Physics

Lesson Plan #11
Diffraction and Interference of Light
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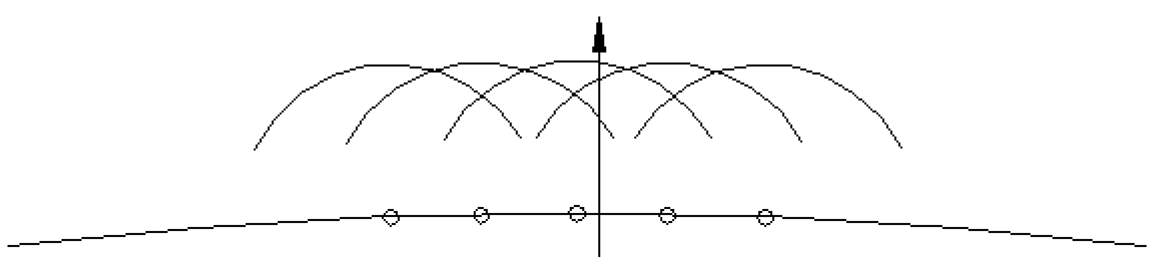
When Light Waves Interfere

Objectives: Relate the diffraction of light to its characteristics; Explain how light falling on two closely spaced slits produces an interference pattern, and use measurements to calculate wavelengths of light; Apply geometrical models to explain single-slit diffraction and two-slit interference patterns.

- Diffraction
  - Newton thought of light as being made of small fast moving particles he called corpuscles. He knew that observations had been made of edges of shadows that were not sharp. Newton thought these were caused by the interaction of light corpuscles and the vibrating particles on the edges of openings – today we know that the small wavelengths of light are responsible for small diffraction effects.
  - Francesco Grimaldi (1618-1663) was the scientist who observed that shadows were not always perfectly sharp, and called this gradual dimming **diffraction**.
  - Dutch scientist Christiaan Huygens (1629-1695) proposed a wave model to explain diffraction
    - Huygens speculated that all the points that make up a wave could be thought of as an infinite series of point sources of light, each creating its own wave, and together the made a wave front



Lesson Plan 11 - Fig 1

- An English physician, Thomas Young (1773-1829), read Newton's works on optics while studying the human eye. He became convinced that from Newton's descriptions of the behavior of light, that light had to have an extremely small wavelength. In 1801 he devised an experiment to make precise measurement of the wavelength of light.
    - In the first part of Young's experiment, he directed a beam of light at two closely spaced narrow slits. The light was diffracted and the light rays from the two slits overlapped. When the light then fell onto an observing screen on the other side of the slits from the light source, a

pattern of bright and dark bands appeared. He called these **interference fringes**, and must be the result of constructive and destructive interference by the light waves from the two slits.

- In the second part of Young's experiment, he used a monochromatic light (has only one wave length, feeding a single slit, that in turned feed the double slit. Each of the double slits created a diffracted circular wave. These two waves set up constructive and destructive interference patterns, causing light and dark bands.
- Young used the double slit experiment to make the first precise measurement of the wavelength of light.
  - With the double slit set up, he deduced that a pair of similar right triangles were setup, where one path was one wavelength longer than the other.
  - In the end, all that was needed was the distance between the slits (d), the distance from the slits to the screen (L), and the distance between bright bands (x), and the equation $\lambda = \frac{xd}{L}$ - you could determine the wavelength with up to 4 significant digits.

Sample Problem

A two slit experiment is performed to measure the wavelength of red light. The slits are 0.0190mm apart. A screen is placed 0.600m away and the separation between the central bright band line and the first-order bright line is found to be 21.1mm. What is the wavelength of the light?

d = 1.90×10^{-5}m
x = 2.11×10^{-2}m
L = 0.600m

$$\lambda = \frac{xd}{L} = \frac{(2.11x10^{-2}m)(1.90x10^{-5}m)}{0.600m} = 6.68x10^{-7}m = 668nm$$

- Multiple Slit Diffraction
  - Suppose you walk down a hall toward a band room. Before you get there you hear the music, before you can see them. Does this mean that sound can bend around corners and light cannot? Both behave as waves, but because light waves are so much smaller, the diffraction of light is less noticeable.
  - When light passes through a single slit, you get a bright central band and dark bands on either side, just like a double slit. If you were to have a slit of width W and divide it into smaller slits then you end up with an arrangement much like the two slit example. The distance between the central band and the first dark band can be determined by the following equation: $x = \frac{\lambda L}{w}$, where λ is the wavelength, L is the distance from the slits to the screen, and w is the width of the slit.
  - Additional dark bands occur when the path lengths differ by 3 λ/2,5 λ/2 and so on.

      - What we see from this is that diffraction takes place with light when it passes through small openings (10-100 times the light's wavelength). But when light passes through a large opening, there is no diffraction.

Applications of Diffraction

Objectives: Explain how diffraction gratings form interference patterns and how they are used in grating spectrometers; Discuss how diffraction limits the ability of a lens to distinguish two closely spaced objects.

- Diffraction Gratings
  - If you have ever looked at a beetle, you may have noticed iridescent colors. These are caused by numerous tiny ridges on the back of the beetle that are only a few hundred nanometers apart. Each space between the ridges acts as a slit, diffracts the light that hits it and therefore produces an interference pattern. This is similar to the two slit diffraction we saw earlier.
  - While a single slit or a double slit will set up a interference pattern to measure the wavelength of light, they are often not used in favor of a diffraction grating.
    - A diffraction grating has thousands of parallel lines per centimeter – up to 10,000. These are scribed onto a piece of glass with a diamond point.
    - The spacing between the lines is as small as 10^{-6}m of 1000nm.
    - Gratings are expensive, so pouring plastic on a glass grating, making an imprint of the glass grating, produces replicas. These replicas can be **transmission gratings** (where light passes through the grating) or **reflection gratings** where light is reflected off the grating.
  - The interference pattern created by a grating is created by the same mechanism as a double slit – but have the advantage of producing more narrow bands of color, making it easier to distinguish individual colors.
  - Where with a double slit interference we used the equation $\frac{x}{L} = \frac{\lambda}{d}$, since it is easy to measure the angle of a grating spectroscope, we can use the equation $\lambda = d \sin \Theta$, where d is the distance between the grating lines, and θ is the angle from the central bright band.
- Resolving Power of Lenses
  - When light enters a telescope, it passes through a lens. The lens diffracts the light as it bends the light, just like a slit. The image of a star appears as a bright central point, surrounded by dark and bright circles – the circles becoming dimmer the farther away from the central point they get.
  - If an two stars are too close together, they cannot be resolved (separated) by a telescope. Lord Raleigh (1842-1919) established minimum distance that two objects can be next to each other and still be resolved – the **Raleigh criterion**.
  - When the central bright band of one star falls on the first dark band of the second start, the stars will just be resolved.
  - The key is the size of the objective – the larger the objective, the greater the resolution and separating power of a telescope.