Polarization has practical applications, such as polaroid sunglasses that reduce glare by blocking partially polarized light reflected from surfaces like water and tarmac.
- TV and radio signals are often plane-polarized by the orientation of rods on the transmitting aerial, and receiving aerials must be aligned in the same plane of polarization to receive the signal effectively.

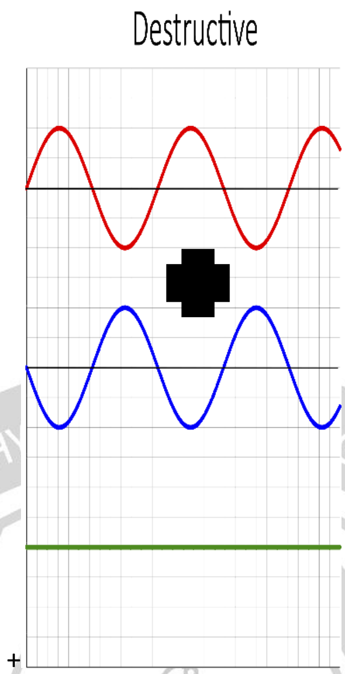


Principle of Superposition of Waves and Formation of Stationary Waves:

- The principle of superposition states that when two waves pass through each other, their displacements are combined, resulting in a resultant displacement that is the vector sum of each wave's displacement.
- There are two types of interference that can occur during superposition:
  - **Constructive Interference:** Occurs when two waves have displacements in the same direction, and their amplitudes add together.
  - **Destructive Interference:** Occurs when one wave has positive displacement and the other has negative displacement. If the waves have equal but opposite displacements, they undergo total destructive interference, canceling each other out.
- When two waves interfere constructively, they reinforce each other, leading to larger amplitudes.



- In destructive interference, they partially or completely cancel out, resulting in reduced or no displacement.

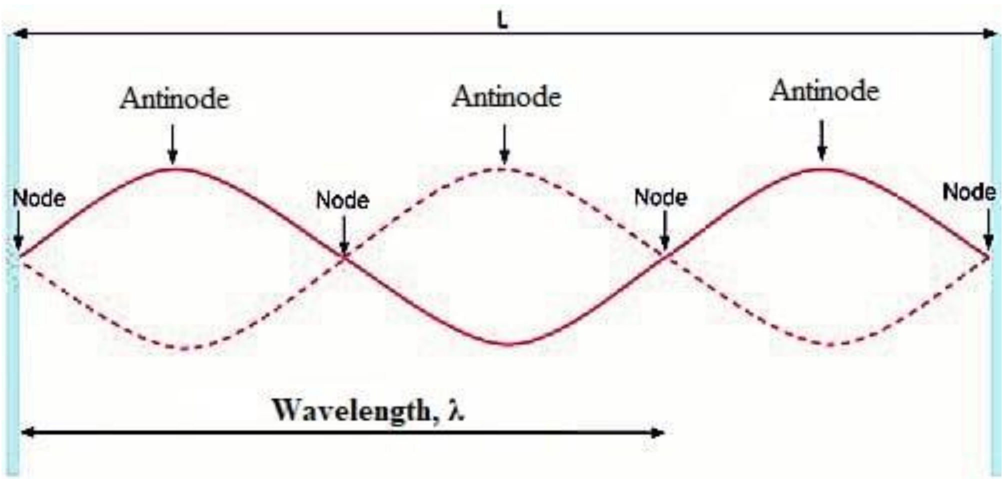


- Stationary waves are formed by the superposition of two waves with the same frequency and amplitude traveling in opposite directions.
- In stationary waves, there are points of constructive interference called antinodes (maximum displacement) and points of destructive interference called nodes (no displacement).
- Stationary waves have characteristic patterns, such as those seen on a vibrating string or in a musical instrument, like a guitar or a flute.

Stationary Waves:

- A stationary wave is formed from the superposition of two progressive waves traveling in opposite directions in the same plane.
- These two waves have the same frequency, wavelength, and amplitude.
- No net energy is transferred by a stationary wave.

- Points where the waves meet in phase experience constructive interference, leading to the formation of regions with maximum displacement called antinodes.
- Points where the waves meet completely out of phase undergo destructive interference, creating regions with no displacement called nodes.



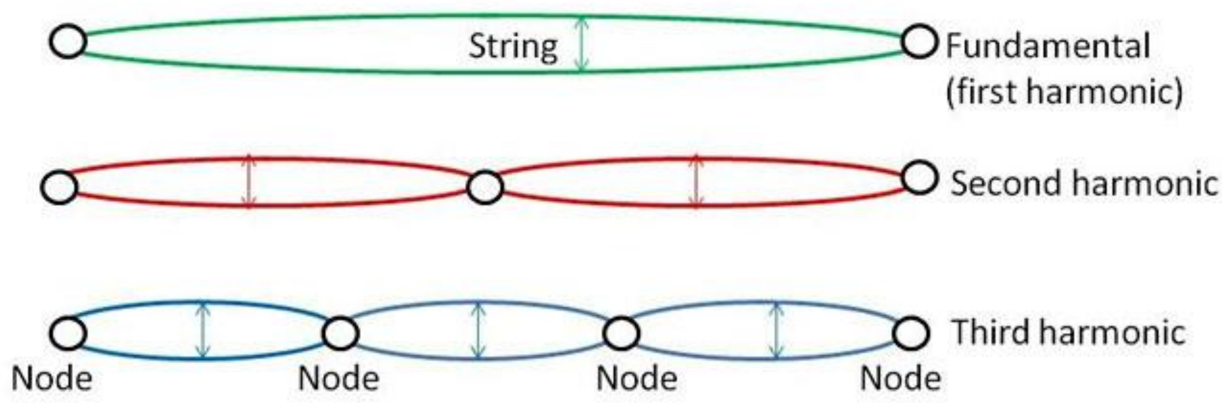
Example with a Fixed String:

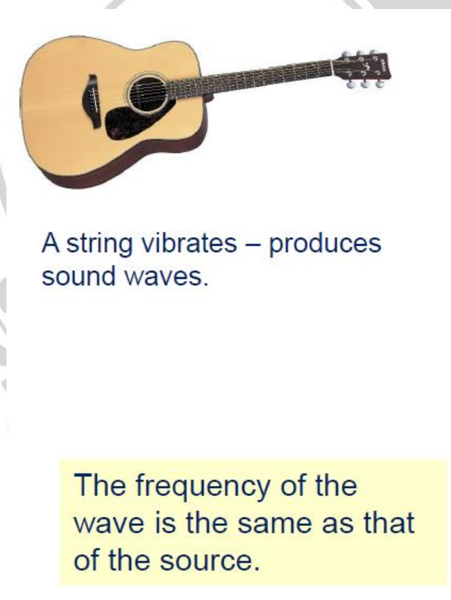
- Imagine a string fixed at one end and attached to a driving oscillator at the other end.
- A wave traveling down the string from the oscillator will be reflected at the fixed end of the string.
- The reflected wave travels back along the string and combines with the incoming wave.
- Because these two waves have the same wavelength, frequency, and amplitude, they form a stationary wave.

Harmonics:

- The lowest frequency at which a stationary wave forms is the first harmonic.
- The first harmonic results in a stationary wave with two nodes and a single antinode.
- The distance between adjacent nodes (or antinodes) in any harmonic is half a wavelength.

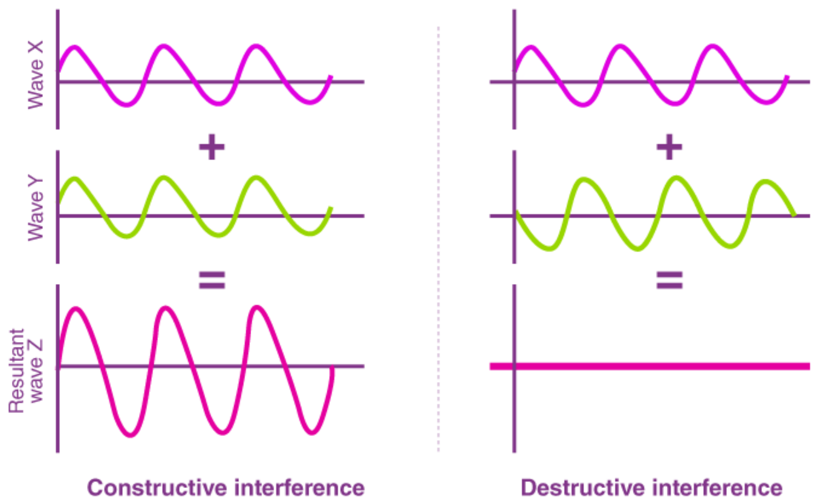
The formation of stationary waves is a key concept in wave physics and is often observed in various physical systems, including musical instruments and stringed instruments like guitars. It leads to the distinctive vibrational patterns seen in these instruments





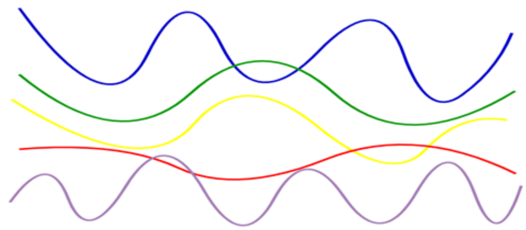
Interference:

- Interference occurs when two waves overlap and combine. The result depends on their relative phases (positions in their cycles) and amplitudes.
- A key factor in interference is the path difference, which is the difference in the distance traveled by two waves.

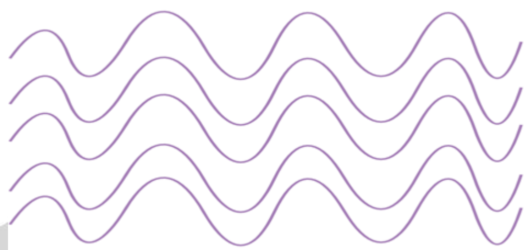


Coherent Light Source:

- A coherent light source has the same frequency, wavelength, and a fixed phase difference.
- Lasers are an example of coherent and monochromatic light sources, emitting a single or a small range of wavelengths.
- Lasers are often used in diffraction experiments to create clear interference patterns.



Incoherent



coherent

Young's Double-Slit Experiment:

- Young's double-slit experiment demonstrates interference of light from two sources.
- To set up the experiment, you can use two coherent sources of light or a single coherent source with a double slit to create an interference pattern.
- If a coherent light source is not available (e.g., a light bulb), you can use a single slit before the double slit to create a fixed path difference and a filter to make the light monochromatic.

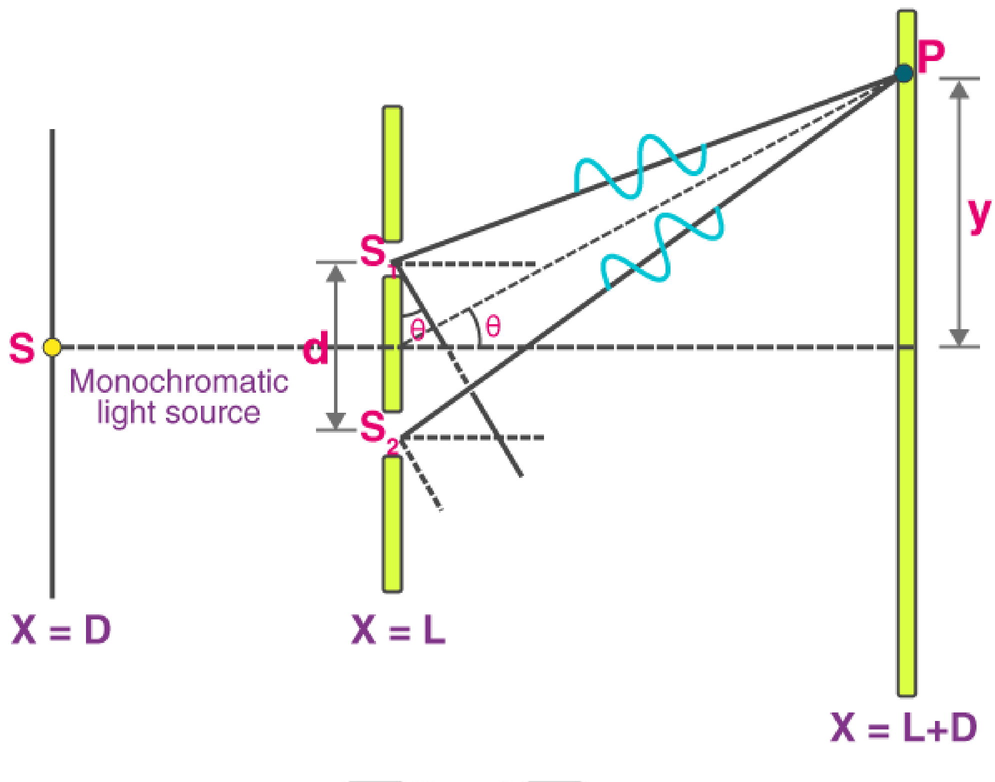
Procedure for Young's Experiment:

- Shine a coherent light source through two slits, approximately the same size as the wavelength of the laser light, causing diffraction.
- Each slit acts as a coherent point source, creating a pattern of light and dark fringes.
- Light fringes occur where the light meets in phase and interferes constructively, with a path difference of a whole number of wavelengths ($n\lambda$, where n is an integer).

- Dark fringes occur where the light meets completely out of phase and interferes destructively, with a path difference of a whole number and a half wavelengths ((n+½)λ).

Formula for Fringe Spacing:

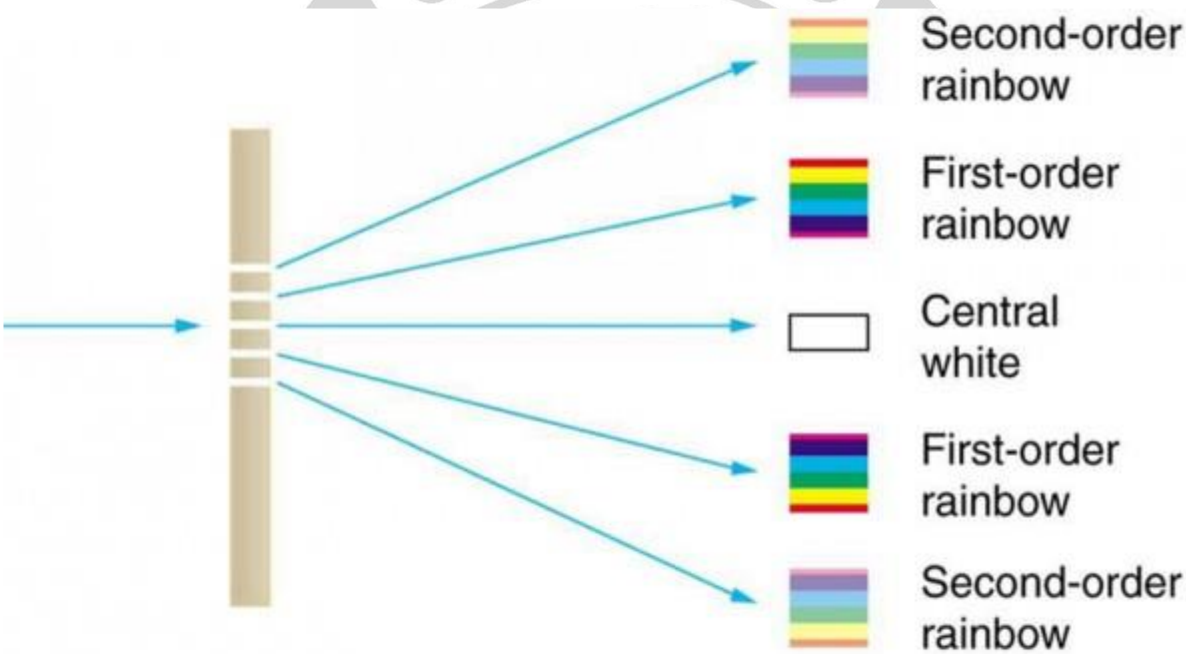
- The formula associated with this experiment is w = λD/s, where w is the fringe spacing, λ is the wavelength of light, D is the distance between the screen and slits, and s is the separation between the slits.

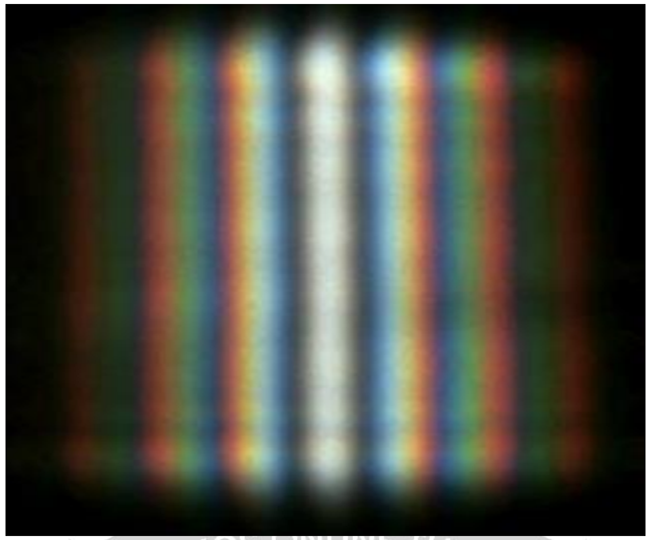


White Light Interference:

- When using white light instead of monochromatic laser light, wider maxima and a less intense diffraction pattern occur.
- The interference pattern includes a central white fringe and alternating bright fringes that create spectra. Violet is closest to the central maximum, and red is furthest away.

Young's double-slit experiment is a fundamental demonstration of wave interference and has been pivotal in understanding the wave nature of light and other wave phenomena.





Laser Safety Precautions:

- When using lasers, it is crucial to follow safety precautions to avoid eye damage:
  - Wear laser safety goggles to protect your eyes from laser light.
  - Avoid shining the laser at reflective surfaces to prevent reflections that can be harmful.
  - Display a warning sign to alert others to the presence of a laser.
  - Never shine the laser at a person to prevent eye injury.

Demonstrating Interference with Sound Waves:

- The type of interference described can also be demonstrated with sound waves, similar to the process used with light waves.
- Instead of using a double slit, you can use two speakers connected to the same signal generator.
- The intensity of the wave can be measured using a microphone to find maxima (equivalent to light fringes) and minima (equivalent to dark fringes).

Wave Nature of Light:

- Young's double-slit experiment provided evidence for the wave nature of light.
- Diffraction and interference are wave properties that demonstrated that electromagnetic (EM) radiation, such as light, behaves as a wave at least some of the time.
- This experiment contradicted theories that suggested light was made up of tiny particles, demonstrating that it is, in fact, a wave.

Diffraction:

- Diffraction is the spreading out of waves when they pass through or around a gap.
- The greatest diffraction occurs when the gap is the same size as the wavelength.
- Smaller gaps cause most waves to be reflected, while larger gaps exhibit less noticeable diffraction.
- When a wave encounters an obstacle, diffraction occurs around the edges, and the degree of diffraction depends on the ratio of the obstacle width to the wavelength.
- Monochromatic light passing through a single slit onto a screen forms an interference pattern with light and dark fringes.
- The central fringe is the brightest and is twice as wide as the other fringes. The bright fringes result from constructive interference, while dark fringes occur due to destructive interference.
- White light creates a different diffraction pattern, displaying a spectrum of colors. The central maximum is white, with alternating bright fringes forming spectra, where violet is closest to the central maximum, and red is furthest away.

Varying Diffraction:

- You can alter the width of the central maximum in a diffraction pattern by changing the slit width and wavelength:
  - Increasing the slit width reduces diffraction, making the central maximum narrower and more intense.
  - Increasing the wavelength increases diffraction, causing the central maximum to widen and its intensity to decrease.

Diffraction Grating:

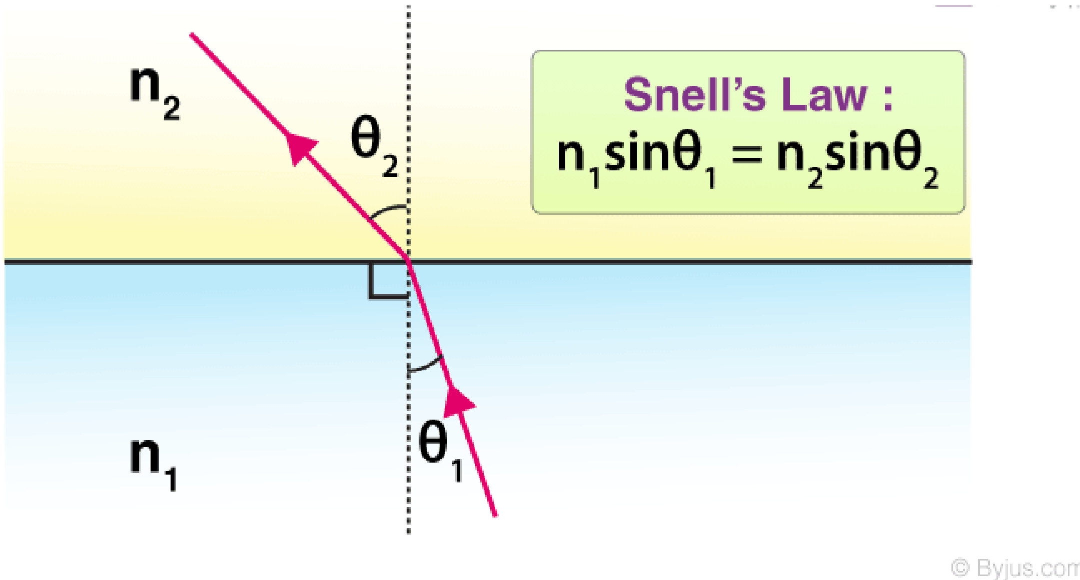
- A diffraction grating is a slide with many closely spaced slits.
- When monochromatic light passes through a diffraction grating, the interference pattern is sharper and brighter than when passing through a double slit, thanks to the reinforcement of multiple rays of light.
- This makes measurements of slit widths more accurate as they are easier to take.
- The intensity of the interference pattern increases with the number of slits in the grating, resulting in a sharper pattern

Refraction at a Plane Surface:

- Refraction occurs when a wave, such as light, enters a different medium, causing it to change direction.
- The extent of refraction depends on the refractive indices of the two materials and the angle of incidence.
- A **refractive index (n)** measures how much a material slows down light passing through it. It is calculated by dividing the speed of light in a vacuum (c) by the speed of light in that substance (cs).

Snell's Law:

- Snell's law is used for calculations involving the refraction of light.
- It relates the refractive indices (n1 and n2) and the angles of incidence (θ1) and refraction (θ2) for the two materials.
- The law states that $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

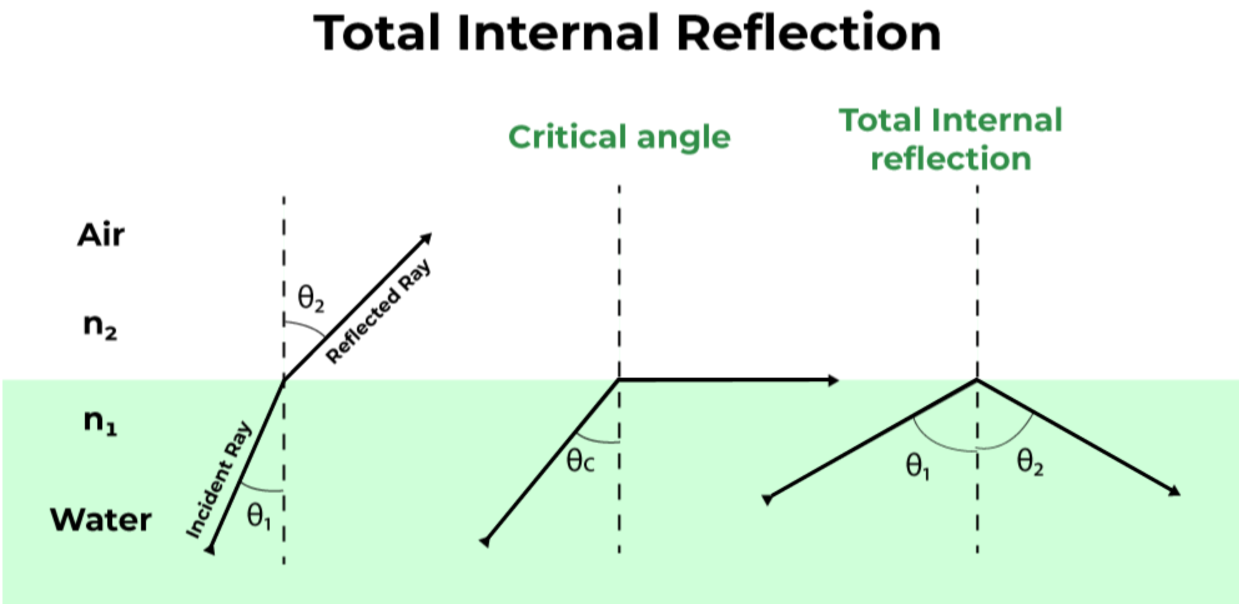


Angle of Refraction:

- The angle of refraction depends on the relative refractive indices of the two materials.
- If the second material (n2) is more optically dense than the first (n1), the light slows down and bends toward the normal.
- If the second material is less optically dense, the light bends away from the normal.

Critical Angle and Total Internal Reflection (TIR):

- The critical angle (θc) is the angle of incidence at which the angle of refraction reaches 90°.
- It can be found using the formula sinθc = n2/n1, where n2 is the refractive index of the second material, and n1 is the refractive index of the first.
- Total internal reflection (TIR) occurs when the angle of incidence is greater than the critical angle, and n1 is greater than n2.
- Optical fibers are a practical application of TIR, used for transmitting light signals. They have a dense core surrounded by cladding with a lower optical density, allowing TIR to occur, protecting the core, and preventing signal loss through light escaping the core.



Diffraction Patterns:

- When light passes through a narrow slit or aperture, it produces a diffraction pattern consisting of alternating bright and dark fringes.
- The central fringe is the brightest, and the bright and dark fringes occur due to constructive and destructive interference.
- The width and intensity of the central maximum depend on slit width and light wavelength.

Using White Light:

- When white light is used, the diffraction pattern shows a spectrum of colors because different wavelengths of light are diffracted by varying amounts.
- The central maximum is white, with alternating bright fringes representing different colors, from violet (closest to the central maximum) to red (farthest away).

Diffraction Gratings:

- A diffraction grating is a device containing many equally spaced slits closely together.
- When monochromatic light is passed through a diffraction grating, it produces a sharp and bright interference pattern due to multiple rays of light reinforcing the pattern.

- The formula associated with diffraction gratings is $d \sin\theta = n\lambda$, where d is the distance between the slits, θ is the angle to the normal made by the maximum, n is the order, and λ is the wavelength.

Applications of Diffraction Gratings:

- Diffraction gratings are used in various applications, such as splitting light from stars to create line absorption spectra for identifying elements.
- In X-ray crystallography, they help determine atomic spacing in materials.
- Diffraction gratings are used in scientific experiments to study the properties of light.

OPTICAL FIBERS

1. **Core and Cladding**: Optical fibers consist of two main parts. The core is the innermost part, typically made of a highly transparent material like glass or plastic, with a higher refractive index. The cladding surrounds the core and has a lower refractive index. This refractive index contrast is essential for TIR to occur.

2. **Total Internal Reflection (TIR)**: When light travels from the core to the cladding, the change in refractive index causes the light to be reflected back into the core rather than refracting out of the fiber. This phenomenon is known as total internal reflection. It allows light to bounce back and forth within the core, effectively "trapping" the light within the fiber.

3. **Signal Transmission**: As light signals bounce off the core-cladding interface through TIR, they can carry data over long distances with minimal loss. This is in contrast to traditional copper wires, where electrical signals can suffer significant attenuation over long distances.

4. **Signal Protection**: The cladding serves a dual purpose. It not only enables TIR but also acts as a protective barrier for the core. It shields the core from external environmental factors, such as moisture or physical damage, which could otherwise affect signal quality.

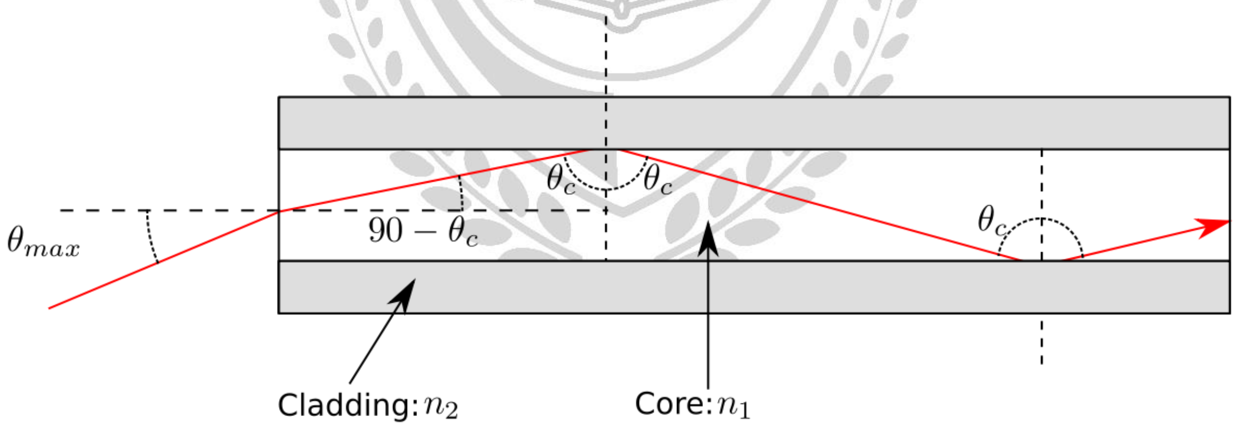
5. **Preventing Signal Degradation**: Because light is confined within the core due to TIR, there is minimal signal loss as light travels through the fiber. This ensures that the data

remains intact and is not subject to degradation, making optical fibers an efficient means of transmitting information.

6. **Information Security**: Optical fibers are also known for their high security. Since light is contained within the core, it is challenging for external sources to intercept or tap into the data being transmitted through the fiber, adding an extra layer of security for sensitive communications.

7. **High Bandwidth**: Optical fibers can carry a vast amount of data due to their high bandwidth capabilities. This makes them essential for applications like internet connections, telecommunications, and high-speed data transmission.

In summary, optical fibers leverage total internal reflection to efficiently transmit light signals, protecting the signals from external interference and minimizing data loss. This technology is a cornerstone of modern telecommunications and data transmission systems, enabling high-speed, reliable, and secure communication.



Signal degradation(decrease in signal quality)

1. **Absorption**: This phenomenon occurs when some of the signal's energy is absorbed by the fiber material itself. The absorbed energy results in a reduction in the signal's amplitude. Over long distances, this can lead to a significant loss of information because the signal becomes weaker. To mitigate absorption, it's important to use materials with low absorption characteristics. For example, high-quality optical fibers are often made from materials like fused silica, which has low absorption properties.

2. **Dispersion**: Dispersion refers to the spreading of the light pulses as they travel through the fiber. There are two main types of dispersion:
   a. **Modal Dispersion**: This type of dispersion is caused by different light rays entering the fiber at varying angles. As a result, these rays take different paths along the fiber, some traveling closer to the center of the core and others being reflected more times. This leads to variations in the time it takes for different rays to traverse the fiber, causing pulse broadening. Modal dispersion can be reduced by making the core of the fiber very narrow, as you mentioned, which minimizes the differences in path lengths for the rays.
   b. **Material Dispersion**: Material dispersion is due to the fact that light consists of different wavelengths, and each wavelength may travel at a slightly different speed through the fiber material. This discrepancy results in pulse broadening as the various wavelengths spread apart. Material dispersion can be prevented or minimized by using monochromatic light, which contains a single wavelength, or by using specialized optical fibers designed to mitigate this type of dispersion.

3. **Optical Fiber Repeaters**: To address both absorption and dispersion issues and extend the range of optical fiber transmission, optical fiber repeaters are used. These repeaters are strategically placed along the fiber optic cable's route to amplify the weakening signals and regenerate them to their original strength and shape. This helps overcome signal attenuation and dispersion problems, ensuring that the signal arrives at its destination with minimal loss or distortion.